BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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THE GEOLOGY OF THE LAWN HILL/ RIVERSLEIGH REGION, QUEENSLAND

BY

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ABSTRACT

The Proterozoic rocks in the Mount Oscar, Lawn Hill and Riversleigh 1:100 000 Sheet areas were examined in detail between 1976 and 1978.

The oldest rocks in the region, the Kamarga Volcanics, consist of amygdaloidal basic volcanics interbedded with and overlain by feldspathic sandstones. The volcanics were intruded by the Weberra Granite, and the whole igneous pile was tilted, uplifted, and eroded before about 1670 m.y. ago.

The major Proterozoic sequence in the region, the McNamara Group, which lies unconformably on the Kamarga Volcanics and Weberra Granite, consists of up to 8000 m of sandstone, siltstone, shale, and dolomite. The basal formation, the Torpedo Creek Quartzite, contains basal conglomeratic lenses overlain by quartzose and feldspathic sandstones; it represents a widespread marine transgression through the region. It intertongues with and is overlain by the Gunpowder Creek Formation - an arkosic sandstone, micaceous siltstone, stromatolitic dolomite, and graded carbonaceous siltstone sequence. Parts of it are sulphide-rich, and, although pyrite is dominant, sphalerite and galena are concentrated in some beds. Overlying the Gunpowder Creek Formation are three carbonate-rich formations: the Paradise Creek, Esperanza, and Lady Loretta Formations. The central unit, the Esperanza Formation, is dominated by stromatolitic chert and siltstone, but the other two are mainly stromatolitic, laminated, and intraclastic dolomite. All three were deposited in shallow-marine and paralic conditions, and the presence of evaporites suggests an arid climate. The Shady Bore Quartzite, a shoreline sand-body, intertongues with dolomite of the underlying Lady Loretta Formation and siltstone of the overlying Riversleigh Siltstone. The upper formations of the McNamara Group - the Riversleigh Siltstone, Termite Range Formation, and Lawn Hill Formation - are mainly fine-grained rocks. Carbonaceous siltstone is common and indicates, in conjunction with probable turbidite sandstones in the Termite Range Formation, that deep-water conditons prevailed. The uppermost Lawn Hill Formation represents a return to shallow-water conditions preceding uplift and deformation.

The McNamara Group was folded into a series of domes and basins, and faulted, before a younger Proterozoic sequence of sandstone and siltstone - the South Nicholson Group - was deposited.

Limestone, siltstone, chert, and phosphorite were deposited, at least in the west, during the Middle Cambrian. There is no record of further deposition until the Mesozoic, when the Mullaman beds were laid down. The region was affected by a widespread lateritisation event during the Tertiary. Erosion, and locally fluvial deposition, have continued to the present.

The only mineral deposits to have been worked are lead-zinc-silver concentrations in faults in the Lawn Hill Formation. A lead-zinc mineral deposit has been located in the lower McNamara Group, and the Cambrian rocks contain phosphorite, but neither concentration is economic at present.

INTRODUCTION

Aims

The Lawn Hill/Riversleigh region was investigated as part of a project to re-examine the Proterozoic rocks of northwestern Queensland. The project, started in 1969, aims to document in detail the geology of the province as an aid to mineral exploration and resource assessment. Production of geologic maps, at a scale of 1:100 000, is an integral part of the project.

Location and access

The Lawn Hill/Riversleigh region, as referred to in this report, covers LAWN HILL,*MOUNT OSCAR, and parts of RIVERSLEIGH, BOWTHORN and MUSSELBROOK (Fig. 1) and is bounded by latitudes 18°S and 19° 30'S and longitudes 138°E and 139°E. Access to Lawn Hill, Gregory Downs, and Riversleigh stations is by sealed road to Camooweal in the south, and to Nardoo in the east, and thence by unsealed roads to Gregory Downs and beyond. Camooweal and Burketown are the nearest towns, but virtually all business and commercial activity is centred on Mount Isa (population 26 500 in 1976) and Cloncurry (3500). Gregory Downs and Lawn Hill stations are served by a weekly air service from Mount Isa, and Riversleigh by a road freight service from Camooweal to Burketown.

Climate and vegetation

The region has a semi-arid to subhumid tropical climate (Slatyer & Christian, 1954), with a short wet season from about December to March, and a long dry season during the remainder of the year. Rainfall, mainly from thunderstorms and tropical depressions associated with the northwest monsoon, and occasionally from tropical cyclones, ranges from an average of 450 mm per annum in the south to about 600 mm in the north. Daily average maximum temperatures range from about 26°C in July to 38°C in January.

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* Names of 1:100 000 Sheet areas are printed in capitals throughout this report.

The annual drought of at least six months is an important factor in plant growth (Slatyer & Christian, 1954), and only species which are drought resistant occupy the area, except near perennial watercourses. Perry & Christian (1954) described the common vegetation associations in the region. The extensive black-soil plains in the northern and central parts of the region support mainly grasses. The remainder of the region is covered in mixed woodland, the hilly areas being dominated by small eucalypts (mostly snappy gum - E. brevifolia) and spinifex grasses (Triodia species). Fringing communities along the Gregory River and Lawn Hill Creek are dominated by large red gums (E. camaldulensis) and paperbarks (Melaleuca sp.) but include several other large and medium-sized trees - e.g., the Livistonia palm. An excellent introduction to the flora and fauna of the Mount Isa region, including the Lawn Hill area, is given by Horton (1976).

Topography and drainage

The region can be divided into two main topographic units - plains in the north and east, and low hills in the remainder of the region. The elevation of the plains increases gradually from 40 m in the north to 120 m in the south. The hilly areas, part of the Isa Highlands of Twidale (1966), rise to about 300 m at several places in southern LAWN HILL and northern RIVERSLEIGH. Rocks of Proterozoic age form a complex series of ridges and valleys, and plateaux and mesas, and Cambrian limestones in the southwest form a rugged, dissected plateau. Local relief is rarely greater than 100 m.

The Lawn Hill/Riversleigh region lies within the 'Gulf Fall' of Stewart (1954) - the area which drains into the Gulf of Carpentaria. The main streams are the Gregory and O'Shannassy Rivers, and Lawn Hill and Elizabeth Creeks.

The Gregory and O'Shannassy Rivers and Lawn Hill Creek are perennial, being fed by springs in the Cambrian limestones. They thus form a natural outlet to a major groundwater basin which underlies the Barkly Tableland (Randal, 1967). The spring-fed flow of the Gregory River at Riversleigh has been reported by Whitehouse (1940) to be about 150 cusecs; that of Lawn Hill Creek is less than half this amount. Saint-Smith (1925) gives figures of 141 million gallons/day (260 cusecs) for the Gregory River and 41 million gallons/day (76 cusecs) for Lawn Hill

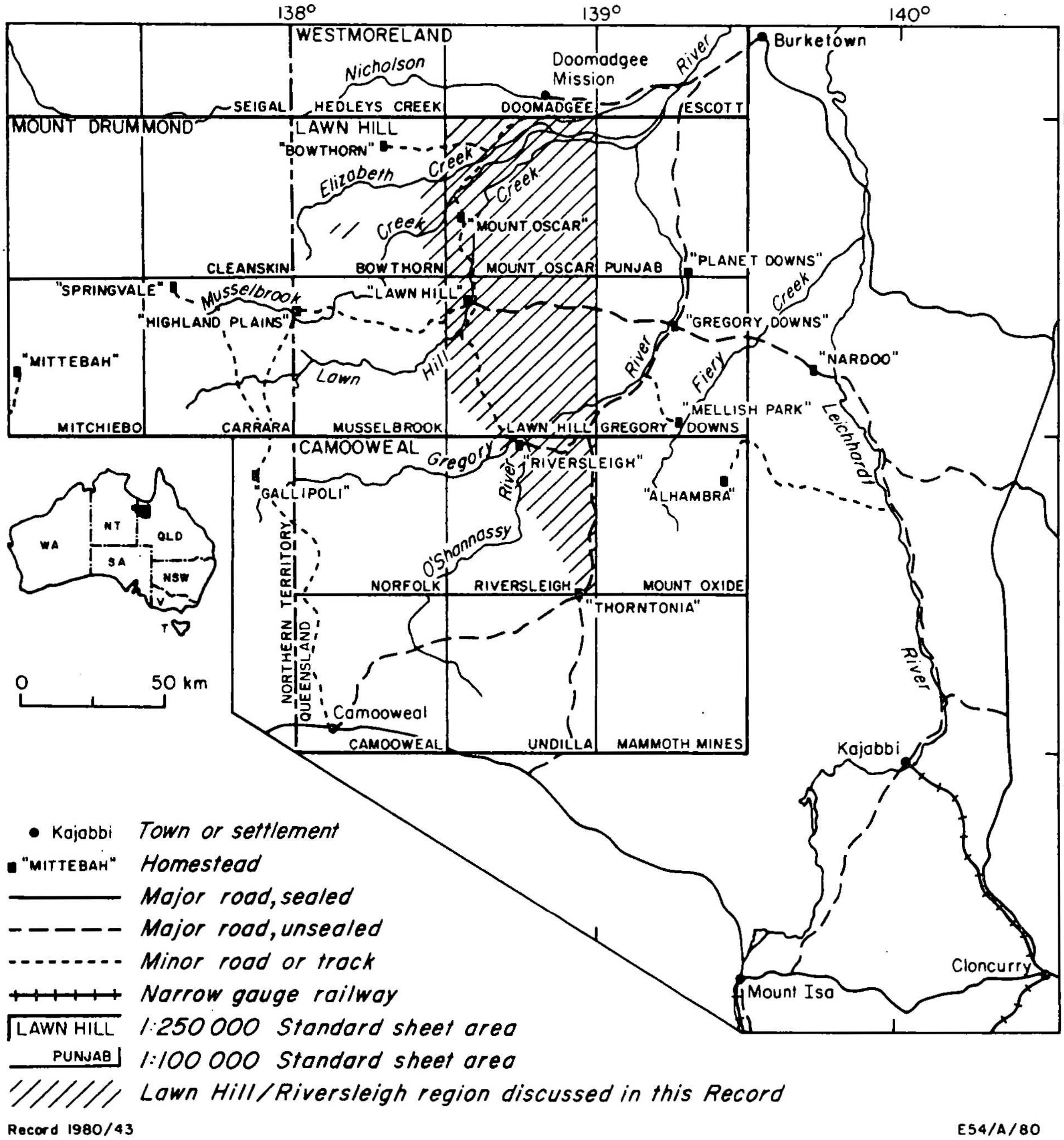

Fig. 1 Location and access map

Creek. The flow of both streams dividles progressively downstream largely as a result of evapotranspiration of the thick vegetation lining the banks (Cox, 1973).

All the creeks and rivers flood extensively during the heavy wet-season rainfalls; much of MOUNT OSCAR lies within a flood plain.

Habitation and industry

Virtually all the land in the region is leased from the State for cattle-grazing. The largest pastoral property, Lawn Hill, covers all of MOUNT OSCAR and part of LAWN HILL. The remainder of LAWN HILL and RIVERSLEIGH include parts of several other properties. The only permanent inhabitants in the region, at Lawn Hill and Riversleigh homesteads, number 50-100 people. Beef-cattle raising and associated activities have been the only industries in the region since mining south of Lawn Hill ceased in 1967.

Previous investigations

Most reports on the Lawn Hill/Riversleigh region before the 1950s concentrated on descriptions of the Burketown Mineral Field in northwestern LAWN HILL (Fig. 25). The first published geological report was that of Cameron (1900), who described the geological setting and development of seven mines in the region. Cameron (1901) provided the first descriptions of regional geology, and placed the mineralised rocks of the area between Cloncurry and Lawn Hill in the Silurian. He observed an angular unconformity between these older, folded rocks and the younger sandstones forming the Constance Range, which he regarded as being Devonian in age. He mistakenly identified the Cambrian limestones as post-Tertiary from gastropods collected from Tertiary limestones near Riversleigh.

The first comprehensive geological report on the region was by Ball (1911), who also described the geography of the region. He studied the lead-silver mines in detail and listed the minerals and their modes of occurrence. Dunstan (1920) referred briefly to the mineral field and Saint-Smith (1925) reported on an inspection of some of the mines. Ball (1931) commented on fieldwork by Blanchard, who had suggested that the stratigraphic sequence was the same as that around the (then) recently discovered Mount Isa lode.

Jensen (1941) reviewed activities on the field, which had been idle since 1930 because of high costs and the 'scattered nature of the ore deposits'. He included a map of the regional geology based on the first aerial photography of the region.

The increased use of air photography after World War II facilitated the undertaking of regional geological surveys. Noakes & Traves (1954) reported on the first of these, but the most important one was a joint Bureau of Mineral Resources (BMR) Geological Survey of Queensland (GSQ) investigation carried out during the early 1950s. This led to publication of 4 mile to 1 inch geological maps (e.g., Lawn Hill Sheet area - Carter & Öpik, 1961), and regional geological interpretations which stood virtually until the present survey. Carter, Brooks & Walker (1961) described the major results of the 1950s survey.

Further reviews of the Burketown Mineral Field and individual mines have been compiled by Edwards (1953), Brooks (1963), Murray (1965), Bellis (1973), Hutton (1973) and Syvret (1975). A large iron deposit was discovered in the western Lawn Hill 1:250 000 Sheet area as a result of the BMR-GSQ survey, and the geology of these deposits has been described by Carter & Zimmerman (1960) and Harms (1965).

Discovery of phosphate in Cambrian rocks of the Georgina Basin led to remapping of the Cambrian in the Lawn Hill 1:250 000 Sheet area by de Keyser (1969).

Cavaney (1975) made the first major reappraisal of the Proterozoic geology of the region since the BMR-GSQ investigations of the 1950s. The Mesozoic rocks were re-examined during another BMR-GSQ investigation by Grimes (1974).

Present investigations

Reconnaissance of the Proterozoic rocks of the Lawn Hill/ Riversleigh region was carried out in 1973 during a BMR-GSQ survey of the Westmoreland region, and tentative correlations between the two regions were made (Plumb & Sweet, 1974; Sweet & Slater, 1975).

Fieldwork at Lawn Hill was carried out by L.J. Hutton (GSQ) and A. Mond and I.P. Sweet (both BMR) in 1976 and 1977. Mond concentrated on the rocks of the South Nicholson Basin in BOWTHORN and parts of MUSSELBROOK, CARRARA, and MITCHIEBO (Fig. 1). Sweet and Hutton concentrated on the older rocks which crop out largely in LAWN HILL, RIVERSLEIGH, GREGORY DOWNS, MOUNT OSCAR, and CARRARA. Preliminary results and photoscale geological compilation sheets for LAWN HILL, RIVERSLEIGH, and GREGORY DOWNS have been released (Sweet & Hutton, 1978, 1979). Fieldwork was completed in 1978, and a stratigraphic diamond drilling program was carried out in 1979. Mineral exploration activity in the Lawn Hill 1;250 000 Sheet area was reviewed by Hutton (1979).

Only minor re-interpretations, based on earlier work and photo-interpretation, have been made to the Phanerozoic geology of the region.

GEOLOGY

Regional tectonic setting

The Lawn Hill/Riversleigh region includes parts of five major tectonic units, whose broader distributions are shown in Figure 2. Only the rocks of the oldest unit, the Lawn Hill Platform are described in this report. The rocks of the South Nicholson Basin are described by Carter & Zimmerman (1960), those of the Georgina Basin and outliers by de Keyser (1969), and those of the Carpentaria and Karumba Basins by Grimes (1974), Doutch (1976), and Smart, Grimes, Doutch, & Pinchin (1980).

Plumb & Derrick (1975), introduced the term 'Lawn Hill Platform' to described the rocks of similar age to, and contiguous with but less deformed than, the rocks of the Mount Isa Orogen. The boundary between the orogen and the platform is defined as the Mount Gordon Fault (Fig. 2); other boundaries are formed by younger basins - mainly the Nicholson and Carpentaria. The Lawn Hill Platform sequence continues beneath these units, and crops out in CARRARA (Sweet & Mond; in preparation), SEIGAL and HEDLEYS CREEK. It is classified as part of the North Australian Platform Cover on the Tectonic Map of Australia (GSA, 1971).

STRATIGRAPHY

PROTEROZOIC-CARPENTARIAN

Introduction

The Proterozoic stratigraphy of the region is summarised in

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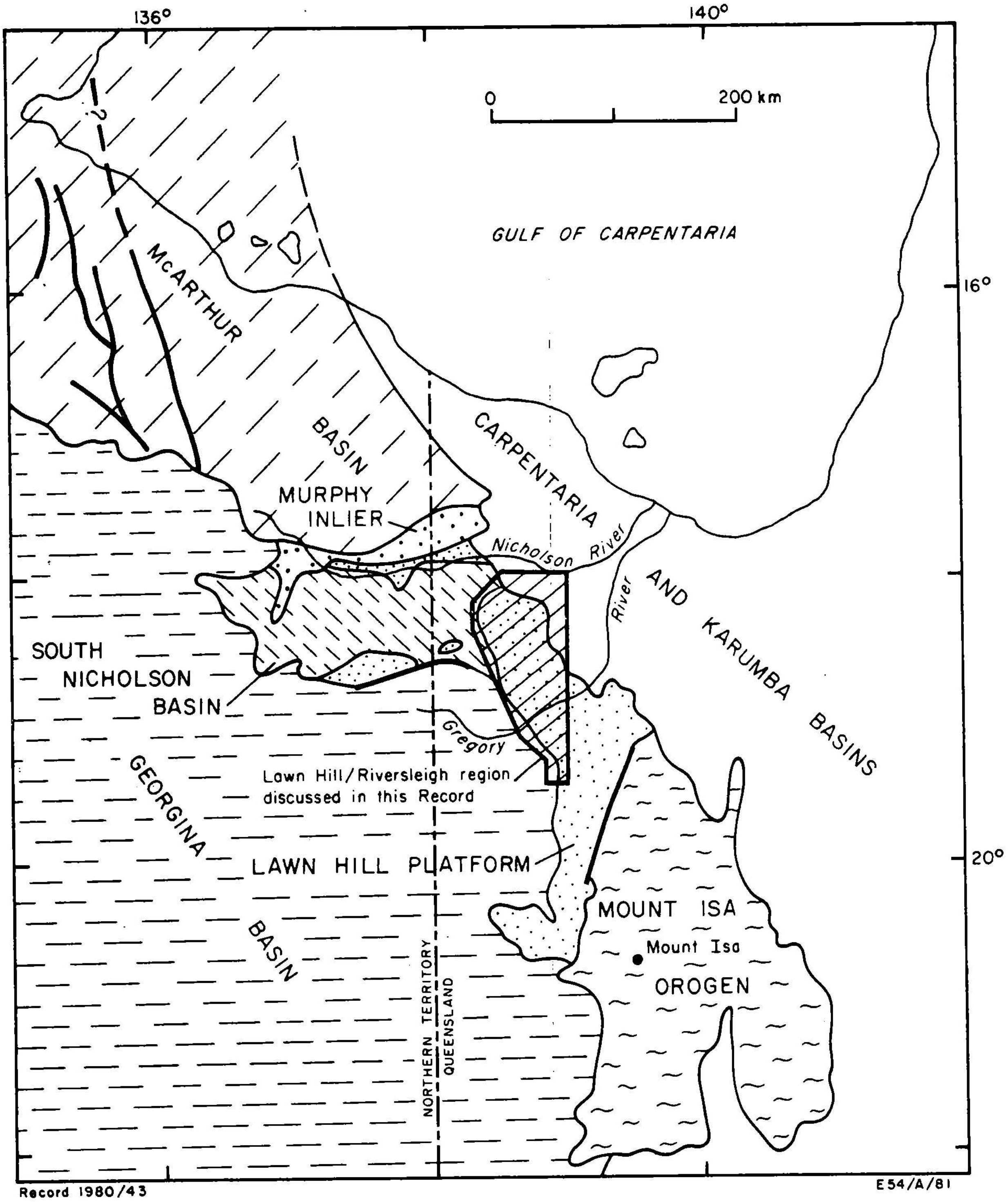

Fig.2 Regional distribution of major tectonic units (after GSA, 1971)

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Table 1.

As a result of previous BMR-GSQ mapping (Carter & Öpik, 1961) the rocks in the Lawn Hill Platform were divided into four major lith-stratigraphic units: namely, the Myally beds, Weberra Granite, Ploughed Mountain beds and Lawn Hill Formation.

The amygdaloidal lavas and associated sediments, mapped as Myally beds, have been renamed the Kamarga Volcanics as they are not equivalent to rocks mapped elsewhere by Carter & Öpik (1961) as Myally beds, and more recently by Derrick, Wilson & Hill (1976) as Myally Subgroup of the Haslingden Group. The Weberra Granite intrudes the Volcanics but not, as Carter & Öpik (1961) suggested, the Ploughed Mountain beds.

The Kamarga Volcanics and Weberra Granite are unconformably overlain by a thick sedimentary sequence, previously called the Ploughed Mountain beds and Lawn Hill Formation, but renamed the McNamara Group by Cavaney (1975). The Group has been subdivided into nine formations, all of which are present in the Lawn Hill/Riversleigh region, although only eight have been shown on the LAWN HILL map. (The Torpedo Creek Quartzite is now regarded as a separate formation, not a member of the Gunpowder Creek Formation as shown in the map reference).

Kamarga Volcanics

Introduction. The oldest rocks cropping out in the region, the Kamarga Volcanics, are basic lavas interbedded with and overlain by sandstones. They were previously mapped as Myally beds by Carter & Öpik (1961), and as Fiery Creek Volcanics by Cavaney (1975). They have been renamed the

Kamarga Volcanics by Hutton & Sweet (in press) because they cannot be confidently correlated with the Myally Subgroup or other rock units previously mapped.

Distribution. The Kamarga Volcanics crop out over 25 km^2 in the core and eastern flanks of a large structural dome in eastern LAWN HILL.

Type section. A composite type section of Kamarga Volcanics has been defined by Hutton & Sweet (1980). The lower component section (holostratotype of ISSC, 1976) lies between LH 827 215*(base) and LH 845 202. About 1000 m of reddish black weathered amygdaloidal and massive basic volcanics, interbedded with minor sandstone bands, crop out in the type section. Overlying the basic volcanics in the holostratotype is about 50 m of arkosic sandstone overlain unconformably by the basal beds of the McNamara Group. Farther east 400 m of this arkosic sandstone sequence is preserved, and the upper component of the type section (a parastratotype), has been designated; it lies between LH 876 227 (base) and LH 888 225 (top).

Boundary criteria and relations. The base of the unit is not exposed. It is overlain with angular unconformity by conglomerate and sandstone of the Torpedo Creek Quartzite, the basal unit of the McNamara Group. It is intruded by the Weberra Granite, as indicated by the presence of veinlets of granite in the basic volcanics.

Description. The Kamarga Volcanics comprise 1400 m of amygdaloidal and massive basic volcanics interbeddd with and overlain by massive feldspathic and ferruginous sandstone, arkose, and conglomeratic sandstone. The volcanics are commonly deeply weathered to a brick-red or black colour. The basal and

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* Letters preceeding the 6 digit grid references refer to 1:100 000 Sheet areas: LH-LAWN HILL: MOs - MOUNT OSCAR: R-RIVERSLEIGH: MO-MOUNT OXIDE

central parts of flows consist of massive equigranular fine-grained basalt. Flow tops are amygdaloidal and commonly include volcanic breccias comprising blocks of basalt in a jasper-like matrix. At LH 740 190 flows are in excess of 40 m thick.

In the northernmost outcrop of the Kamarga Volcanics two sandstone bands, one a medium-grained quartzose sandstone and the other an arkose, each about 50 m thick, crop out between basalt flows.

The 400-m sequence in the parastratotype consists of alternating massive feldspathic sandstone and arkose and softer, more ferruginous feldspathic sandstone and minor coarse siltstone. Conglomeratic sandstone bands are distributed throughout the sequence. This sandstone sequence is difficult to distinguish from the overlying Torpedo Creek Quartzite, although the angular break between them shows up clearly on air photographs.

Petrography. Descriptions and modal analyses of six thin sections from the Kamarga Volcanics are presented in Table 2. Four of the six rocks described are basalts. The freshest of the basalt samples, which were from CRA Exploration Pty. Ltd. diamond drill core, contain 55% oligoclase to andesine and significant amounts of chlorite, calcite, and opaque minerals (specimens 76410121 and 76410122, Table 2); most grains are between 0.1 and 0.2 mm. A vesicular basalt (76410036, Table 2) from LH 832 202 contains 40% vesicles, most of which are lined with a zeolite mineral - possibly chabazite. All feldspar grains are sericitised to a greater or lesser degree.

The other two rocks studied are sandstones (76410135 and 76410138, Table 2) from interbeds in the northernmost volcanic outcrops. One of these sandstones is a medium to coarse-grained well sorted quartzose sandstone with some accesory tourmaline. The second is a more poorly sorted arkose containing 25% feldspar grains, 5% rock fragments, 5% matrix and 65% quartz grains; it also has accessory tourmaline and muscovite.

Discussion. The Kamarga Volcanics are the oldest rocks cropping out in LAWN HILL. Several features such as the brecciated flow tops and the massive volcanic flows with vesicular flow tops suggest that the volcanics were erupted subaerially or into shallow water.

PROTEROZOIC-CARPENTARIAN

Weberra Granite

Introduction. The Weberra Granite was defined by Carter & others (1961) to include two bodies, the larger of which lies northwest of Alhambra Station in MOUNT OXIDE and the smaller in eastern LAWN HILL.

The relation between the granite in LAWN HILL and the Weberra Granite in MOUNT OXIDE is unknown. However as both bodies are high-level leucocratic granites of similar composition, it is probable that they both belong to the same intrusive episode. Although the granite which crops out in LAWN HILL is called the Weberra Granite, it will be renamed the Yeldham Granite when the first-edition map of LAWN HILL is produced.

Stratigraphic relations. The Weberra Granite in LAWN HILL intrudes the Kamarga Volcanics. Together, the Kamarga Volcanics and the Weberra Granite form the basement to the succession in LAWN HILL. The Weberra Granite is non-conformably overlain by the McNamara Group, and does not intrude it as suggested by Carter & others (1961). The presence of granite clasts in a conglomerate at the base of the McNamara Group (sample 76410140, Table 5) at grid reference LH748 203 indicates that the contact is non-conformable.

Distribution and exposure. The Weberra Granite crops out over 12 km^2 in three separate outcrops in eastern LAWN HILL. The granite is generally well exposed as weathered platforms with less than 50 m relief.

Description. The bulk of the Weberra Granite in LAWN HILL is an equigranular medium-grained pink-grey muscovite granite. Grain-size varies between about 1 and 6 mm, but averages about 1-2 mm. Some hornblende is present in the granite adjacent to the contact with the Kamarga Volcanics.

The granite is cut by pegmatite veins which crop out at LH788 310 and LH790 255; the veins contain quartz and feldspar grains up to 10 cm.

A muscovite schist which crops out in the northern granite body at LH778 310 has been interpreted as greisenised granite.

Xenoliths of graphitic quartz-hematite banded rock crop out at LH800 318. The rock is coarsely banded with alternating quartz-rich and quartz-poor bands in a hematitic matrix. The dimensions of the xenolith are not known, but they are probably several tens of metres long.

Sheared granitic rocks adjacent to major faults contain high percentages of hematite (sometimes as specularite) and quartz. Such rocks crop out at LH783 329 and LH730 197.

Petrography. Six thin sections from the Weberra Granite and xenoliths have been described (Table 3), and estimated modal compositions for 3 of them have been plotted in Figure 3. Granite and granodiorite are the rock types represented in this suite.

The Weberra Granite in LAWN HILL has a hypidiomorphic granular texure. It is equigranular, and has grainsizes ranging from 1 to 6 mm with an average of 1-2 mm. The minerals present are quartz, plagioclase, potash feldspar, and muscovite; minor hornblende is present adjacent to some contacts. Plagioclase, generally oligoclase to andesine, is subhedral to euhedral and is extensively sericitised. The potash feldspar is also subhedral to euhedral but is not as extensively sericitised as the plagioclase. Several grains of potash feldspar show the cross-hatched twinning characteristic of microcline, but other grains show no twinning and may be orthoclase or anorthoclase. Quartz grains are anhedral to subhedral and are commonly recrystallised.

A greisenised granite (76410 128B, Table 3), from the centre of the northern granite outcrop (LH778 310), has a strong schistose texture due to parallelism of the muscovite flakes. Ghost outlines of completely sericitised feldspar grains and some hornblende indicate that the rock was formed by the modification of an existing granite by pneumatolytic components of the magma. Graphite forms 10% of the rock, and probably comes from absorption of carbon from carbonaceous xenoliths. Graphite is also present in a banded xenolith which crops out in the northern granite mass at LH800 318. This is a hematite-rich rock which contains quartz-rich bands and 20% opaque grains comprising hematite and graphite.

A sheared hematitic granite (76410167, Table 3), which crops out at LH784 329, has a strong foliation but still retains much of the original granitic texture. The rock is probably related to a younger shearing which was accompanied by an infusion of hematite and quartz.

Conclusions. The Weberra Granite, both in LAWN HILL and MOUNT OXIDE, shows many features of an epizonal granite (Buddington, 1959). Features

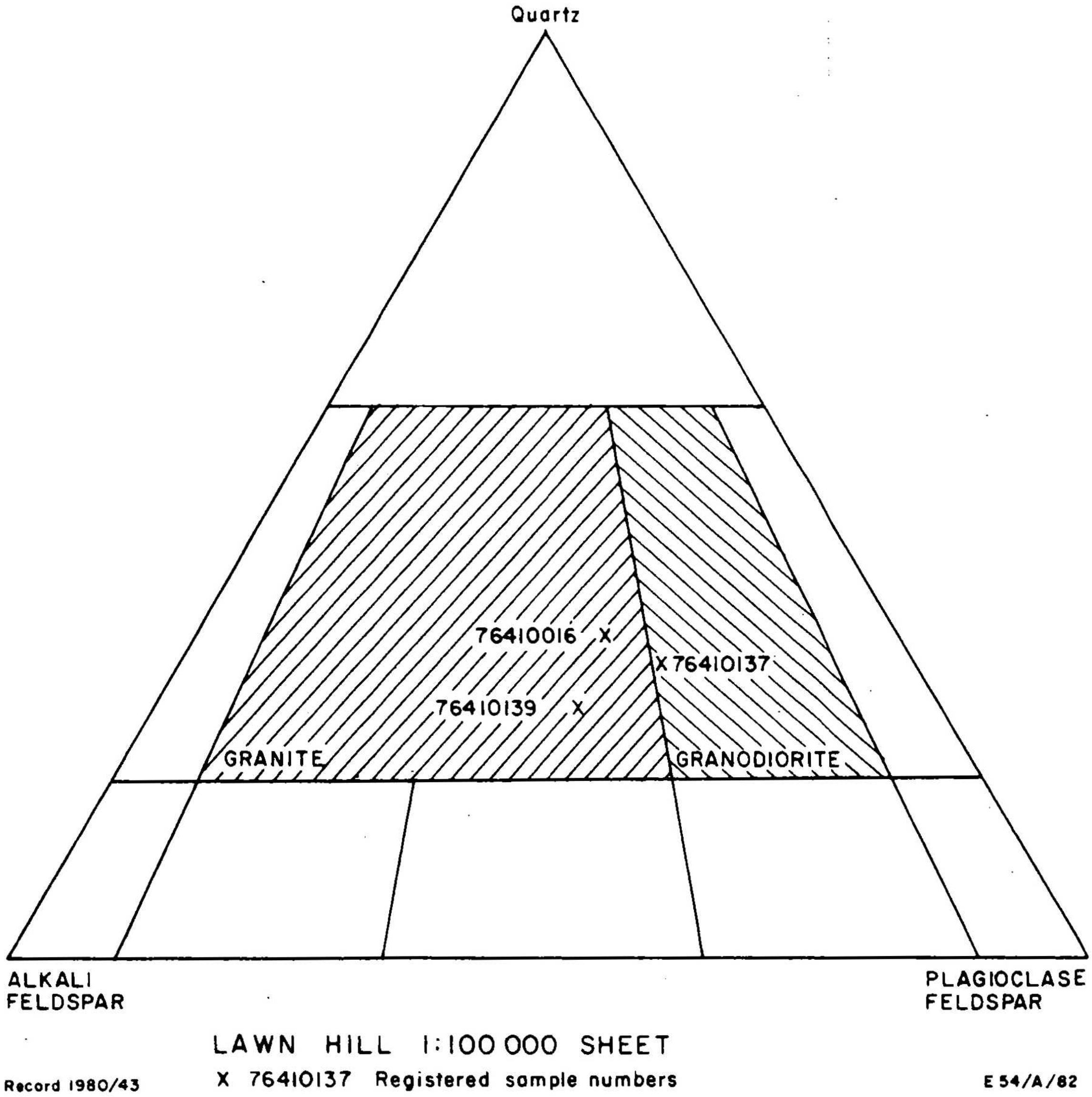

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Fig. 3 Estimated Modal Compositions - Weberra Granite of epizonal granites include - (a) a thin, low-grade metamorphic aureole; (b) a cross-cutting relation with the intruded beds; and (c) finer-grained granite near the margins of the intrusion. Although the contact between the Weberra Granite and the Kamarga Volcanics is poorly exposed, both the cross-cutting relation and the poorly developed metamorphic aureole can be observed; the granite is also finer-grained near the contact than it is in the centre of the intrusion.

The presence of graphite in several of the late-stage phases may indicate contamination of the granite by carbonaceous country rocks.

McNAMARA GROUP

The term McNamara Group was introduced by Cavaney (1975) to describe the sequence of carbonates and mainly fine clastics which unconformably overlies the Fiery Creek Volcanics, Carters Bore Rhyolite, and older units throughout the Lawn Hill Platform. Cavaney recognised nine formations in the McNamara Group, and traced most of them from KENNEDY GAP in the south, to LAWN HILL in the north. In Table 4 Cavaney's nomenclature is compared with de Keyser's (1958), Carter & others' (1961), and ours.

The term Mammoth Formation has been abandoned because a slight break in the sequence has been recognised near its top (Derrick, Wilson, & Sweet, 1980). They have included the older part of the Mammoth Formation in the Surprise Creek Formation, and excluded it from the McNamara Group. The part of the Mammoth Formation above the break, the Torpedo Creek Quartzite Member, has been raised to formation status and becomes the basal unit of the McNamara Group. (Note that on the LAWN HILL preliminary map the Torpedo Creek Quartzite is shown as a member of the Gunpowder Creek Formation. This will be changed on the first-edition map).

The term Ploughed Mountain beds (Table 4), intoduced by Carter & others (1961), has been abandoned because it includes units other than the McNamara Group in some areas - e.g., as mapped in MOUNT OXIDE it includes Quilalar Formation, Fiery Creek Volcanics, and Surprise Creek Formation. (The term Ploughed Mountain beds was retained in the MOUNT OSCAR Sheet, but not in LAWN HILL and RIVERSLEIGH. Table 1 shows the relation between symbols used in MOUNT OSCAR and symbols used in the other sheet areas).

Cavaney (1975) retained the Gunpowder Creek Formation as originally defined by de Keyser (1958), but modified the nomenclature of the Paradise Creek Formation. He retained the type section of the Paradise Creek Formation but excluded from it the stromatolitic cherts at its top. These he placed in a new unit, the Esperanza Formation, and erected another new unit, the Lady Loretta Formation, to include carbonates and siltstones overlying the cherts.

Sandstones at the top of the sequence in western MAMMOTH MINES - which de Keyser (1958) also included in the Paradise Creek Formation, and Carter & others (1961) mapped as Ploughed Mountain beds - were defined as Carrier Quartzite (now Shady Bore Quartzite) by Cavaney (1975). Virtually all outcrops of the three formations above the Shady Bore Quartzite - the Riversleigh Siltstone, Termite Range Formation, and Lawn Hill Formation - occur in RIVERSLEIGH or areas farther north. Only the Lawn Hill Formation was mapped as a formation by Carter & others (1961); the older units were all included in the Ploughed Mountain beds.

Torpedo Creek Quartzite

The Torpedo Creek Quartzite is shown on the LAWN HILL map as a member (Bmw_a) of the Gunpowder Creek Formation, but we now regard it as a formation, the basal unit of the McNamara Group. It was named by Cavaney (1975) who followed nomenclature of Williams & Love (1968). Cavaney included it as a member of the Mammoth Formation, which has been defined as the Surprise Creek Formation by Derrick & others 1980.

Distribution. The Torpedo Creek Quartzite is a thin but widespread sandstone unit cropping out mainly in MOUNT OXIDE and MAMMOTH MINES. It crops out over a few square kilometres in eastern LAWN HILL, forming low cuestas and dip-slope pavements.

Type section. The type section is at Torpedo Creek, in northern MAMMOTH MINES. A reference section covering the Torpedo Creek Quartzite and the Gunpowder Creek Formation in LAWN HILL has been nominated; it extends from LH785 188 (base) to LH787 174 (top).

Relations and boundary criteria. In LAWN HILL the Torpedo Creek Quartzite rests with angular unconformity on the Kamarga Volcanics. Its relation in LAWN HILL thus differs from that to the south where it rests conformably or disconformably on the Surprise Creek Formation. It is overlain conformably by, and in some localities intertongues with, the Gunpowder Creek Formation. Its upper boundary is placed at the top of the last sandstone bed, above which siltstone predominates.

Description. The Torpedo Creek Quartzite (Bmw_a) in LAWN HILL consists of conglomerate and sandstone. The conglomerate is polymictic with clasts which range from pebble to cobble size. The presence of both granitic (76410140, Table 5) and volcanic clasts (76410170, Table 5) indicates erosion of the underlying basement. In the reference section the conglomerate grades upwards into cross-bedded quartzose to feldspathic sandstone, siltstone, and shale. Coatings of malachite, probably from disseminated chalcopyrite, are commonly associated with the Torpedo Creek Quartzite; pyrite is also common in the sandstone. The unit is absent or very thin around LH740 187. It thickens eastwards to 100 m at the reference section, but averages about 20 m in the core of the Kamarga dome. These variations indicate that the formation was deposited on an uneven erosion surface.

A lens of siltstone (Emw_b) which has been photointerpreted as lying beneath the Torpedo Creek Quartzite between LH795 178 and LH850 203 is probably a tongue of Gunpowder Creek Formation, and is underlain by a thin basal conglomerate.

Petrography. Descriptions of two conglomerate samples from the Torpedo Creek Quartzite are presented with descriptions of Gunpowder Creek Formation samples in Table 5. Both are polymictic pebble conglomerates containing rounded clasts of granite and basic volcanics in a clayey or fine sandy matrix .

Discussion. The presence of lenticular conglomerates suggests that the Torpedo Creek Quartzite is in part a fluvial deposit. However, its thinness and wide distribution indicate that the upper part of the unit is probably the product of a marine transgression through the region.

Gunpowder Creek Formation

Introduction. The Gunpowder Creek Formation (de Keyser, 1958) in LAWN HILL comprises sandstone, siltstone and dolomite. The sediments which crop out in LAWN HILL are coarser grained than those in the type section of the Gunpowder Creek Formation, in MAMMOTH MINES.

Distribution. The Gunpowder Creek Formation crops out over an area of 50 km^2 in eastern LAWN HILL.

Type section and reference section. The type area of the Gunpowder Creek Formation, between Gunpowder Creek and Paradise Creek in MAMMOTH MINES was described by de Keyser (1958), and Carter & others (1961) defined the type section. The type section is mainly flaggy micaceous siltstone with minor shale, sandstone, dolomite, and leached carbonaceous shales near the top. These lithologies differ from those which crop out in LAWN HILL and hence a reference section has been nominated. It extends from LH787 174 (base) to LH788 160 (top), and contains about 800 m of ferruginous arkosic sandstone, micaceous siltstone, stromatolitic dolomite, and graded carbonaceous siltstone.

Boundary criteria. The base of the Gunpowder Creek Formation is generally sharp, and the unit is apparently conformable on the Torpedo Creek Quartzite.

In the type section, in MAMMOTH MINES, the top of the Gunpowder Creek Formation is placed at the base of a laminated chert horizon named the Oxide Chert Member by Cavaney (1975). A similar chert has been found in LAWN HILL (D. Jones, Newmont, personal communication) where it forms a boundary between a mainly clastic sequence below and dolomite above. This lithological boundary can be traced throughout the remainder of the outcrop area of the Gunpowder Creek Formation in Lawn Hill, and although the chert marker is not present it is mapped as the top of the formation. This boundary has been intersected in both GSQ Lawn Hill 3 and GSQ Lawn Hill 4 stratigraphic drillholes. Although no chert has been found in these drillholes, the boundary is marked by a change from laminated dolomite and silty dolomite of the Paradise Creek Formation, to graded siltstones and carbonaceous shales of the Gunpowder Creek Formation.

Description. The Gunpowder Creek Formation has been divided into three informal mapping units, based on outcrop and drill core information.

Overlying the Torpedo Creek Quartzite, and labelled Bmw_b on the LAWN HILL map, is a thin sequence of micaceous siltstone, shale and minor sandstone. In GSQ Lawn Hill 3 Bmw_b is represented by a sequence of strongly carbonaceous shale and minor sandstone. The unit is pyritic and graded bedding is common near the base of the black shales. This sequence is a recessively weathering unit which forms a valley between more prominent sandstones and conglomerates of the overlying and underlying units. It intertongues with both the Torpedo Creek Quartzite and the overlying arkosic sandstones. Graded bedding on a fine scale is present in sample 76410164 (Table 5).

Overlying Bmw_b is a sequence of cross-bedded, ferruginous arkosic sandstones interbedded with minor conglomerate, siltstone, and stromatolitic dolomite (Bmw_c). Several of the sandstone beds contain mudflake conglomerates. A prominent stromatolite band, which contains round to polygonal, branched, divergent columnar stromatolites crops out at LH767305 (Fig. 4).

Overlying the topmost sandstone bed of Bmw_c is a zone of ferruginous, silicified and extremely weathered rock labelled Bmw_d on the LAWN HILL map. This unit crops out poorly and lithologies are difficult to determine from the very weathered surface exposures. GSQ Lawn Hill 3 intersected 265 m of Bmw_d, which was found to comprise two graded sandstone to carbonaceous siltstone sequences separated by dolomite, oolitic dolomite, and dolomitic sandstone (70 m) overlying 195 m of chlorite-bearing dolomite and dolomitic siltstone. The graded sequences, both between 20 and 30 m thick, contain a succession of thin beds (1-5 cm) of medium to fine sandstone to laminated carbonaceous siltstone and shale capped by a thin band of framboidal pyrite. The lower of the two graded sequences displays prominent sand dykes intruding the underlying argillaceous sediments.

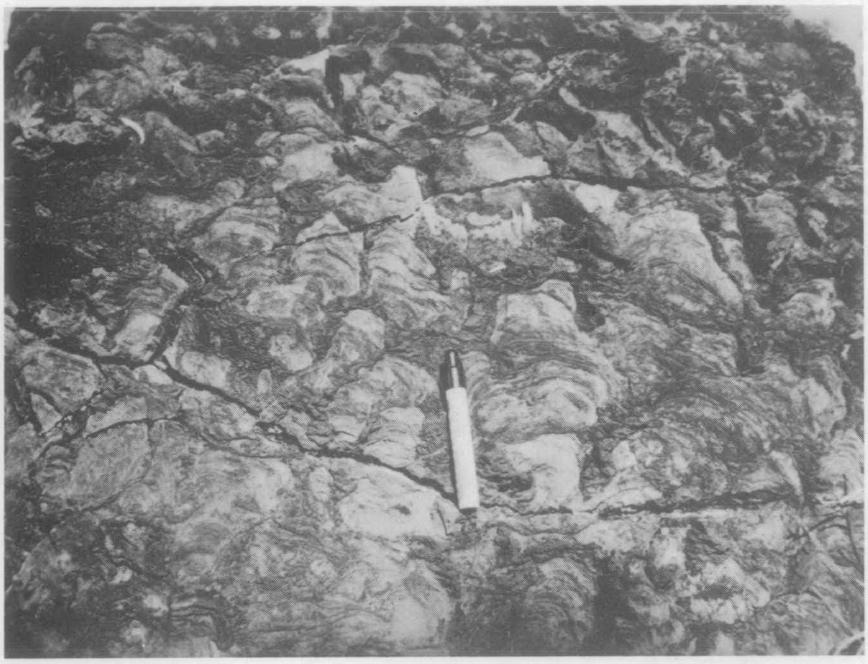

Fig. 4: Parallel and divergently branching columnar stromatolites in the Gunpowder Creek Formation (Bmw_c) at LH767 305, near the centre of the Kamarga dome. The material between the columns is coarse dolomitic sandstone (Neg. GB/1389).

The 195 m thick sequence of silicified dolomite, dolomitic siltstone and dolomitic sandstone is characterised by the presence of patches of chlorite up to 10 mm across. Stromatolites, notably Conophyton, as well as stylolites and breccias are common. Chalcopyrite cubes were found in vugs in the dolomite in GSQ Lawn Hill 3. Evidence of evaporites - in the form of pseudomorphs of gypsum, anhydrite, and halite - have been found in Bmw_c and Bmw_d (D. Shearman, Imperial College, D. Jones, Newmont; personal communication).

Petrography. Eight thin sections from the Gunpowder Creek Formation have been described (Table 5).

Both pyritic and graded mudstones have been described from Bmw_b. Both the coarser and finer fractions of the graded sample (76410164, Table 5) are poorly sorted, indicating deposition from a waning current (Pettijohn, 1957, p. 171).

All of the four samples from Bmw_c are from drill hole WC1 drilled by CRA Exploration Pty Ltd in LAWN HILL. One of the samples is a polymictic pebble conglomerate containing clasts of granite and rounded micritic fragments, granules of quartz in a matrix of micritic fragments, granules of quartz in a matrix of micritic dolomite, and sparry dolomite. The crystalline dolomite permeates all parts of the rock, including granite clasts, and is at least in part secondary. Other samples from Bmw_c comprise between 40 and 80% quartz grains, up to 15% fresh microcline, some chert grains and a matrix of dolomitic mud and sparry cement. Sample 76410119 (Table 5) has a reddish colour, probably due to the presence of hematite.

Two samples are described from Bmw_d, one is a mudstone from LH768170 and the other is a sandy dolomite similar to those in Bmw_c.

Mineralisation. Disseminated chalcopyrite in a red-bed association is evident in arkosic sandstone and conglomerate in Bmw_b and Bmw_c.

Disseminated galena and sphalerite have been found in the dolomites of Bmw_d.

Discussion. The black carbonaceous shales and siltstones of Bmw_b were possibly deposited in reducing conditions in a restricted marginal sea or lagoonal environment.

Emw_c comprises cross-bedded ripple-marked arkosic sandstone interbedded with conglomerate, siltstone, and stromatolitic dolomite. The amount of primary dolomite is difficult to determine as some of the crystalline dolomite is in veins. The presence of hematite in sample 76410119 gives it the appearance of a typical red-bed sediment, indicating subaerial exposure.

Towards the top of Emw_d in GSQ Lawn Hill 3, cyclic graded bedding is characterised by the presence of abundant sand dykes which indicate high fluid pressures in sandy layers and thus indicate rapid deposition (J. Draper, GSQ, personal communication). The presence of framboidal pyrite - possibly an indicator of algal activity (Part & MacDiarmid, 1970, p. 133), particularly when not associated with thick black shale accumulations and other indicators of a reducing environment, and evidence of evaporites - suggests a shallow-water, possibly intertidal environment.

It is probable that at the time of deposition of the lower McNamara Group the Kamarga Volcanics/Weberra Granite basement was being eroded, and that the Torpedo Creek Quartzite Emw_b and Emw_c represent fluvial shallow-marine and lagoonal deposits at the margin of the landmass. Unit Emw_d, which underlies the shallow-water shelf sediments of the Paradise Creek Formation, was probably deposited in a nearshore or intertidal environment.

The Gunpowder Creek Formation in LAWN HILL is coarser-grained and more dolomitic than the formation in the type area in MAMMOTH MINES, and it is therefore believed that the LAWN HILL area is closer to the source of the sediments.

Paradise Creek Formation

Introduction. The Paradise Creek Formation as defined by de Keyser (1958) has been subdivided by Cavaney (1975) into three formations: the Paradise Formation, Esperanza Formation, and Lady Loretta Formation. The Paradise Creek Formation as mapped in LAWN HILL is equivalent to the Paradise Formation of Cavaney. It is the lowermost of three dolomitic units which crop out in LAWN HILL, and it forms low-relief hills with a distinctive photopattern on aerial photographs. Cavaney has since changed the name of his Paradise Formation to Paradise Creek Formation.

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which range from 0.005 to 0.01 mm. Banding in the rock is due to layering of quartz grains and opaques in a dolomitic sparry cement.

Dolomitic breccias up to 5 m thick, which are present in the sequence at LH872089 and near GSQ Lawn Hill 4, contain angular blocks up to 30 cm in a dolomitic matrix. The mode of formation of these breccias is not known.

Intraclast bands, thin breccia bands, and oolites are found throughout the sequence; oolites and breccia bands are commonly associated with stromatolitic beds. A dolomitic bed at LH748362 contains ooliths whose diameter increases from 1 mm at the base of the bed to about 5 mm at the top (Fig. 5). This bed is overlain by a bed of dolomite containing specular hematite flakes.

Evidence of evaporites, mainly cauliflower cherts (Walker & others, 1977), have been found in several horizons by Newmont geologists (D. Jones, personal communication). Several structures which may be cauliflower cherts have been found in GSQ Lawn Hill 4. Limonite pseudomorphs after gypsum are also abundant (D. Jones, personal communication).

Clastic units within the Paradise Creek Formation in LAWN HILL form only a small percentage of the sequence. Where present they are commonly pyritic grey to brown siltstone, and friable quartzose to clayey sublabile sandstone.

The Paradise Creek Formation crops out in several small areas in RIVERSLEIGH. Some highly ferruginised and scattered outcrops occur just to the west of Police Creek, about 20 km south of the Gregory River. A further 10-15 km south of these outcrops, again on the eastern margin of the Sheet area, more Paradise Creek Formation is present, comprising mainly dolomite and siltstone.

GSQ Lawn Hill 4 was drilled to intersect the Paradise Creek Formation in LAWN HILL. The sequence intersected comprises mainly stromatolitic dolomite and dolomitic siltstones with less than 5% of the sequence made up of clastic sediments. The stromatolite beds are associated with breccia bands of unknown origin. These bands are described from drill core where they consist of blocks of dolomite with very little matrix. Where matrix is present it is micritic dolomite. They are probably primary or diagenetic features rather than tectonic breccias. Oolite bands were also found.

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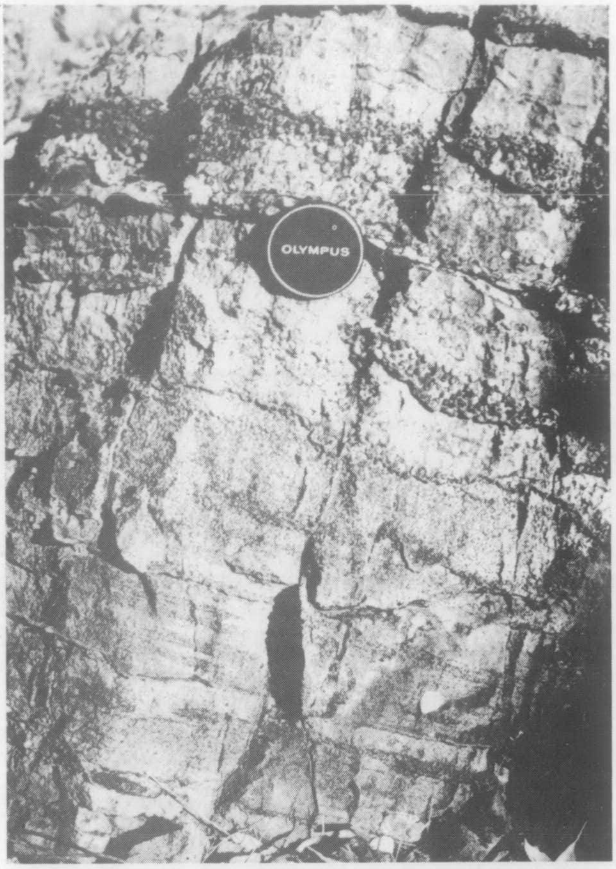

Fig. 5: Oolite-pisolite bed in the Paradise Creek Formation at LH748 362; note the coarsening-upwards cycle (GB/2236).

To the north of the Gregory River, in eastern LAWN HILL, a later weathering event has resulted in silicification and ferruginisation of several units, including the Paradise Creek Formation. These rocks are collectively labelled Em_c.

Stromatolites. Bulbous, domal, and columnar stromatolites all occur in the Paradise Creek Formation. Bulbous stromatolites, 30 to 40 cm in diameter, are usually round in plan but oblong shapes, probably indicating the effects of current activity on morphology, are also present. Columnar 'digitate' stromatolites, up to 2 cm in diameter are usually chertified, are also common. A species of Conophyton up to 10 cm in diameter has been found at LH748359. Domal bioherms, up to a metre in diameter and comprising layers of 'digitate' columnar stromatolites, form reef-like structures at LH872089. Wavy laminations, a feature of some of the dolomitic sequences, may be algal in origin.

Discussion. The Paradise Creek Formation comprises laminated algal dolomite, dolomitic siltstone, and dolomitic sandstone with minor sandstone and siltstone beds. Intraclast bands, breccia, and ooids are commonly found in the unit. The association of stromatolites and ooids suggests either a lagoonal or open-sheld environment.

Cauliflower cherts are formed by accumulations of anhydrite from pore fluids after deposition, and indicate that highly saline brines are forming in adjacent localities during early diagenesis.

The lack of coarse clastic sediments indicates that the adjacent landmass was flat and stable by this time. The breccias may be diagenetic in origin (i.e., collapse breccias) or if they are primary they may be related to periodic high-energy events (i.e., storms).

The environment of deposition thus indicated is a flat stable shallow-water shelf with local basins, some evaporitic, possibly formed by ooid banks. Stromatolites were formed on the shelf. Larger-relief reef-like structures formed by domal bioherms are also a feature of this shelf.

Esperanza Formation

Introduction. The Esperanza Formation (Cavaney, 1975) - a stromatolite chert, sandstone, and siltstone unit - crops out as ridges bounded on either side by low-relief dolomitic units. It includes the massive stromatolitic cherts which make up the upper part of the original type section of the Paradise Creek Formation as defined by de Keyser (1958).

Distribution. The Esperanza Formation crops out over 50 km^2 in LAWN HILL. The unit is best exposed around the Kamarga dome in the eastern part of the Sheet area. It also crops out as folded and faulted outcrops adjacent to the Gregory River.

In RIVERSLEIGH, the Esperanza Formation crops out over 32 km^2, principally in the core of a large faulted anticline west of Police Creek in the northeast corner of the Sheet area.

Type section. Cavaney (1975) nominated a type area in the Paradise Creek/Redie Creek area, in MAMMOTH MINES. The rocks in the type area are stromatolitic chert interbedded with siltstone and fine-grained sandstone. These lithologies are also characteristic of the Esperanza Formation in LAWN HILL.

Boundary criteria. Both upper and lower boundaries of the Esperanza Formation are conformable and generally are placed at the top and base, respectively, of massive stromatolitic chert beds. In places the chert characteristic of the basal Esperanza Formation is absent, in which case the lower boundary is placed at the base of a sandstone bed which forms a prominent ridge.

Description. The Esperanza Formation comprises 200-250 m of stromatolitic chert, siltstone, sandstone, and dolomite. A feature of this unit is its variability along strike owing to the discontinuity of the stromatolitic cherts. In some sections three separate stromatolitic chert beds are present, but commonly either one or more of these is absent or non-stromatolitic. In some sections, sandstone beds form a major part of this formation; where they do, the sandstone is considered to be a lateral equivalent of the massive cherts of other sections. A section of the Esperanza Formation at LH885060 contains no outcrops of stromatolitic chert. The ridge-forming units which crop out at this locality are medium-grained ripple-marked cross-bedded sandstones interbedded with laminated dolomites and siltstones. These rocks are overlain by a ferruginous breccia (Bml_b) which forms the basal beds of the Lady Loretta Formation.

A section through the Esperanza Formation southwest from LH765253 contains several massive stromatolitic chert bands, one in excess of 2-3 m thick, interbedded with siltstone, fine-grained sandstone, and dolomite. The first massive chert band, which marks the base of the Esperanza Formation in this section, is underlain by an oolite bed which was found to be present in several other localities.

The stromatolitic cherts grade laterally into thinly flat-laminated cherts; one such bed crops out at LH830140.

In northeastern RIVERSLEIGH the Esperanza Formation consists of stromatolitic chert, dolomite, siltstone, sandstone, and oolitic dolomite. The stromatolitic chert beds are massive with large domal bioherms. The westernmost outcrop of Esperanza Formation in RIVERSLEIGH, at grid reference R681955, consists of a thick-bedded basal sandstone overlain by several thin chert beds and highly weathered dolomitic siltstone. The chert beds contain 'digitate' columnar stromatolites.

Petrography. Descriptions of 10 thin sections from the Esperanza Formation are presented in Table 6. Three of these samples were taken from core from drillhole WC2 drilled by CRA Exploration Pty Ltd in LAWN HILL.

The majority of samples are siltstones or very fine-grained sandstones sampled randomly from the Esperanza Formation; several are dolomitic. A representative sample (77410010, Table 6) at LH811040 contains 65% poorly sorted quartz grains, 1% plagioclase grains, 4% chert grains, 3% mica flakes and 27% iron-stained fine silty matrix. The quartz grains are 0.03 mm in diameter (coarse siltstone) and the plagioclase grains are generally albite to oligoclase; some are relatively fresh. A sample of oolitic dolomite (77410015, Table 6) at LH880169 is a sandy oolitic wackestone comprising 45% quartz grains which range in size from 0.02 mm to 0.5 mm, 15% ooids up to 0.15 mm in diameter, and 35% micritic mud matrix.

Stromatolites. Several different types of stromatolites occur in the Esperanza Formation. The largest and most conspicuous are large domal bioherms (Fig. 6), which are present at several localities in MOUNT OXIDE and LAWN HILL. At LH750247 a domal bioherm measures about 3 m in diameter and 1 m high. The bioherms are made up of layers of small columnar stromatolites, rarely more than 1 cm in diameter and 5 cm long, radially distributed in the dome. These large bioherms are preserved only as chert beds.

Other stromatolites in the Esperanza Formation are small closely packed columnar types. These stromatolites are more variable in size than those which make up the bioherms being up to 10 cm long and 2 cm in diameter. As with the domed bioherms, these types are only found in chert beds. Probable chertified Conophyton crop out at LH885023.

Discussion. The chert in the stromatolitic beds may be either primary, diagenetic, or a product of later silicification. The widespread distribution of massive chert beds, restricted to this unit, indicates early diagenetic chertification. The chert beds are continuous at depth, as is shown in drill core recovered by AMAX in GREGORY DOWNS (Nutter, 1976).

At LH885060 a section of the Esperanza Formation contains no chert. Cropping out in the section is a cross-bedded ripple-marked medium-grained quartzose sandstone, as well as siltstone and dolomite. These sandstone bodies form in areas where greater clastic sediment supply precluded the formation of carbonate-bonded stromatolites. Environments where this may occur are river channels or restricted beaches, both of which could form in the shallow-marine environment indicated for the remainder of this formation.

The Esperanza Formation was probably deposited in deeper water than the Paradise Creek Formation and the Lady Loretta Formation (M. Walter, BMR, personal communication). Domal bioherms up to 1 m high form in subtidal conditions with the height of the bioherm indicating a minimum depth of water. Where the bioherms are replaced by laminated cherts, shallower conditions may have prevailed.

Lady Loretta Formation

Introduction. The Lady Loretta Formation is the youngest of the three formations which Cavaney (1975) subdivided from the Paradise Creek Formation of de Keyser (1958). De Keyser described the sediments defined by Cavaney as Lady Loretta Formation as 'younger strata which are not present in the type area'. Carter & others (1961) stated that these strata 'can be seen along a line that extends from latitude 19°48'20"S, longitude 138°59'20"E

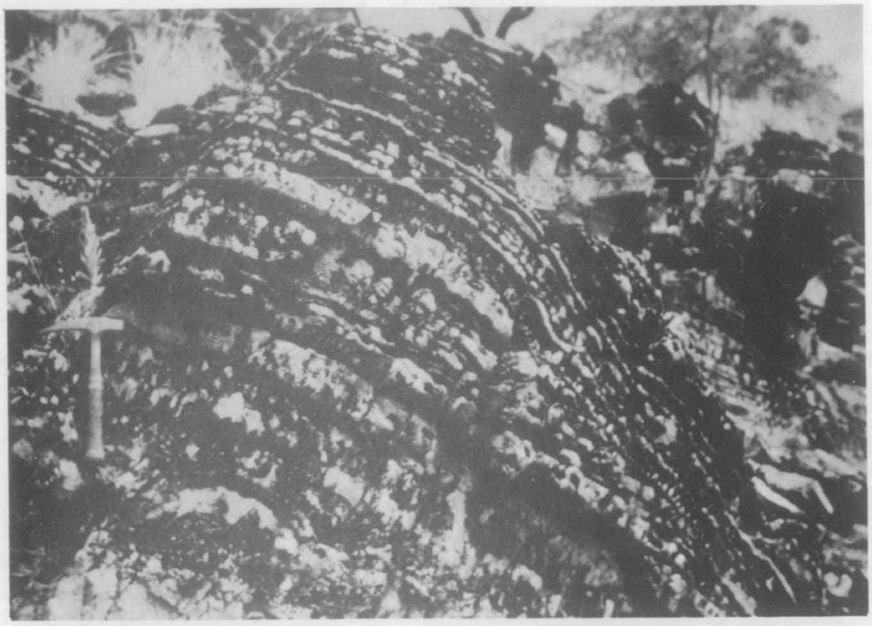

Fig. 6: Partly silicified stromatolite bioherm in the Esperanza Formation, MOUNT OXIDE. Erosion of the lower part of the structure took place and was followed by further growth of algal mats. The stromatolites are probably pseudocolumnar and columnar-layered varieties; the beds dip at about 45° away from the observer (GB/2230).

Distribution. The Paradise Creek Formation crops out over 86 km^2 in LAWN HILL and is best exposed around a large structural dome in the eastern part of the Sheet area. It is also exposed in a poorly defined anticlinal structure along both sides of the Gregory River to the south of the dome, in the Ploughed Mountain anticline near the northern margin of LAWN HILL, and in northeastern RIVERSLEIGH.

Type section. The type section of the Paradise Formation (Cavaney, 1975) almost coincides with de Keyser's (1958) type section of the Paradise Creek Formation along the course of Paradise Creek in MAMMOTH MINES, except for the stromatolitic cherts which form the top part of de Keyser's type section; Cavaney assigned these to the Esperanza Formation. Dolomite, algal dolomite, siltstone, sandstone, and stromatolitic chert crop out in the type section. These lithologies are similar to those which crop out in the Paradise Creek Formation in LAWN HILL.

Boundary criteria. The upper boundary is placed at the base of the first of several massive stromatolitic chert beds. Where chert is not present in the overlying Esperanza Formation, the boundary is placed below the first prominent ridge-forming band - usually a sandstone.

The lower boundary of the Paradise Creek Formation is placed at the base of the Oxide Chert Member (Cavaney, 1975). In LAWN HILL the Oxide Chert Member has been recognised only in the eastern part of the Sheet area. This boundary can be recognised in GSQ Lawn Hill 3 and 4 as a change from graded sandstone to laminated dolomite. In outcrop the boundary is difficult to place accurately because of the extensive weathering of both formations.

Description. The Paradise Creek Formation in LAWN HILL comprises about 500 m of dolomite and algal dolomite with minor siltstone, sandstone, and chert. The thickness of the unit is uniform around the Kamarga dome.

The Oxide Chert Member crops out poorly in LAWN HILL. It consists of two bands of laminated chert, each a couple of metres thick, separated by several metres of weathered siltstone.

The dolomites are usually dark grey when fresh, but weather to dark brown, black, white, or pink. They are usually laminated to thinly bedded and are commonly stromatolitic. A thin section of dolomite from drillhole WC2 contains fine-grained micritic dolomite with quartz grains (about three miles west of Lady Annie copper mine) north-west for about three miles' in MAMMOTH MINES.

The formation comprises thinly bedded to laminated dolomite, dolomitic siltstone, intraclast dolomite, siltstone, sandstone, and breccia. It crops out as low rolling hills with a distinctive photo-pattern similar to that of the Paradise Creek Formation.

Distribution. The Lady Loretta Formation crops out over 170 km^2 in eastern and southern LAWN HILL, and is best developed around the Kamarga Dome in the eastern part of the Sheet area. It also crops out in the north - in the cores of the Ploughed Mountain Anticline, in LAWN HILL, and the Mount Caroline Anticline, in MOUNT OSCAR.

In RIVERSLEIGH the Lady Loretta Formation crops out over 100 km^2 in the northeast and east.

Type section. The type section of the Lady Loretta Formatiom, in MAMMOTH MINES, is defined by Cavaney (1975) as 'that exposed above the Esperanza Formation in the synclinal structure containing the Lady Loretta zinc, lead and silver deposit, immediately east of the Lady Annie copper mine'. The type section consists of leached dolomitic and pyritic carbonaceous silt-stone with minor sandstone and dolomite. As these rocks are different from those which crop out in LAWN HILL, a reference section has been nominated. It lies between LH770130 and LH722102 near Wangunda Creek.

Boundary criteria. The lower boundary of the Lady Loretta Formation is placed immediately above the top stromatolitic chert of the Esperanza Formation, and corresponds to a photogeological boundary. In the reference section, the basal sequence is a ferruginous siliceous breccia. This breccia is usually, but not always, present at this boundary.

The upper boundary of the Lady Loretta Formation is placed at the base of the first of a series of orthoquartzite beds. This boundary is difficult to define, as the change from a mainly dolomitic unit to a sequence containing a significant proportion of orthoquartzite is a gradational one. The transitional beds have been mapped as a member (Eml_t) within the Lady Loretta Formation in RIVERSLEIGH, but they were tentatively included in the Shady Bore Quartzite in LAWN HILL (shown as Ems_b). The base of the transi-tional beds is an orthoquartzite bed up to 5 m thick; it is overlain by fine sandstone, siltstone, and dolomite.

Description. The reference section in LAWN HILL contains over 2 000 m of thinly-bedded to laminated dolomite, dolomitic siltstone, stromatolitic dolomite, intraclast dolomite, siltstone, and sandstone (Fig. 7). A ferruginous breccia at the base of the formation is a weathering product of an as yet unseen rock-type.

The ferruginous breccia forms the base of the Lady Loretta Formation in most localities in LAWN HILL. In MOUNT OXIDE, a siliceous breccia at this level can be seen grading into unbrecciated stromatolitic dolomite and dolomitic siltstone. Exploratory drilling by AMAX in GREGORY DOWNS indicates that the breccia represents the weathered outcrop of a pyritic shale and siltstone unit (Nutter, 1976).

Overlying the breccia in the reference section is a zone of weathered laminated chert and siltstone. Some of the chert beds contain stromatolites and may represent a replacement of dolomite by chert. In MOUNT OXIDE, this zone contains a cyclic sequence comprising *Conophyton* bands and laminated dolomite.

Overlying the band in the reference section is 1200 m of thinly bedded to laminated dolomite, commonly with chert stringers, interbedded with intraclast dolomite, siltstone, and fine-grained sandstone with some chertified ooids, chert nodules, and several dolomitic beds containing linked bulbous stromatolites up to 30 cm in diameter. Ripple marks and slump structure are common, particularly in siltstone beds. The uppermost beds in LAWN HILL and RIVERSLEIGH are richer in siltstone and sandstone, and less dolomitic, than the remainder of the Lady Loretta Formation, and are transitional into the orthoquartzites of the Shady Bore Quartzite.

Variations within the Lady Loretta Formation in LAWN HILL can be demonstrated by examining a section between LH710358 and LH699370, about 25 km along strike from the reference section. This section comprises thinly bedded dolomite with minor siltstone, sandstone, and a bed of edgewise conglomerate (also known as sharpstone conglomerate), and contains both bulbous and columnar stromatolites. The ferruginous and cherty breccia appears not to be continuous and is replaced at the base of the Lady Loretta Formation by a brecciated, chertified siltstone.

Fig. 7: Typical outcrop of Lady Loretta Formation in LAWN HILL. Interbedded laminated and intraclastic dolomites weather differentially to give terraced appearance (GB/2239).

Fig. 8: Conophyton column near top of Lady Loretta Formation in the west limb of the Kamarga Dome, LAWN HILL (GB/2226).

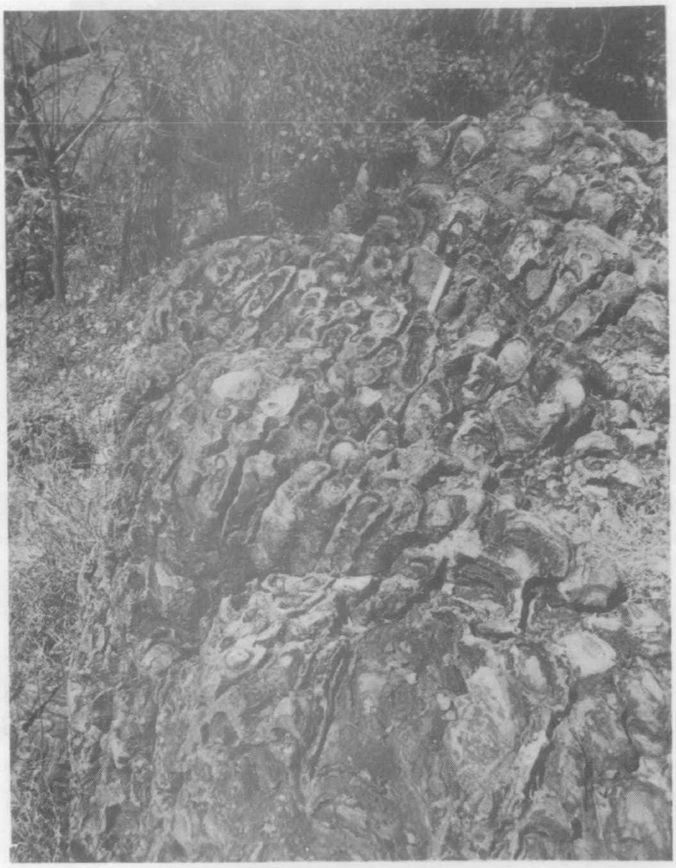

Fig. 9: Closely spaced stromatolite columns, probably from the same bed shown in Figure 8; includes both convex lamina types and Conophyton (M/2099).
Oblique view of bed; marker pen is 13 cm long.

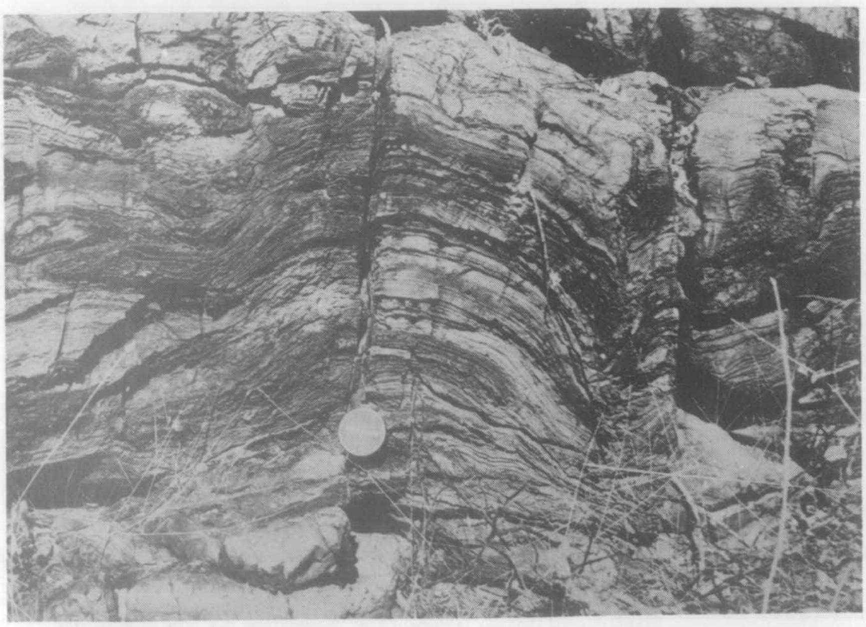

Fig. 10: Gently convex, pseudocolumnar stromatolite biostrome in the Lady Loretta Formation in southern LAWN HILL (GB/2228).

In the Ploughed Mountain Anticline, in northern LAWN HILL, the Lady Loretta Formation comprises laminated dolomite with minor cherty interbeds, siltstone, and quartzose sandstone. Also cropping out in this anticline is a massive dolomitic breccia. This breccia consists of large blocks (some laminated) up to 30 cm in diameter, erratically distributed in a recrystallised dolomitic matrix. At this locality, these breccias are closely related to faults, suggesting that they may be tectonic. However, they are also found elsewhere, not always related to obvious faults and they may also be primary or early diagenetic structures.

Chert and leached siltstone cropping out in the core of the Mount Caroline Anticline, in MOUNT OSCAR, have been assigned to the Lady Loretta Formation.

In northern RIVERSLEIGH and southeastern LAWN HILL the Lady Loretta Formation comprises massive and laminated dolomite, intraclast dolomite, and siltstone.

Five thin sections, representing the main rock types in the Lady Loretta Formation, have been described (Table 7). In all sections dolomite is micritic, suggesting that the dolomite is primary rather than a secondary replacement after calcite. These sediments indicate low-energy conditions.

Stromatolites. Two major types of stromatolite occur throughout the Lady Loretta Formation. The first are hemispherical and bulbous stromatolites up to 50 cm in diameter and up to 30 cm high (Fig. 10). These are generally round in plan, but are sometimes elongate, and can be either laterally linked or separate.

The second type of stromatolite is a columnar type. These show more variation than the hemispherical types both in size and shape. In plan, these stromatolites are generally circular and vary from 2 to 20 cm in diameter, and in section they vary between branched and unbranched, and slightly bulbous ones. Beds containing *Conophyton* are present in the western limb of the Kamarga Dome (Figs. 8, 9).

The stromatolites in the Lady Loretta Formation generally indicate low-energy conditions; those showing elongation indicate mild current activity.

Discussion. Sedimentary structures in the Lady Loretta Formation indicate a shallow-water marine environment. These structures include ripple marks, cross-bedding, edgewise conglomerate, intraclast dolomite bands, oolites, clay balls, mud-cracks, and stromatolites.

Intraclast bands form when a mud layer is partly lithified and then broken up by current activity and incorporated into the overlying layer. This generally only occurs if the mud layer is exposed and desiccated before the overlying layer is deposited. Thus the presence of abundant intraclast bands within the sequence indicates regular subaerial exposure. Edgewise conglomerates, in which clasts are arranged in imbricate fashion, indicate strong current activity; they may represent beach or tidal channel deposits.

The Lady Loretta Formation is dominated by thinly-bedded to laminated dolomite, intraclast dolomite, and siltstone. These lithologies indicate that low-energy conditions prevailed for most of the time, and also that the adjacent landmass was stable and mature, supplying only small quantities of clastic sediments.

The environment thus indicated was one of an extensive marine shelf, characterised by periodic subaerial exposure and crossed by oolite and stromatolite banks, adjacent to a stable mature landmass.

Shady Bore Quartzite

Cavaney (1975) used the term 'Carrier Quartzite' for this unit, but subsequently changed it to Shady Bore Quartzite. He nominated a type section in southwestern MOUNT OXIDE and traced the formation both northwards and southwards from it.

Type section. The type section extends along the south bank of a creek adjacent to a trach from Thorntonia homestead (in northeastern UNDILLA) to Shady Bore (in southwestern MOUNT OXIDE). The base of the formation is at M0911439, and the top is about 500 m to the west, at M0906439. Minor faults occur both north and south of the type section, but the section itself appears to be relatively undisturbed. The section is about 250 m thick.

Stratigraphic relations and boundary criteria. The boundary between the Shady Bore Quartzite and the underlying Lady Loretta Formation is placed at the base of a series of orthoquartzite beds. At least one similar bed occurs

50 m below this, in the upper part of the Lady Loretta Formation, and it is a somewhat arbitrary decision to place the boundary higher. The main consideration was the proportion of sandstone to other rock types. The boundaries of the Shady Bore Quartzite are placed to include that part of the sequence with about 25% or more of sandstone relative to siltstone and dolomite.

The upper boundary of the Shady Bore Quartzite is similarly placed at the top of the main group of sandstone beds. The boundary at the type section is sharp; siltstone overlies sandstone, but elsewhere the contact is more gradational, and the boundary, like the basal one, is placed to include the majority of sandstone beds in the Shady Bore Quartzite.

Both lower and upper contacts of the Shady Bore Quartzite are conformable.

Distribution and topographic expression. The Shady Bore Quartzite crops out in a series of domes and basins in eastern RIVERSLEIGH and LAWN HILL, and in southern MOUNT OSCAR. It forms prominent strike ridges with relief of up to 150 m, and is therefore readily traceable as a photogeological, as well as a lithological, unit.

Lithology and thickness. The Shady Bore Quartzite is characterised by medium-grained quartz-rich sandstone, but in very few localities does such sandstone predominate. Even in the type section, recessively weathering beds, mostly scree-covered, make up perhaps 30% of the total thickness. These beds include finer, more friable sandstone, siltstone, and dolomite. The sandstones do dominate in outcrop though, and it was this feature, along with their indurated nature, that caused Cavaney to call the unit a 'Quartzite'. Since the sandstones are orthoquartzites (see below), the name has been retained.

The quartz-rich sandstones can be classified as orthoquartzites (quartz arenite of Pettijohn, Potter & Siever, 1973). They are generally very well sorted, and range in grainsize from fine to medium; there are very few coarse sandstones. Bedding partings are generally flaggy to blocky (i.e., 1 cm- 1 m apart), but many beds are massive. It is the massive nature of the beds at the base and top of the formation which give it its resistant, ridge-forming character.

Bedding is commonly only vaguely visible, because of the uniform composition of the sediment, but where visible it is generally cross-bedded. In a good exposure at R868714 the basal sandstone contains tabular cross-bedded units 0.5-1 m thick in which the foreset laminae are inclined at low to moderate angles. Small-scale cross-bedding and associated ripple marks are ubiquitous. Ripple marks are generally best seen on the bases and tops of massive beds because silty partings flake away, exposing them, but ripple lamination is commonly visible within massive beds on vertical joint faces. The third very common feature of the orthoquartzites is the presence of mudflake conglomerates. These range from trains of single grains as small as 1 mm across to thin beds containing a high concentration of mud clasts from 1-20 mm across. The clasts are commonly weathered out leaving voids.

Although less common than the structures mentioned, mud-cracks have been observed in outcrops throughout the region; they are generally curved where they have formed in mud layers draped over ripple marks. The most unusual structure observed was a small slab of fine sandstone containing both flute moulds and halite casts (Fig. 11).

The orthoquartzites are interbedded with finer sandstone, siltstone, and dolomite. These crop out in several localities in LAWN HILL, including:

(a) At LH735072, in the east limb of a major syncline north of the Gregory River. Blocky dark purple dolomite, with some laminae and intraclasts, grades up into thinly interbedded siltstone and fine sandstone; wavy and ripple-laminated bedding predominate. This is overlain by blocky porous red-weathering sandstone containing ripple marks and mud-cracks.

(b) Similar soft interbeds crop out in a well exposed cliff section in the west flank of the Kamarga Dome, at LH697373. At least 10 orthoquartzite beds, ranging in thickness from about 0.2 to 2 m, show as white bands in a mainly (70-80% of total) silty and dolomitic sequence (Fig. 12).

(c) In the Ploughed Mountain Anticline, orthoquartzite beds 2-3 m thick, thinly cross-bedded and ripple-laminated, are interbedded with laminated intraclastic and oolitic dolomite; the carbonates constitute about 75% of the sequence.

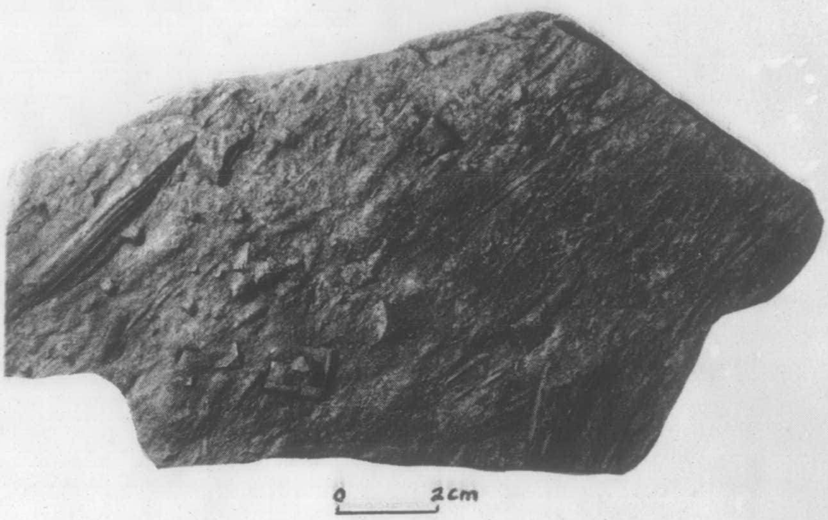

Fig. 11. Halite casts and flute moulds preserved in a thin dolomitic sandstone bed of the Shady Bore Quartzite, Ploughed Mountain Anticline (GB/2242).

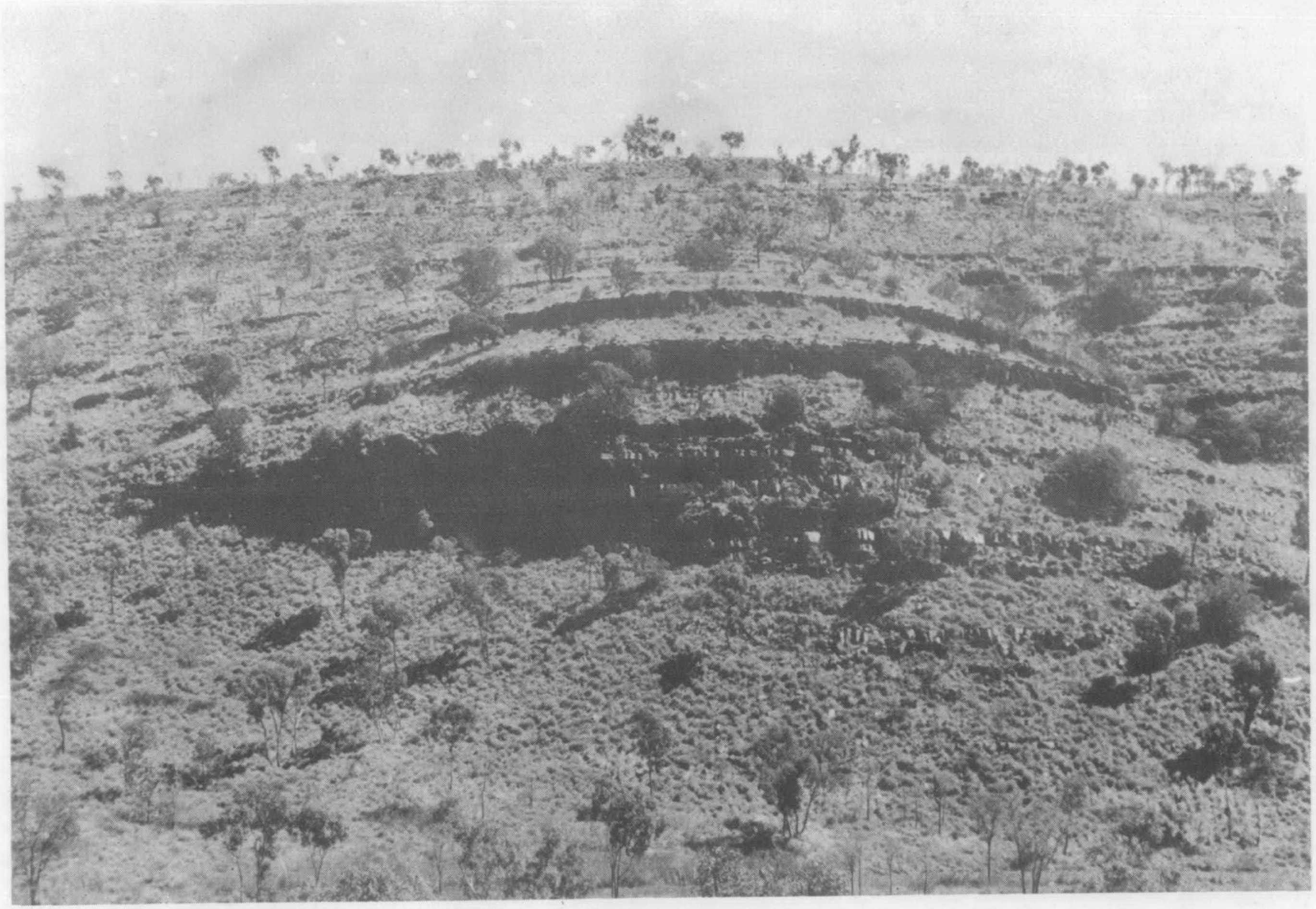

Fig. 12. General view of scarp-slope outcrops of the Shady Bore Quartzite at LH696 372. The light-coloured orthoquartzite beds are interbedded with dark brown-weathering dolomite and dolomitic siltstone. The proportion of quartzite in the sequence is low, but increases towards the top of the scarp. Overall it makes up about 25% of the section (M/2099).

In the most northerly outcrops of the Shady Bore Quartzite, in the Mount Caroline Anticline, at MOs555588, the whole section of 270 m is sandstone; there are no siltstone or dolomite interbeds.

The lower boundary of the Shady Bore Quartzite is best regarded as gradational, with the transitional beds assigned to the Lady Loretta Formation (they were tentatively included in the Quartzite in LAWN HILL, but are shown as Eml_t in RIVERSLEIGH). The upper boundary is generally sharp, as in the type section, except in central RIVERSLEIGH, where a sequence of ferruginous orthoquartzite and interbedded siltstone forms the upper part of the formation. North, east, and southeast of this section the quartzites thin and intertongue with the Riversleigh Siltstone.

Figure 13 shows the thickness of the Shady Bore Quartzite in 25 localities. The thicknesses were calculated from air photographs using measured dips; the southernmost is the type section, whose true position is just outside the margin of RIVERSLEIGH. The two main features illustrated are the marked thinning eastwards in central RIVERSLEIGH, and the less marked, but significant, variations from north to south . The thickest sections, Nos. 9 and 11, of over 500 m occur in the area where the ferruginous quartzite beds mentioned above are present - the marked thinning away from this area coincides with the intertonguing of these quartzites with the Riversleigh Siltstone. The outcrop patterns and thicknesses of sections 13 and 14, on opposite sides of the Termite Range Fault, are distinctly different, and it was initially thought that early fault movements may have influenced sedimentation. However the thickness variations are clearly not related to the fault.

The marked thinning in eastern Riversleigh corresponds with a decrease in grainsize and the number of quartzite beds. As a result the unit does not form such a prominent ridge as in the east. Section 7 appears to consist of two thin tongues of sandstone separated by siltstones similar to those in the Lady Loretta Formation.

Lensing of sandstones at both the base and top of the formation occurs northwards from the type section, with a corresponding reduction in thickness of the unit from 300 m to less than 100 m. This effect can also be seen in the west limb of a syncline north of the Gregory River in LAWN HILL, where the thickness of the unit decreases from 390 m in the south, to between 200 and 250 m in the north.

Discussion. The Shady Bore Quartzite is considered to have been deposited in a marginal-marine environment. The mineralogical and textural maturity of the orthoquartzites, and their association with carbonate rocks, indicate probable shoreline, lagoonal, and other peritidal environments.

The occurrence of cross-bedding, ripple marks, primary current lineations, and the good sorting and medium grainsize of the sands suggests significant current and/or wave activity. The presence of mud-flake conglomerates, mud-cracks and halite casts in the quartzite, and the presence of laminated, oolitic and intraclastic dolomite interbeds, suggest that arid conditions with desiccation prevailed. The fine-grained sediments probably include both subtidal and supratidal deposits, but data available are insufficient to distinguish them.

On a regional scale (Fig. 13) the thickness and facies variations in the Shady Bore Quartzite suggest that sediment may have been derived from the west or southwest. In RIVERSLEIGH both thickness and grainsize decrease eastwards. Similar variations in thickness and in the proportion of sand in the formation were noted elsewhere. This may reflect proximity to rivers supplying sand to the area. The thick sequence in central RIVERSLEIGH, in which lenses of sandstone of Shady Bore type are surrounded by Riversleigh Siltstone may even represent a small deltaic complex.

Riversleigh Siltstone

The Riversleigh Siltstone was named and briefly described by Cavaney (1975), who nominated a type area 'north of Riversleigh Homestead in the Gregory River area'. Our mapping has allowed accurate definition of a type section and the identification of several informal numbers, three of which are shown on the accompanying maps.

Type section. The type section is a composite one (Fig. 14). In line with ISSC (1976) terminology one of the two component sections (the upper one) is nominated as the holostratotype; the lower one is the parastratotype. Both upper and lower sections are within Cavaney's type area, and are respectively 3 and 10 km northwest of the confluence of the Gregory and O'Shannassy Rivers, in LAWN HILL. They are located as follows .

Top of holostratotype (and top of formation)	LH576 070
Base of holostratotype	LH604 073
Top of parastratotype	LH624 007
Base of parastratotype (and base of formation)	LH641 012

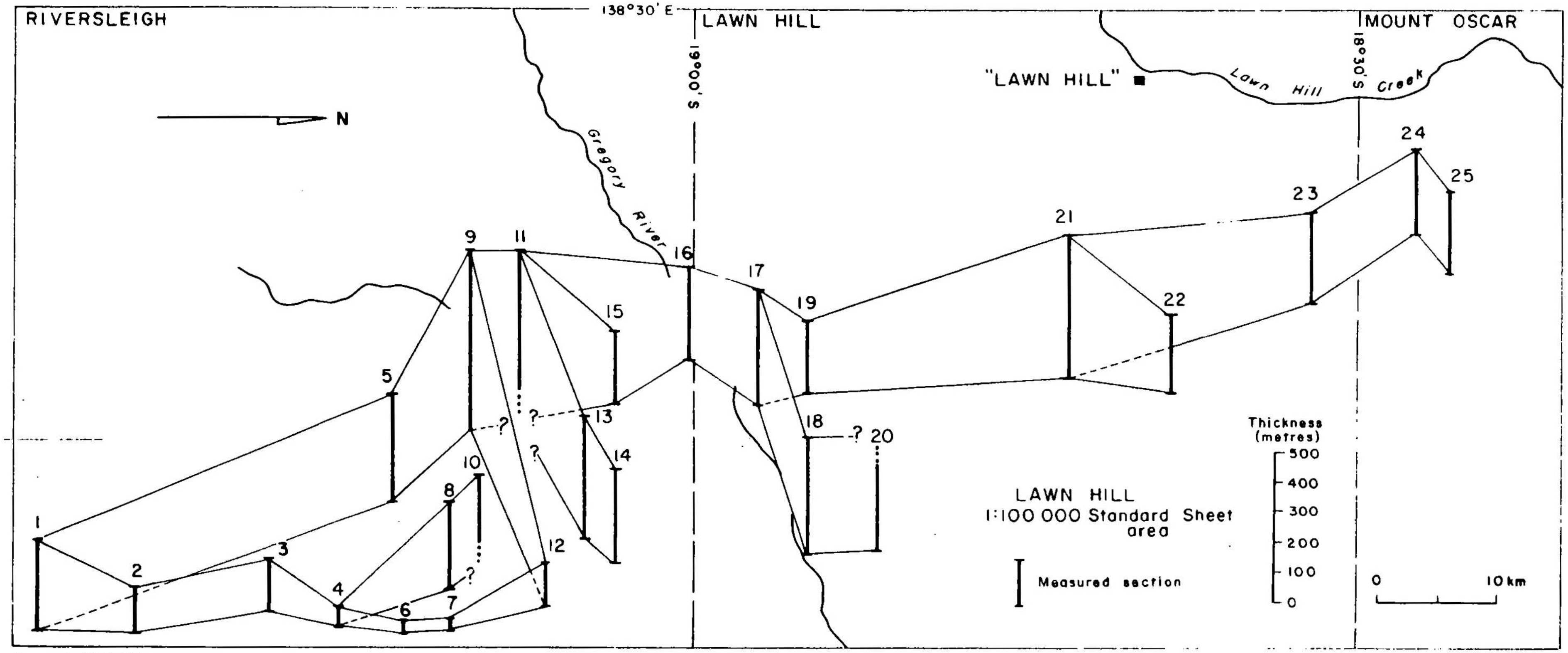

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Fig. 13 Fence diagram showing thickness variations in the Shady Bore Quartzite

E54/A/83

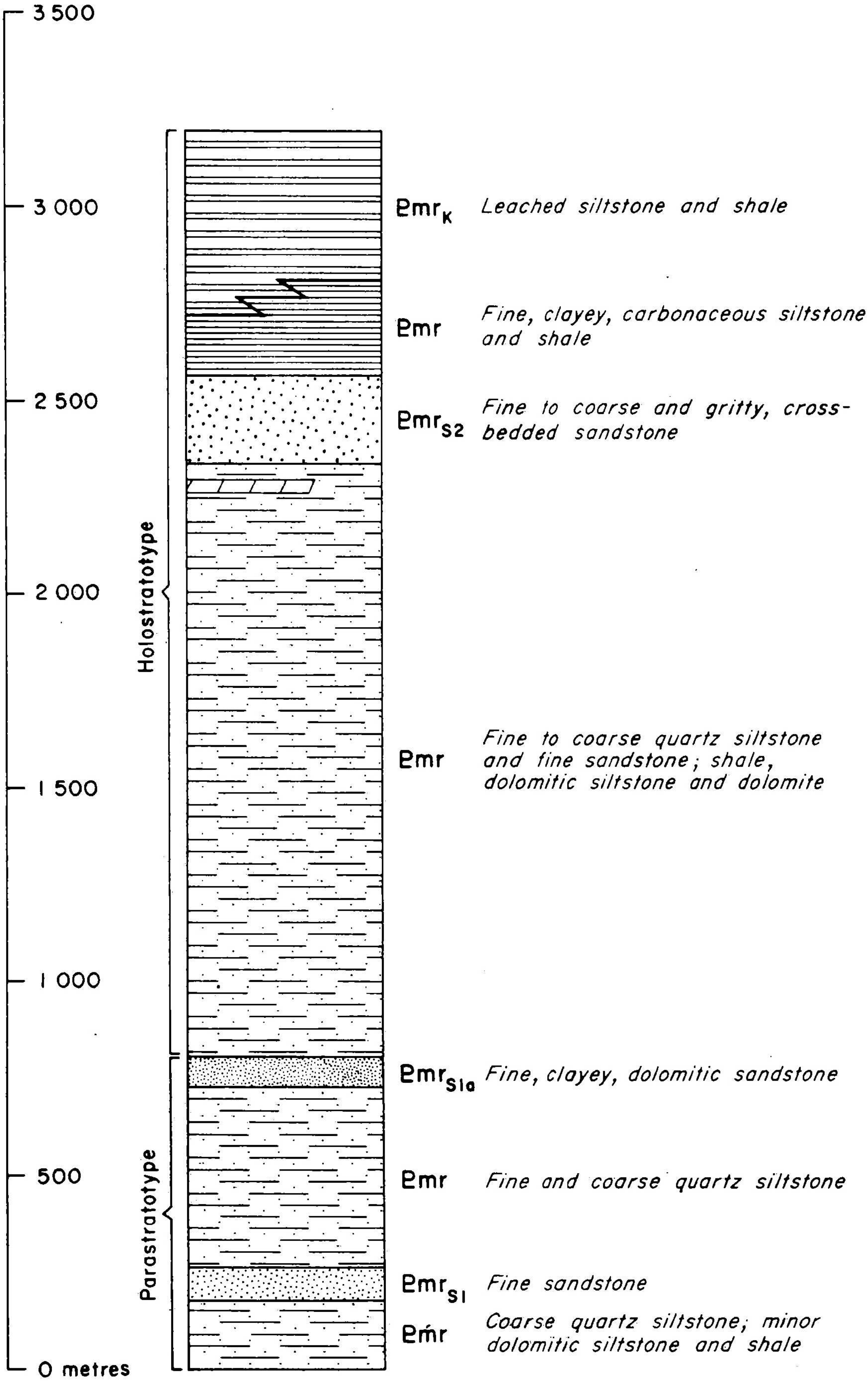

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Fig. 14 Type section of the Riversleigh Siltstone

The composite type section consists of 3200 m of siltstone, minor sandstone and dolomite.

Boundary criteria and stratigraphic relations. The base of the formation in the parastratotype is sharp, and is marked by a change from massive white orthoquartzite of the Shady BOre Quartzite to flaggy and fissile quartz siltstone of the Riversleigh Siltstone. The contact is conformable, and in some sections south and east of the type section the boundary is more difficult to place, as it is gradational, or the two formations intertongue.

The upper boundary of the holostratotype, at LH576 070, is also sharp, and is placed at the base of the first quartz-wacke bed of the Termite Range Formation. It also is conformable, and the possibility of an intertonguing contact north of the type section cannnot be ruled out.

Distribution and topographic expression. The Riversleigh Siltstone is exposed in a series of domes and basins in eastern RIVERSLEIGH, central LAWN HILL, and southern MOUNT OSCAR. It is generally recessivly weathering and forms valleys and rounded hills flanked by the more resistant ridges of Shady Bore Quartzite and Termite Range Formation. Three sandstone members within the formation in the type area form prominent strike ridges.

Lithology and thickness. The Riversleigh Siltstone consists of quartz siltstone, dolomitic siltstone, carbonaceous siltstone and shale, and minor dolomitic sandstone and dolomite. The type section, which contains all these rock-types, is 3200 m thick (Fig. 14), and is the thickest preserved section of the formation. The formation thins northwards, and in the northern Kamarga Dome it is only 570 m thick (Fig. 15). In the northernmost outcrop, in the Mount Caroline Anticline, it is 800 m thick. There are no complete sections of Riversleigh Siltstone south or east of the type area, and the values shown in Figure 15 are preserved thicknesses.

Three informal members, Ɇmr$_{S1}$, Ɇmr$_{S2}$, and Ɇmr$_{1}$ have been delineated in LAWN HILL, and a fourth one, Ɇmr$_{S1a}$, has been recognised but is delineated only on the RIVERSLEIGH map. Ɇmr$_{S1}$ and Ɇmr$_{S2}$ are sandstones present in th type section (Fig. 14), but Ɇmr$_{1}$, a coarse siliceous siltstone, is present only in northern LAWN HILL.

The siltstones in the Riversleigh Siltstone are designated Ɇmr and $Ɇmr_k$. Coarse quartz siltstone, thinly interbedded with lenticular beds of fine sandstone, predominates in the sequence between the Shady Bore Quartzite and $Ɇmr_{S1}$. It is this interval which grades into, or intertongues with, the Shady Bore Quartzite in central Riversleigh. Finer clayey siltstone and some shale also crop out, mainly in southern RIVERSLEIGH and northern LAWN HILL, where they are dolomitic. $Ɇmr_1$, siliceous siltstone, forms a distinctive unit only because it is overlain and underlain by finer siltstones which are, relatively, recessively weathering.

The siltstone between the sandstone members is similar to but generally finer-grained than that below $Ɇmr_{S1}$. Of the 1520 m of fine clastics between $Ɇmr_{S1a}$ and $Ɇmr_{S2}$ in the type section (see Fig. 14), the lower 800 m crops out very poorly, and probably includes both fine siltstone and shale. The upper 700 m crops out better, and includes finely laminated, fissile grey siltstone thinly interbedded with coarse siliceous siltstone; some ripple-laminated silts may be present. At LH588 083, less than 50 m below the base of $Ɇmr_{S2}$, is a 2 m bed of highly altered ferruginous and manganiferous dolomite. Similar dolomites crop out in eastern RIVERSLEIGH, and 12 km southeast of Riversleigh homestead where two cycles, each about 1.5 m thick, of shale and laminated siltstone grade upwards into very finely laminated dolomite.

The siltstone above $Ɇmr_{S2}$ is distinctly different from that below. It is best exposed in the type section, where it comprises 630 m of fine clayey siltstone and shale. The fresh rock is dark grey to black and strongly carbonaceous (sample 76410165, Table 8), but most outcrops are intensely leached, and almost white. They have been designated $Ɇmr_k$ (i.e., kaolinitic) in the type area. The same facies crops out in the north in the Ploughed Mountain Anticline above $Ɇmr_1$.

South of the type section, in RIVERSLEIGH, the Riversleigh Siltstone occupies the centres of several small structural basins. Good outcrops occur in the northernmost basin, at R720865, where a white-weathering, black carbonaceous shale (sample 77410067, Table 8) is interbedded with fissile, laminated siltstone and grey crystalline dolomite. These rocks appear to be stratigraphically low in the Riversleigh Siltstone - probably below $Ɇmr_{S2}$. Five kilometres farther south a sequence of massive sandstone beds, probably $Ɇmr_{S1a}$, is overlain by dolomitic siltstone,

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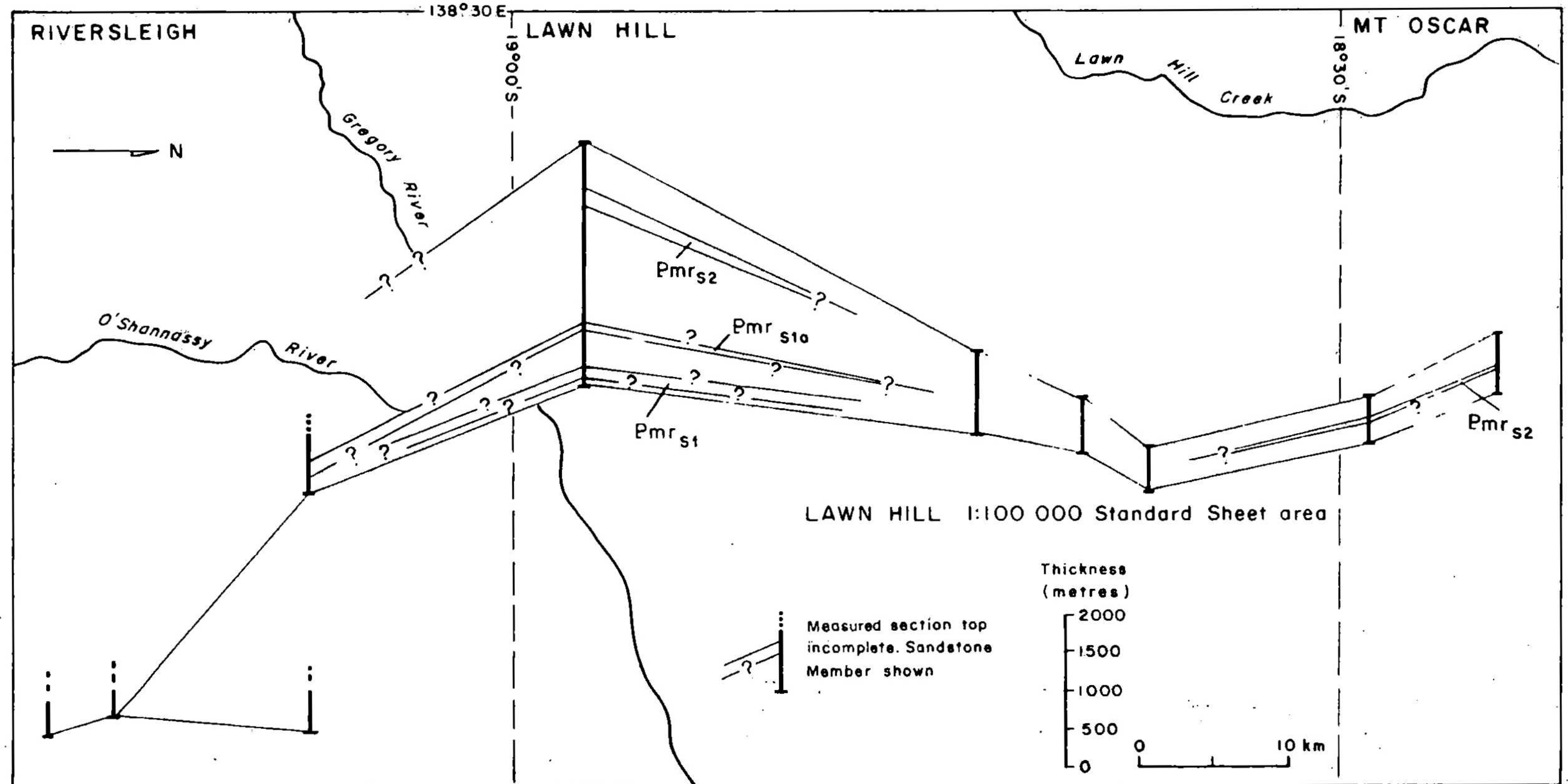

Record 1980/43

Fig. 15 Fence diagram showing thickness variations in the Riversleigh Siltstone

E54/A/85

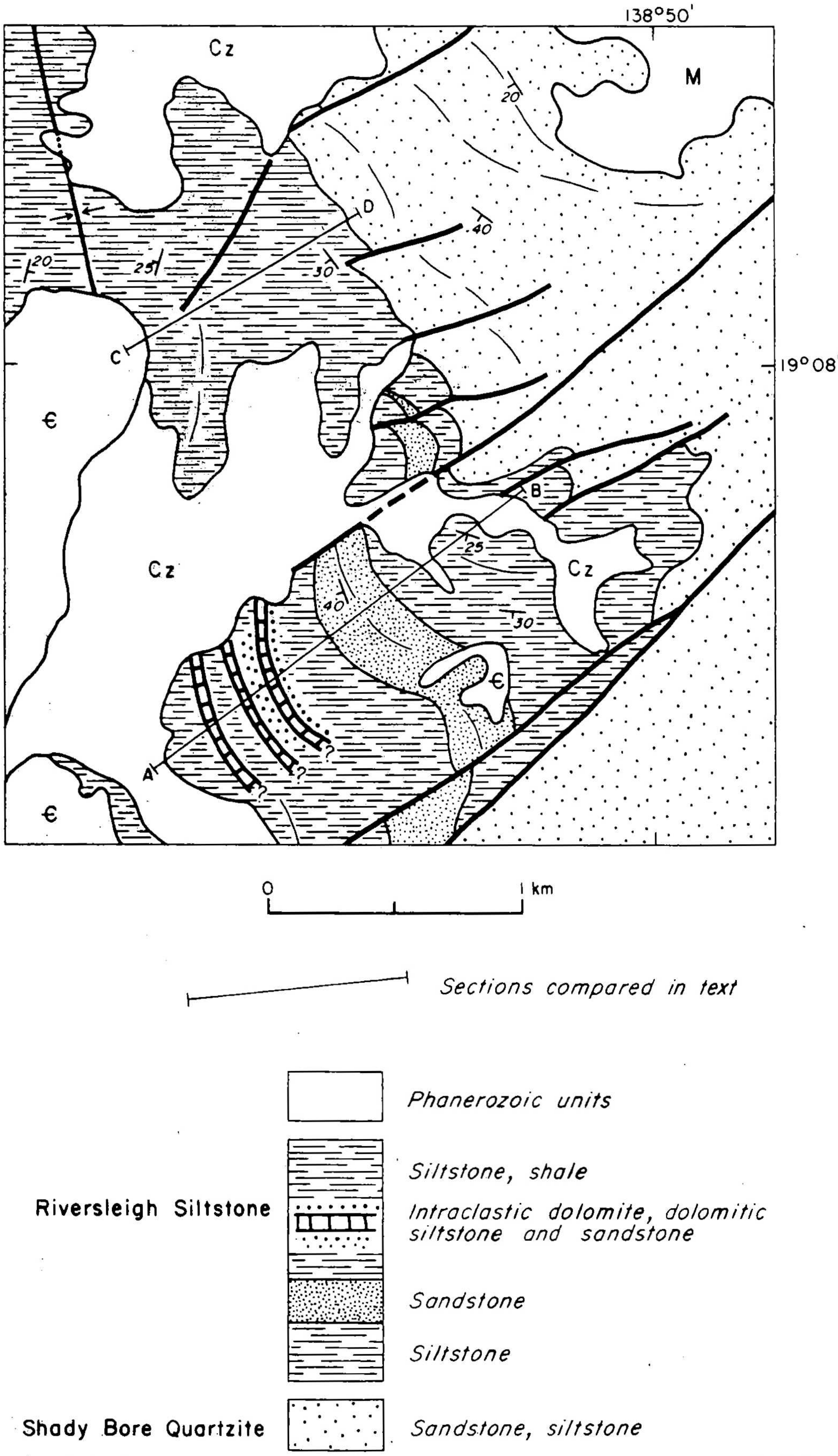

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Fig. 16 Facies change in Riversleigh Siltstone 15 km southeast of Riversleigh Homestead and intraclastic dolomite (Section AB, Fig. 16). This sequence of Riversleigh Siltstone is terminated by a northeast-trending fault, to the northwest of which is a sequence (Section CD, Fig. 16) of the equivalent part of the unit, but of markedly different lithology - mainly fine siltstone and shale. The fault movement is relatively slight, and a marked facies change is therefore evident within the unit. Emr_{S1a}, the sandstone unit, can be seen to lens out abruptly.

$\underline{Emr}_{S1}$, $\underline{Emr}_{S1a}$, $\underline{Emr}_{S2}$. The three sandstone members in the Riversleigh Siltstone are best developed in the type area and thin to the north, east, and south. The two lower members (Emr_{S1}, Emr_{S1a}) consist of thick-bedded fine-grained, moderately sorted clayey or dolomitic sandstones (Table 8, samples 77410025, 29, 62, 65) similar in appearance to the quartzwackes of the overlying Termite Range Formation. Emr_{S2} differs markedly from the two lower members in that it consists of fine to coarse and gritty sandstone, has no siltstone interbeds, and contains abundant tabular cross-beds and primary current lineations. The base of Emr_{S2} interfingers with the underlying siltstone at a scale visible in LAWN HILL - e.g., at LH588065.

All three sandstone members thin northwards and lens out within 20 km of the type section. A sandstone similar to Emr_{S2} crops out farther north, in the northeastern Ploughed Mountain and Mount Caroline Anticlines. It could be a separate lens, or a tongue of a formerly more extensive sand body which included Emr_{S2}. It has been designated as Emr_{S2}. It appears to grade southwestwards into $\underline{Emr}_{1}$, a thin-bedded to laminated siliceous siltstone, which separates laminated dolomitic siltstone below from flaggy leached (carbonaceous?) siltstone above.

Ten kilometres east of the type section, near Freeman Creek, the lower part of the Riversleigh Siltstone totals 600 m, compared with 800 m in the type section; the sandstone members are also thinner than in the type section.

Only one sandstone member has been delineated in RIVERSLEIGH, mainly in the area referred to in Figure 16; it is probably Emr_{S1a}. Emr_{S1} appears to grade into the Shady Bore Quartzite in central RIVERSLEIGH. Examples of Emr_{S1a} outcrops are best seen west of the Camooweal-Burketown road in eastern RIVERSLEIGH - e.g., at R878663 and R876838. At both localities the sandstone beds lack internal structure and are silicified, resulting in conchoidal fracture surfaces.

The southernmost outcrops of Riversleigh Siltstone in RIVERSLEIGH consist of finely laminated fissile siltstone and shale interbedded with lenticular, flaggy to blocky, coarse siltstone and very fine sandstone. In the 400 m of section exposed there are no mappable sandstone members.

Petrography. Table 8 summarises the descriptions of 10 thin sections of samples of Riversleigh Siltstone, including five from its sandstone members. Samples 77410066 and 0068 are typical of the coarse, non-carbonaceous siltstones; they both contain a significant amount of dolomite and clay. Samples 76410165 and 77410067 typify the carbonaceous siltstones and shales in the formation. Samples 77410062 and 0065 were collected from the base and top, respectively, of a single sandstone bed in Bmr_{S1a} in RIVERSLEIGH. There may be slightly less matrix in 0065, suggesting that the bed is graded.

Discussion. The Riversleigh Siltstone records a markedly different set of depositional environments from the peritidal environments of the Shady Bore Quartzite. Siltstone, which is the dominant rock-type, changes from quartz and dolomite-rich low in the sequence, to clay and kerogen-rich (carbonaceous) in the upper part. Many of the coarser siltstone beds low in the sequence are wavy or lenticular, and some may be internally ripple-laminated; flute casts and mud-cracks were also observed. Dolomitic rocks are present below Bmr_{S2} but have not been observed above; many of the dolomites are ferruginous or manganiferous and all lack stromatolites. The formation, including the sandstone members, thins north and possibly east of the type section.

Above Bmr_{S2}, carbonaceous siltstone and shale are dominant. Although carbon-rich rocks can form in shallow-water reducing environments, the absence of other shallow-water facies, and the presence of deep-water deposits overlying them, suggests that the upper part of the Riversleigh Siltstone was deposited in a deep water, euxinic environment.

The depositional environments of the sandstones in the Riversleigh Siltstone are not well understood. The thinly lenticular sandstones of Bmr_{S1} may have been deposited in a tidal-flat environment, but the main features of the Bmr_{S1a} sandstones - their lack of characteristic shallow-water current structures, the presence of some clayey and dolomitic matrix, and their alternation with siltstones - suggest that, like the sandstones of the Termite Range Formation, they may be deep-water sediments, perhaps turbidites. Emr_{S2} displays evidence of strong current activity and could be either a shallow or deep-water channel deposit.

This evidence indicates that the Riversleigh Siltstone marks a general basinal subsidence, with a resultant shift from shallow-water high-energy environments to deeper-water lower-energy environments. The presence of intraclastic dolomite, dolomitic sandstone, and lenticular coarse siltstone and fine sandstone beds indicates that there were some reversals to the general basinal subsidence, with a temporary return to shallow-water deposition. Development of a very thick sequence of Riversleigh Formation in the type area means that sediment supply was greater in that area than elsewhere. It does not necessarily mean that subsidence was substantially greater, as other parts of the basin may simply have been starved of sediment.

Termite Range Formation

Derivation of name. The name Termite Range Formation is derived from the Termite Range, 20 km south of Lawn Hill station. Cavaney (1975) tentatively named the formation the Gregory Quartzite, but has since changed it to Termite Range Quartzite. We have modified the name to Termite Range Formation, as quartzite is not the main rock type in the unit.

Distribution. The Termite Range Formation is best exposed in a north-northwest-trending belt, the Termite Range, in southwestern LAWN HILL (Fig. 17). It is also the main unit cropping out in Ploughed Mountain, and in the range running northeast from Mount Caroline, both of which straddle the boundary between LAWN HILL and MOUNT OSCAR. Three isolated outcrops form roughly east-trending ridges in eastern BOWTHORN. These will be briefly discussed even though they are beyond the Lawn Hill/Riversleigh region as defined in this Record.

Type Section. The type section, in the type area east of Lilydale Spring designated by Cavaney (1975), extends from LH576 069 (base) to LH560 064 (top).

Boundary criteria and stratigraphic relations. The lower boundary of the unit at the type section is placed at the base of the first massive sandstone bed. This level coincides with a photogeological boundary which reflects the resistant nature of the sandstone compared with the Riversleigh Siltstone. The upper boundaries, although sharp, are conformable. The lower is believed to be time transgressive, as it appears that the basal sandstones grade northwards into the Riversleigh Siltstone.

Description. The Termite Range Formation consists of a sequence 200-1100 m thick of interbedded sandstone, quartzwacke, greywacke, siltstone, and shale. In the outcrops south-southeast of Lawn Hill homestead the formation contains a central fine sandy and silty member, Bmt_2, overlying a basal sandy unit, Bmt_1. Both of these units appear to become finer-grained northwards, and grade laterally into Riversleigh Siltstone. Only Bmt_3, the uppermost member, can be traced northwards to the Ploughed Mountain and Mount Caroline Anticlines, and farther to the northwest, into eastern BOWTHORN. A mappable greywacke unit, Bmt_{3g}, has been delineated within Bmt_3 in these northern outcrops.

The thickness of the Termite Range Formation in 15 sections is shown as a fence diagram in Figure 19. The thickness decreases from 1100 m in the type section to around 900 m in the Mount Caroline Anticline. This apparently slight change in overall thickness masks a reduction from 780 m to zero in the thickness of Bmt_1 and Bmt_2 and a corresponding increase from 320 to 900 m in the thickness of Bmt_3. A marked thinning of the whole formation occurs eastwards; section 4, near Archie Creek, is only about 200 m thick. A similarly marked decrease probably takes place southwards from the type section into northern RIVERSLEIGH, but faulting and poor exposure preclude thickness measurements.

The type section contains nearly 1100 m of interbedded sandstone and siltstone. The basal ridge-forming 240 m, Emt$_1$ contains about 30% sandstone in beds up to about 2 m thick. The sandstone is blocky to massive, silicified, coarse-grained, and contains scattered white clay grains (probably rock fragments) and 5-25% clayey matrix (e.g., Table 9, sample 76410010). A sandstone bed near the base of Emt$_1$ contains shale clasts and about 25 percent matrix (Table 9, sample 76410017). The sandstones in Emt$_1$ range from sublitharenites to quartzwackes according to the classification of Pettijohn & others (1973, p. 158).

Emt$_2$ in the type section consists of 540 m of interbedded light clayey siltstone, and ferruginous coarse quartz siltstone and fine sandstone. The finer grainsize, thinner bedding and lower proportion of sandstone beds in Emt$_2$, compared with those in Emt$_1$ and Emt$_3$, results in recessive weathering and poorer outcrop.

Emt$_3$ in the type section contains a small proportion of siltstone beds, but sandstone probably exceeds 50% of the thickness. As in Emt$_1$ the sandstone beds are massive, thick and almost structureless, and can be classified as sublitharenites and greywackes (Table 9; 76410009, 0013, 0037).

South of the type section, in outcrops near the Gregory River, there is less difference between the members in the Termite Range Formation. The sandstone beds are thinner and less abundant than in Emt$_1$ and Emt$_3$ elsewhere, and the whole formation is thinner.

North of the type section the proportion of sandstone decreases in Emt$_1$, which becomes more difficult to distinguish from Emt$_2$. In an anticline 9 km north of the type section Emt$_2$ consists of flaggy, reddish-weathering, very fine to medium sandstone containing rare ripple lamination interbedded with poorly outcropping green, purple, and brown fissile and thin flaggy siltstones. Ꝑmt$_3$ thickens from 300 m at the type section to 420 m 3 km to the north. A prominent dark grey siltstone bed at the top of the unit may be a tongue of the overlying Lawn Hill Formation.

Sixteen kilometres north of the type section the Termite Range Formation forms a series of complex folds in the nose of an anticlinorial zone, the axis of which is cut by the Termite Range Fault. Ꝑmt$_3$ forms a characteristically banded ridge (Fig. 18), but Ꝑmt$_1$ and Ꝑmt$_2$ have become finer-grained northwards and are increasingly difficult to distinguish from the Riversleigh Siltstone.

A striking feature of Ꝑmt$_1$ and Ꝑmt$_3$ is the way in which the sandstone beds crop out prominently, shedding debris onto and generally completely obscuring the softer beds between them (Figs. 17, 18). A rare exposure of the soft beds in Ꝑmt$_3$ at LH 505 223 consists of interbedded shale, siltstone, and sandstone. Several 5-10-cm thick fine-grained dark grey sandstone beds are interbedded with finely laminated grey and purple shale and a 20-cm bed of conchoidally fracturing structureless siltstone.

The Termite Range Formation is only about 200 m thick near Archie Creek, 30 km north-northeast of the type section. Ꝑmt$_1$ and Ꝑmt$_2$ are absent and have either thinned out or, as suggested by the gradation observed north from the type section, they have graded into the Riversleigh Siltstone. An outcrop at LH 680 386, 1.5 km east of Archie Creek, consists of several beds up to 2 m thick in a sequence of flaggy purplish micaceous siltstone. Two hemispherical bodies 1.5 m across of silicified fine-grained siltstone, in a bed of similar composition, are probably pillow structures.

Fig. 17: Termite Range Formation; view looking south from type area, LAWN HILL, showing typically banded appearance of the formation (GB/1403).

Fig. 18: Massive sandstone bed in the Termite Range Formation at LH506 245; the bed dips at 50° to the left and is about 4 m thick; note the intense joining normal to the bedding (GB/2229).

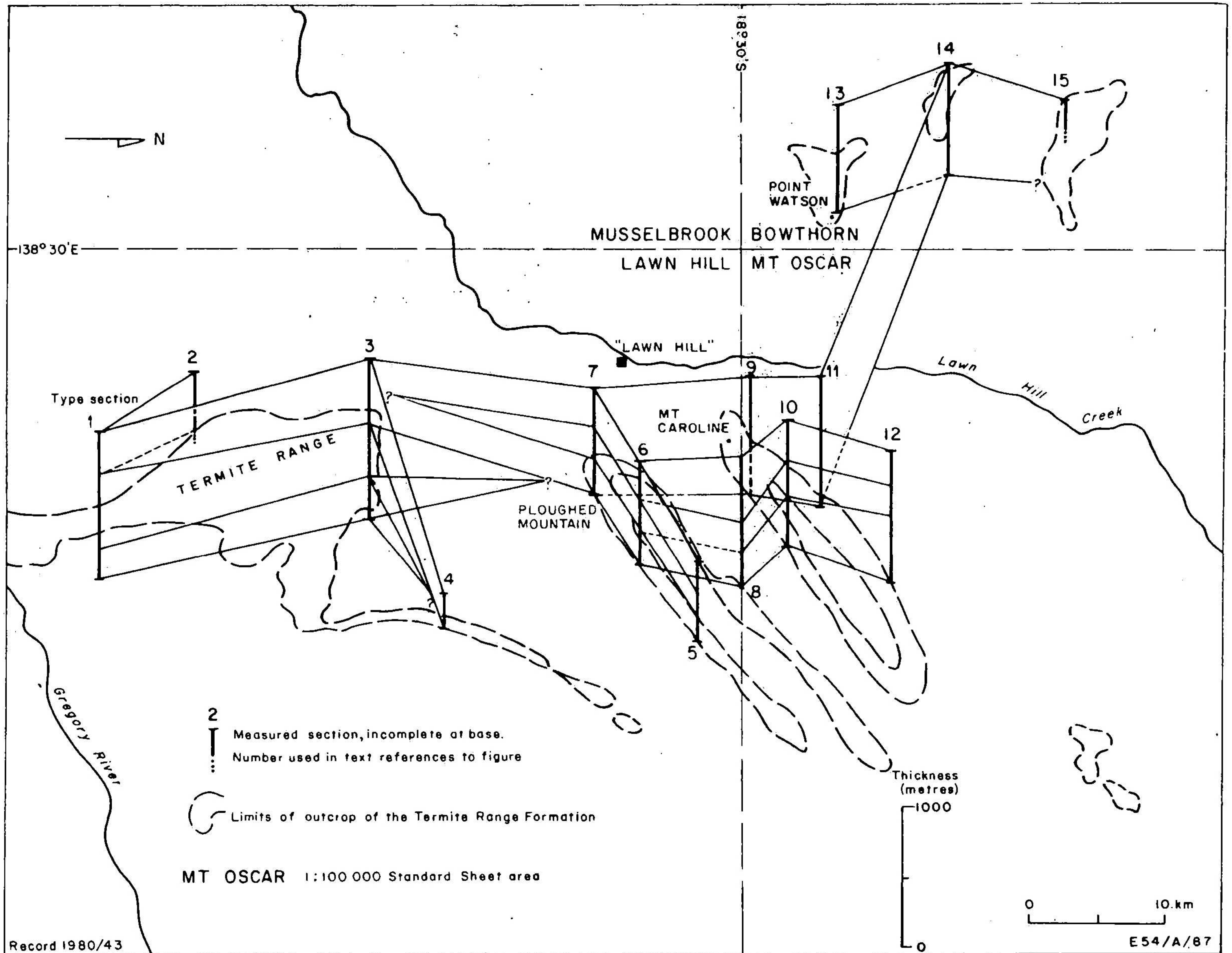

Fig. 19 Fence diagram showing thickness variations in the Termite Range Formation

An outcrop of Bmt_3 adjacent to the Lawn Hill/Gregory Downs road, at LH 716428, consists of poorly sorted blocky sandstone, micaceous siltstone, and dark steel-grey silicified fine-grained pyritic sandstone. The dark grey sandstone has a distinctive appearance, and is identical to Bmt_{3g} which forms a mappable unit within Bmt_3 to the north.

The Termite Range Formation is well exposed in the Ploughed Mountain and Mount Caroline Anticlines in northern LAWN HILL and southern MOUNT OSCAR. The alternation of hard and soft bands is spectacularly developed in these ranges because of near-vertical dips; exposure of the soft bands is rare because of masking by rubble from the sandstones. The thickness of Bmt_3 increases rapidly northwestwards from 560 m (section 5, Fig. 19) to 950 m (section 8, Fig. 19). Within the south-eastern limb of the Ploughed Mountain Anticline it increases gradually to the southwest - to 750 m at section 6, and to 780 m at section 7. In the Mount Caroline Anticline there is a slight increase in thickness northeastwards from 860 m at section 9 to 950 at section 12.

The rocks in both anticlines are similar to those farther south except that a mappable member, Bmt_{3g}, consisting of dark grey, silicified greywacke interbedded with siltstone, occurs in the middle of the unit. The distinctive dark grey rocks stand out from the generally light-coloured sandstones, and can be traced on air photographs. They form a slightly lower series of ridges and valleys than the sandstones, probably because they are more closely jointed and are therefore more susceptible to erosion. They appear to have a higher matrix content than the surrounding light-coloured greywackes and sublitharenites. Bmt_{3g} increases in thickness northwestwards from about 150 m to 400 m. Slight variations in colour, photopatterns, and topography suggest that the greywacke intertongues with the light-coloured sandstones.

The northernmost outcrops of Ꞓmt$_3$ are in three anticlines which trend roughly eastwards from the Constance Range in BOWTHORN. They were previously mapped by Carter & Öpik (1961) as Lawn Hill Formation, but are lithologically identical to the Ꞓmt$_3$ previously described and are overlain by shales typical of the Lawn Hill Formation. The southern anticline, which is within 10 km of the southeast corner of BOWTHORN, contains 560 m of Ꞓmt$_3$ overlying siltstone, assumed to be Ꞓmt$_2$, in its core. The central anticline, which flanks the northern bank of Musselbrook Creek, contains about 800 m of sandstone which is faulted against a sequence which may extend down to Riversleigh Siltstone. The northernmost anticline contains only Ꞓmt$_3$, the base of which is not exposed - only the uppermost 300 m of sandstone can be seen. As in outcrops to the south the sandstones in BOWTHORN are massive, thick-bedded, structureless and silicified, containing significant matrix and scattered feldspar or clay grains. Siltstone and shale beds are present but rarely crop out; sandstone:shale ratios are not known.

Petrography. Eight thin sections of rocks from the type section were examined (Samples 7641 0009-0013, 0017, 0018, 0037, Table 9). Six are sandstones, all containing grains ranging from about 1 mm through fine sand down into coarse silt sizes; in some samples grains of around 0.5 mm predominate. Only the largest grains are well rounded. The sandstones are classified as sublitharenites and greywackes according to the scheme of Pettijohn & others (1973, p. 158). The greywackes are richer in rock fragments than in feldspar and are quartz-rich; however, they plot just outside the quartzwacke field, and are therefore lithic greywackes. No feldspar was seen in any of the Ꞓmt$_1$ samples, but was present in all the Ꞓmt$_3$ samples. This could be interpreted as indicating the unroofing of granitic or gneissic rocks in the source area as erosion proceeded. The rock fragments indicate a mixed sedimentary/low-grade metamorphic source and a volcanic component. Grains of sedimentary rocks include chert, chalcedony, silty sandstone, siltstone, shale and composite quartz (these could be from veins or metamorphic rocks); metamorphic rock fragments include quartz-muscovite and chlorite schists, and composite sutured quartz. The probable volcanic components are fine-grained cloudy quartz/feldspar grains which could be devitrified groundmass from acid volcanics. Coarser quartzofeldspathic grains in two of the Єmt_3 samples are probably from plutonic rocks, and support the notion that granite was being eroded at that time.

Seventeen thin sections from Єmt_3 and Єmt_{3g} in the Ploughed Mountain and Mount Caroline Anticlines were examined (i.e., all samples in Table 9 except those from the type section, which have field number LH 11/18). The rocks are not substantially different from those rocks in the type section although they appear to include more coarse-grained, and some matrix-rich, varieties. Feldspar is present in all samples except numbers 76410160 and 76410181 (Table 9), both of which are near the base of the sequence. Samples from section 12 (samples 7641 0153-0157, Table 9) and 76410173 are the most feldspathic, but the significance of this is not understood.

<u>Discussion</u>. Two outstanding features of the Termite Range Formation, and of Єmt_3 in particular, are the regular alternation and continuity of thickness of sandstone and siltstone beds; and the rarity of sedimentary structures within the sandstone.

In the sandstones, which form beds ranging from 0.5 to 5 m thick and averaging 1-2 m, no thickness variation can be observed in exposures, and some individual beds can be traced for 2 km or more on airphotos with little or no variation in thickness. From a total of over

100 observations of the sandstones only 15 contained visible sedimentary structures. These included seven examples of faint parallel lamination, four of mud clasts, two of ripple lamination and two of graded bedding. It has been established that x-ray techniques generally show more internal structures (Hamblin, 1965), but such detailed work has not yet been attempted on the Termite Range Formation. The sandstones are distinctly different from those lower in the McNamara Group and from those in the Lawn Hill Formation, all of which contain abundant cross-bedding, ripple marks, and other current features. The lack of characteristic sedimentary features renders it unlikely that the Termite Range Formation was deposited in alluvial, deltaic, estuarine, beach/barrier, or aeolian environments, because such deposits invariably contain abundant primary structures. The style of bedding, and the few contained structures are, however, partly consistent with the sandstones beint turbidites. Graded bedding and sole marks are the most widely known features of turbidites. Graded bedding may be more common in the Termite Range Formation than is suggested by the two observations mentioned - the recognition of grading will depend mainly on the range of particle sizes available from the initial sediment source, and the degree of grading will depend on the 'maturity' of the turbidity current (Walker, 1965).

Complete 'Bouma' sequences of graded, parallel-laminated, and rippled sand or silt grading up into finer sediment (Bouma, 1962) have not been recognised, although parts of the Bouma sequence have been. For example, the graded sandstones are possibly Bouma division a, and the parallel laminated sandstones division b. The mud clasts could be mudstone rip-up clasts, a common feature of division a (Stanley, 1963), and the ripple-laminated sandstones division c. The soft beds between the sandstones would be assigned to division e. One puzzling feature is the ubiquity of massive sandstone with apparently sharp bases and tops.

The presence of apparently upgraded sandstones in sequences recognised as turbidites has been discussed by Walker (1965, 1967, 1970) and Nelson & Nilsen (1974). Nelson & Nilsen (1974) described from both the Butano Sandstone and Astoria deep-sea fan 'a' sequences, consisting of numerous amalgamated sandstone beds, and 'ae' sequences, consisting of alternating sandstone and mudstone with no sign of divisions b, c, or d. The sandstones are generally upgraded. Nelson & Nilsen (1974) did not discuss a mechanism for deposition, but regarded them as proximal deep-sea channel deposits. The sandstones are coarser and more lenticular than those in the Termite Range Formation. Walker (1967) discussed the formation of 'traction carpets' in some turbidity currents. Such 'carpets' can result in the deposition of ungraded beds with sharp tops, and may provide a mechanism for the deposition of the Termite Range Formation, Butano Sandstone, and the Astoria fan sediments. Traction carpets are most likely to develop when current velocities are high (in the 'upper flow regime' of Simons & Richardson, 1961). In this situation very high shear stress exists within the current and strong dispersive pressure is developed between grains - this can result in up to about 50% grains by volume in the basal part of the traction carpet. "When the applied shear stress falls below a critical value, the dispersive pressure can no longer be maintained, but the grain concentration is so high that gradual deposition is impossible - instead, the traction carpet 'freezes' instantaneously" (Walker, 1967, p. 37). This seems to provide a suitable machanism for deposition of the ungraded beds in the Termite Range Formation, and can account for the sharp tops of the beds.

Lawn Hill Formation

The Lawn Hill Formation was defined by Carter & others (1961) to describe the succession which conformably overlies the Ploughed Mountain beds (our Termite Range Formation). The name had been used previously by Jensen (1941). The Lawn Hill Formation is the youngest formation of the McNamara Group (Cavaney, 1975).

Distribution. The Lawn Hill Formation crops out over an area of 450 km^2, mostly in western LAWN HILL but also in MOUNT OSCAR, BOWTHORN, MUSSELBROOK, and RIVERSLEIGH. The formation crops out as sinuous strike ridges of more resistant members flanked by extensive black-soil plains in which less resistant members are poorly exposed. In the area south of Adels Grove, the formation crops out as low continuous strike ridges in marked contrast to the more rugged, furrowed appearance of the underlying Termite Range Formation. North of Adels Grove, outcrop is less continuous.

Type section. Jensen (1941) did not define a type section, and, although Carter & others (1961) suggested that a nearly complete section existed between the Lawn Hill airstrip and the Caroline Range, they did not formally define a type section. Our mapping has shown that the most complete section is south of Lilydale Springs, and we have therefore defined it as the type section. It extneds from LH 537 086 (base) to LH 506 064 (top).

Stratigraphic relations and boundary criteria. The lower boundary of the Lawn Hill Formation is placed at the change from massive sandstone (the Termite Range Formation) to carbonaceous shale. Intertonguing of the two units has been observed at LH 550 064. The shales weather easily and the top sandstones of the Termite Range Formation form a prominent ridge, making photointerpretation of this boundary easy. Although sharp in all localities the boundary is believed to be conformable.

The Lawn Hill Formation is the youngest preserved formation of the McNamara Group. It is overlain unconformably by cross-bedded conglomeratic sandstones of the Constance Sandstone in BOWTHORN and in places by limestone, chert, and shale of the Cambrian Border Water Hole Formation and Thorntonia Limestone.

Description. The Lawn Hill Formation consists of about 2000m of shale, siltstone, tuff, and minor sandstone and dolomite.

As a result of the present mapping the formation has been subdivided into six members, Pmh$_1$ to Pmh$_6$. Two sandstone members, Pmh$_3$ and Pmh$_5$, have been named formally - the Bulmung Sandstone Member and the Widdallion Sandstone Member respectively.

The 1800 m sequence preserved in the type section is shown in Figure 20, and the thicknesses of measured and calculated sections in the type section and elsewhere are shown in Figure 23.

The basal unit, Pmh$_1$, consists of about 220 m of grey-weathering shale and black carbonaceous shale with thin siltstone beds. Characteristic concretionary structures (Fig. 21) are present in the dark shale and convolute bedding is common in the siltstone interbeds.

In the type section Pmh$_2$ crops out in the scarp slope of a ridge capped by the resistant Bulmung Sandstone Member, Pmh$_3$. Plmh$_2$ comprises about 80 m of flaggy to fissile, thin to medium bedded tuff, siltstone, and minor sandstone and shale. Petrographic studies indicate that the proportion of tuff exceeds that of siltstone. The rocks are typically green in colour, fine to very fine-grained, and generally silicified.

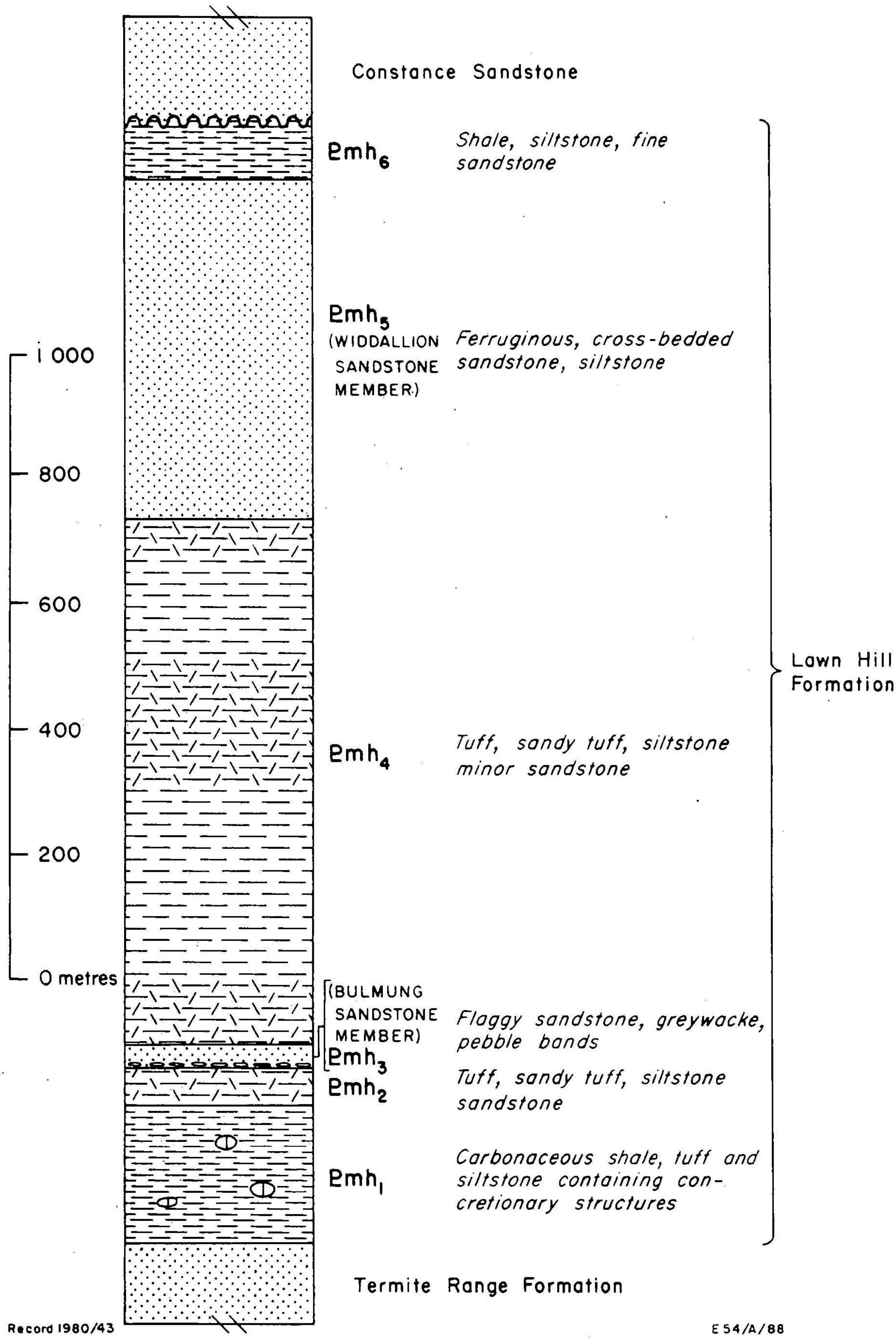

Fig. 20 Type section of the Lawn Hill Formation (base at 537 086, top at 506 064)

Fig. 21: Ovoid concretions in the Lawn Hill Formation at LH454 182 (GB/2233).

Away from the type section, rocks mapped as Emh_2 include lenses of siltstone within Emh_1. One such area is in southwestern MOUNT OSCAR, where the ridges of Emh_2 (El_1 on the map) between Lawn Hill and Edith Creeks are almost certainly at a lower stratigraphic level than Emh_2 (El_1) west of Edith Creek.

In the syncline between Ploughed Mountain and Mount Caroline, Emh_2 is directly overlain by Emh_4, indicating that the Bulmung Sandstone Member has lensed out. In this area Emh_1 is much thicker than in the type section, consisting of at least 1000 m of concretion-bearing grey to black shale containing a lens of Emh_2 - laminated to thin bedded, wavy, lenticular and ripple-laminated siltstone and fine sandstone, tuff, and shale.

A thick sequence of Lawn Hill Formation is present between Lawn Hill homestead and Ploughed Mountain. The Bulmung Sandstone Member is absent, and the sequence to the base of Emh_4 is about 1930 m thick. At least 300 m of Emh_4 - tuff, shale, siltstone, and fine sandstone - is preserved. (Fig. 23).

<u>The Bulmung Sandstone Member (Emh_3)</u> consists of about 40 m of flaggy to blocky micaceous lithic and conglomeratic sandstone. The member crops out as a prominent strike ridge which clearly outlines the structure of the formation. The basal bed of the member is a conglomeratic sandstone in which virtually all the clasts are green siliceous siltstone, apparently derived from the underlying Emh_2. The type section of the Bulmung Sandstone Member is part of the type section of the whole formation. The Member varies little in thickness north-northwestwards from the type section (Fig. 23), but it thins eastwards and lenses out east of Lawn Hill Creek in northern LAWN HILL.

<u>Unit Emh_4</u> comprises about 850 m of flaggy to fissile siltstone, tuff, shale, and dolomite. Like Emh_1 the member is poorly exposed except for resistant bands near the base and top. East and northeast of Lawn Hill homestead the basal resistant bands form two ridges, each of white to pale green-weathering siliceous siltstone which in places is mottled owing to the weathering of small ferruginous inclusions. The two ridges are about 100 m apart, and fissile siltstone and shale between them is poorly exposed. Samples from the ridges 9 km northeast of Lawn Hill homestead consist of

sandy tuff. Thinly-bedded recrystallized dolomite crops out in Bmh_4 at LH 511091.

The Widdallion Sandstone Member, Bmh_5, comprises about 550 m of ferruginous sandstone with siltstone interbeds. In the type section it consists of friable, massive and blocky, fine-grained, thick-bedded, reddish-brown to cream sandstone, and minor coarse siltstone. The friable sandstones weather easily, resulting in low rounded outcrops which have a characteristic banded airphoto pattern.

Unit Bmh_6, comprising over 80 m of green shale, siltstone and fine sandstone, is preserved only in sporadic outcrops beneath the Constance Sandstone and Thorntonia Limestone; the best exposures are in the type section. It is the youngest preserved unit of the McNamara Group.

Between Lawn Hill Creek and the Constance Range escarpment in western LAWN HILL, and in eastern BOWTHORN and MUSSELBROOK, the Lawn Hill Formation is folded into a series of northeast and easterly trending anticlines and synclines. The thickness and lithology of rocks which crop out in this area are similar to those in the type section. An exposure at LH385 520 about 10 km northwest of Lawn Hill homestead consists of massive tuff beds previously identified by Johnston (1975) as lavas.

Lawn Hill Formation in southwestern BOWTHORN

An inlier of Lawn Hill Formation, surrounded by Constance Sandstone, crops out in BOWTHORN about 50 km northwest of Lawn Hill homestead. Figure 22 shows the distribution of the units mapped in the inlier. A simple north-dipping sequence in the northern half of the inlier has been subdivided into Bmh_4 and Widdallion Sandstone Member. The sandstone member, of which 125 m is preserved beneath the Constance Sandstone, is identical to that in the type section, and the rocks below have been labelled Bmh_4 on the basis of superposition. Bmh_4 consists of 1380 m of black shale and siltstone, in the centre of which is 330 m of interbedded dolomite and siltstone (Bmh_{4d}). Although separated from these rocks by a fault, the sequence in the southern part of the inlier appears to underlie that in the north. It is highly folded, but appears to comprise: dark greyish-green shale at the base; overlain by about 330 m of thin-bedded very fine-grained sandstone, siltstone, and shale; overlain by about 125 m of

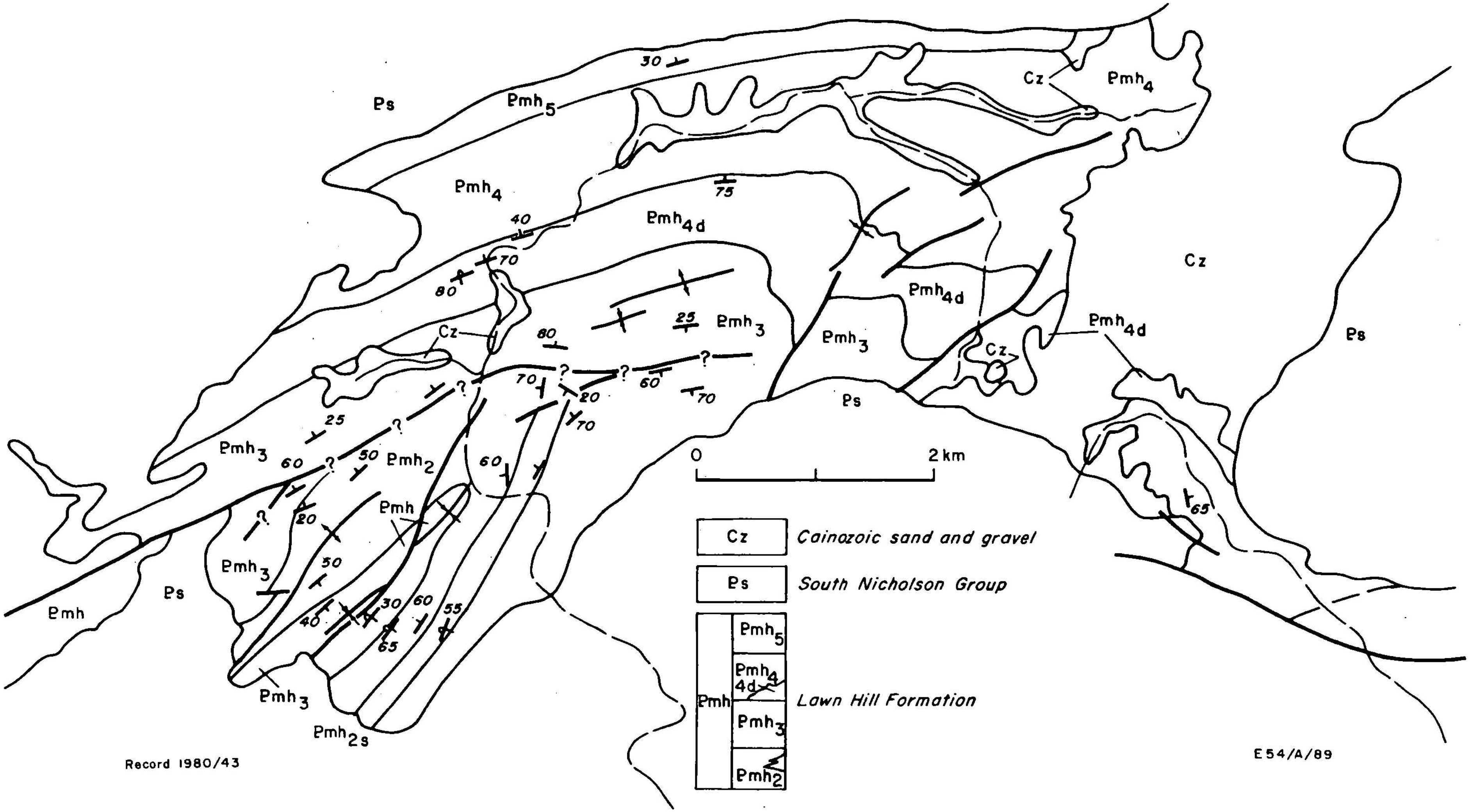

Fig. 22 Geological sketch of an inlier of Lawn Hill Formation in southwestern BOWTHORN

micaceous sandstone, siltstone, and fine-grained orthoquartzite. The sequence is tentatively identified as Emh_1 - Emh_3.

An inlier 10 km farther northwest contains only Emh_4 and Widdallion Sandstone Member of the Lawn Hill Formation. Festoon cross-bedding is a well-developed feature of the sandstone, and in one exposure ripple marks, primary current lineations, mudflake conglomerates, and a glauconite-like mineral were noted.

<u>Petrography</u> Forty thin sections from the Lawn Hill Formation have been described (Table 10), most of them in order to determine the proportion of tuffaceous material in Emh_2 and Emh_4. From the samples studied, it seems that about 80% of fine-grained rocks in these units are tuffs.

Unit Emh_1 comprises black shales with interbeds of siltstone and tuff. The black shales were analysed by R.L. Jack (Ball, 1911) and found to contain up to 2.2% fixed carbon and 5% volatile hydrocarbons. The presence of concretionary structures is diagnostic of this unit.

Units Emh_2 and Emh_4 comprise tuff, siltstone, shale, and minor sandstone. In hand specimen, the tuff and silicified siltstone are difficult to distinguish, as both are fine-grained siliceous rocks, but thin section studies show that most are tuff and sandy tuff. The tuff consists of a high percentage of matrix, which has been weathered to clay, poorly defined glass shards (samples 76410033, 76410127, 76410130, Table 10), and, in some specimens, vesicles infilled with zeolites (76410019, 76410132 Table 10). Further evidence of the tuffaceous nature of these rocks is provided by scoriaceous material (76410027, 76410127, Table 10) now completely ferruginised. Many samples contain detrital sand grains, generally quartz (Table 10 - 76410130, 76410002), which indicate a source of clastic, as well as tuffaceous material. The sandstone of Emh_4 (Table 10, sample 76410026) are generally fine-grained and consist of 50% rounded quartz, 10% feldspar, 5% chert fragments, 10% iron oxides and mica flakes, and 25% groundmass.

The sandstones in the Widdallion Sandstone Member are more feld-spathic than those lower in the sequence. A typical sandstone consists of 60% subrounded, well sorted quartz grains, 15% plagioclase grains, 15% rock fragments which include chert fragments, 5% mica flakes, 5% iron oxides and zircon and tourmaline as accessory minerals (Table 10, samples 76410024, 76410025). These sandstones are mineralogically similar to those in the Termite Range Formation: both contain fresh potash feldspar and cloudy plagioclase, a similar suite of rock fragments, and similar accessory minerals (e.g., compare samples 76410179, Table 9, and 76410183, Table 10).

Discussion. The Lawn Hill Formation is conformable with, and much of it is mineralogically similar to, the Termite Range Formation, and it may therefore have been deposited in similar or related environments, with similar source areas. The occurrence of carbonaceous shale in Bmh_1 and Bmh_4, and of matrix-rich sandstone in Bmh_3, indicates that deep-water sedimentation continued. During periods of low current activity only fine sediments were supplied to the basin, and euxinic conditions prevailed. An increase in sediment supply, perhaps linked to tectonic activity, resulted in the deposition of the Bmh_3 sandstones, possibly by turbidity currents. A period of volcanicity resulted in ash being supplied to the basin. The location of vents or other eruptive centres is unknown: there are no lavas interbedded with other Lawn Hill Formation sediments. The ash was mixed with other clastic sediment and is preserved as tuffaceous siltstone, particularly in Bmh_2 and Bmh_4.

The lower Lawn Hill Formation thus appears to represent a continuation of the deep-basin conditions which prevailed during deposition of the upper Riversleigh Siltstone and the Termite Range Formation, but that shallowing of the basin occurred, probably as a forerunner to the tectonism that terminated sedimentation in the whole of the Lawn Hill Platform. A thickening of the lower Lawn Hill Formation, and the lensing out of the Bulmung Sandstone Member towards the Ploughed Mountain area suggests that a local depocentre developed there (Fig. 23). The upper part of the Lawn Hill Formation is generally eroded, and such thickness trends cannot be drawn for members Bmh_4, Bmh_5, or Bmh_6.

The occurrence of cross-bedding, ripple marks, mudflake conglomerate, and possibly glauconite in the Widdallion Sandstone Member indicate a much higher-energy environment in relatively shallow water, possibly on a marine shelf.

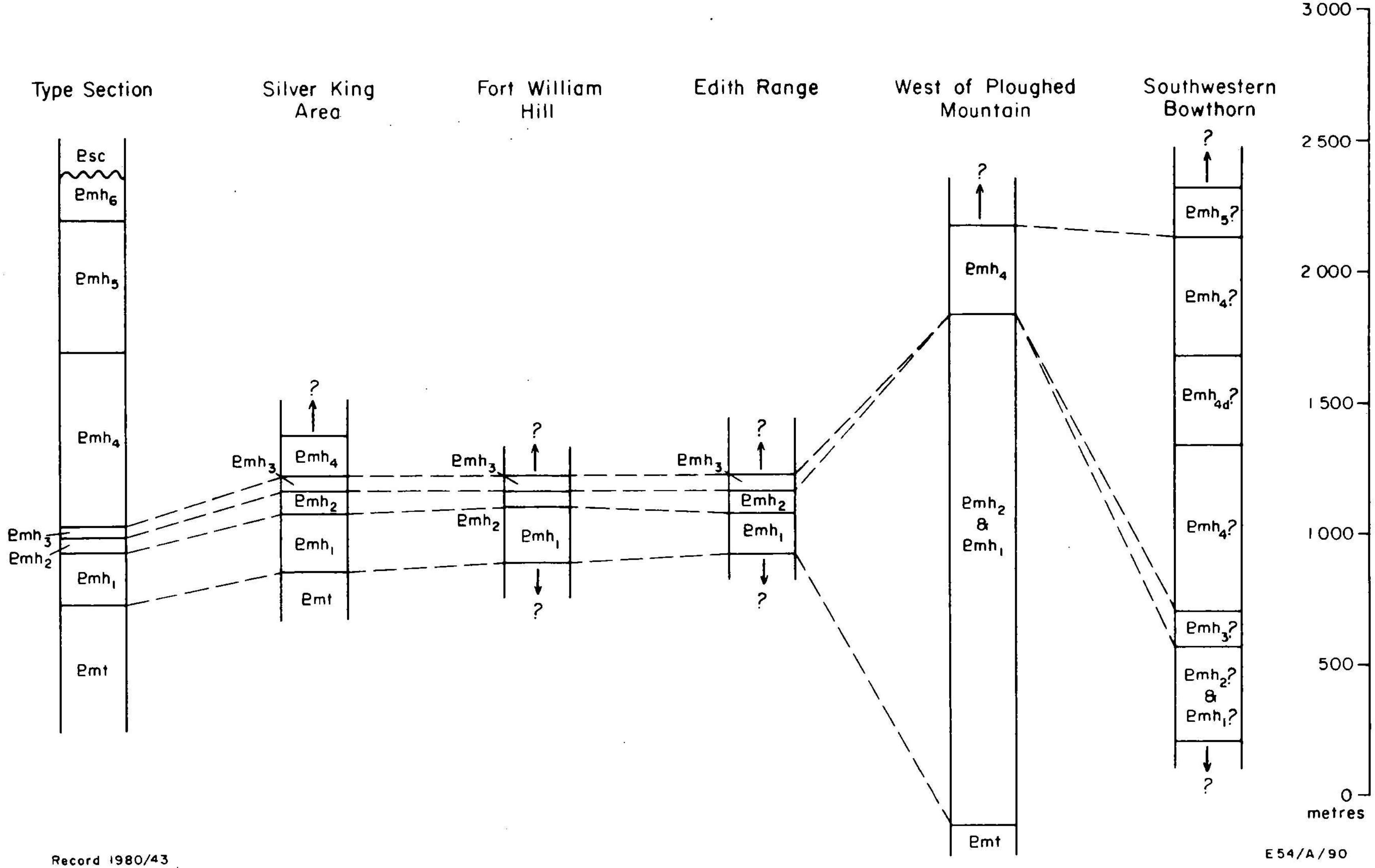

Fig. 23 Lawn Hill Formation — Sections

SOUTH NICHOLSON GROUP

Quartz sandstone and siltstone of the South Nicholson Group unconformably overlie the Lawn Hill Formation and Termite Range Formation in western LAWN HILL and eastern BOWTHORN. The basal unit of the group, the Constance Sandstone (Ėsc), overlies the Lawn Hill Formation disconformably and, in places, with marked angular unconformity. The Mullera Formation, which contains major iron ore deposits in BOWTHORN and MUSSELBROOK, is described in detail by Carter & Zimmerman (1960) and Harms (1965).

CAMBRIAN

Two units have been shown on the LAWN HILL map - Thorntonia Limestone (Єmt) and Border Waterhole Formation (Єmo). Both rest unconformably on the South Nicholson Group and the Lawn Hill Formation. The Border Waterhole Formation is a siltstone-chert-phosphorite facies which grades laterally, quite abruptly, into the Thorntonia Limestone. The Cambrian rocks are described in more detail by de Keyser (1969).

Єmt is easily interpreted on airphotos because of its distinctive photopattern, mainly small-scale joint-controlled pinnacle karst. De Keyser (1969) mapped Єmo in outcrops near Lawn Hill homestead, and we have reinterpreted these outcrops, with some modifications. In the southwestern part of LAWN HILL, areas of poor outcrop and chert rubble probably indicate the presence of Єmo marginal to Єmt, and these areas have been delineated, based partly on airphotointerpretation and partly on maps produced by Mines Exploration Pty Ltd, who successfully explored for phosphate deposits in LAWN HILL (Rogers & Keevers, 1976).

MESOZOIC

Gilbert River Formation (JKg) and Mullaman beds (JKm) have been delineated. The Gilbert River Formation is the basal sandstone in the Mesozoic sequence in the Carpentaria Basin (Grimes, 1974) and all isolated mesas of friable ferruginous sandstone in valleys cut in the Precambrian rocks in northeastern and eastern LAWN HILL are assigned to it.

Similar sandstone and claystone capping hills formed of Precambrian rocks in western and southwestern LAWN HILL are assigned to the Mullaman beds. Both units are of Late Jurassic and/or Early Cretaceous age.

CAINOZOIC

Tpf. Plains with ferruginous soil in the northeast may represent laterite surfaces, and are shown as Tpf, the symbol used by Grimes (1974) for laterite in the Westmoreland 1:250 000 Sheet area.

Tc. Small mesas of crystalline limestone near the southern margin of LAWN HILL are part of the Carl Creek Limestone, of late Oligocene or early Miocene age (Tedford, 1967). Where the Carl Creek Limestone overlies the Thorntonia Limestone it is virtually impossible to interpret a boundary accurately. Accordingly, any Tc/Єmt boundaries shown should be regarded as inferred only.

Tr? Isolated outcrops of flat-lying limestone in northeastern LAWN HILL may be part of the Gregory Limestone, thought by Grimes (1974) to be of similar age to the Carl Creek Limestone.

TQn (Armraynald beds; Grimes 1974). Although described by Smart, Grimes & Doutch (1972) as a lithological unit, the presence of TQn in LAWN HILL has been inferred mainly on geomorphological grounds. The surface of TQn in MOUNT OSCAR consists of black-soil plains with few stream channels, and the southern continuation of these into LAWN HILL has been shown as TQn. Patches of travertine (Czt), apparently within TQn, and sandy soil, are common near Little Archie Creek. Both of these appear to belong to the same phase of deposition as TQn, and are included in it. TQn is slightly above present stream level in most of LAWN HILL, and gullying is occurring in outcrops along creek bands. A terrace of extensively gullied silt and clay with a black-soil surface occurs about 5-8 m above the present level of the Gregory River, and has been mapped as TQn.

Czg. These are gravels cemented by iron oxides. They may represent the same episode as that resulting in Tpf, but it seems more likely that Czg is younger. The gravels form terraces slightly above present stream level, and appear to be piedmont deposits related to an earlier Quaternary or Late Tertiary erosion cycle.

Czs includes a variety of residual soils, colluvium, and possibly also some largely alluvial material, and superficial deposits which could be assigned to Czg with more detailed mapping. It probably includes both Late Tertiary and Quaternary sediments.

Qa includes alluvium which is difficult to distinguish from TQn, particularly in the northeast, where boundaries should be regarded as tentative, and non-active and overbank deposits elsewhere.

Qha. Active stream alluvium in large stream-beds - e.g. the Gregory River.

STRUCTURE

Structure of the Proterozoic rocks

The main structural features of the region (Fig. 24) are the series of domes and basins, the Termite Range Fault, and a series of mainly northeasterly trending faults.

The most prominent structures northeast of the Termite Range Fault are the Mount Caroline and Ploughed Mountain Anticlines, and the Kamarga Dome. The anticlines have northeast-trending axes, and steep, even overturned limbs, but the dome is a symmetrical structure with gently dipping limbs. Southwest of the Termite Range Fault in LAWN HILL the fold axes display a northerly trend whereas to the south, in RIVERSLEIGH, the domes and basins are more symmetrical and smaller than elsewhere.

Mount Caroline Anticline. The anticline is a concentrically folded structure outlined clearly by the closure of the Termite Range Formation. Both limbs are steeply dipping. A series of quartz-filled cross-faults of small displacement are tensional and of the kind believed by Hobbs, Means, & Williams (1976) to be related to changes in the plunge of the fold axis. The plunge of the axis increases suddenly in the southwest, and is greater than 45° at the western end of the structure. An oblique fault which cuts across the centre of the anticline does not appear to be directly related to the fold - i.e., it is not a longitudinal fault in the sense of Hobbs & others (1976), but an expression of a major lineament, visible on LANDSAT imagery (flight-path co-ordinates 107-073). It extends west-southwest into the Carrara Range region in the Northern Territory, and appears to have dextral transcurrent movement of 0.5-1 km.

Ploughed Mountain Anticline. Like the Mount Caroline Anticline the Ploughed Mountain Anticline is a concentric fold. The Termite Range Formation appears to have determined the fold style, resulting in space problems in the core of the structure and resultant longitudinal faulting. The anticline is exposed to deeper levels than the Mount Caroline Anticline, and the Paradise Creek Formation is exposed in the core. This, and probably the Esperanza Formation, have been crushed and largely recrystallised along the axial zone of the fold, and some of the breccia so formed has been injected into the overlying rocks along faults. The mechanism envisaged is similar to that proposed by Burns, Stephansson, & White (1977) for the Flinders Ranges breccias of South Australia. The breccia zone, up to 300 m wide and 6 km long, is shown on the LAWN HILL map.

Kamarga Dome and other fold structures. The Kamarga Dome is a broad structure whose limbs rarely dip at greater than 30°, and mostly less than 20°. Several northeast-trending faults cut the dome, and appear to indicate mainly minor vertical rather than horizontal displacement. For example, the pattern of outcrop of the Esperanza Formation adjacent to the northernmost fault indicates north block up. Greater displacement has occurred on the southeasternmost fault, and the structure of the eastern side of the dome is also complicated by an east-trending fault - again with a downthrow to the south - 1-2 km north of Sandy Creek.

The Lawn Hill Formation displays basin-and-dome folding north of the Termite Range Fault, around Lawn Hill homestead. The folds are outlined by thin sandstone and siliceous tuff bands in an otherwise poorly exposed siltstone-shale sequence.

Major fold axes (shown on the accompanying maps) are mainly north-trending north of the Gregory River west of the Termite Range Fault. Northeast-trending cross-faults appear to be tensional features, and, in the north, quartz-siderite fault-fill hosts the Lawn Hill lead-

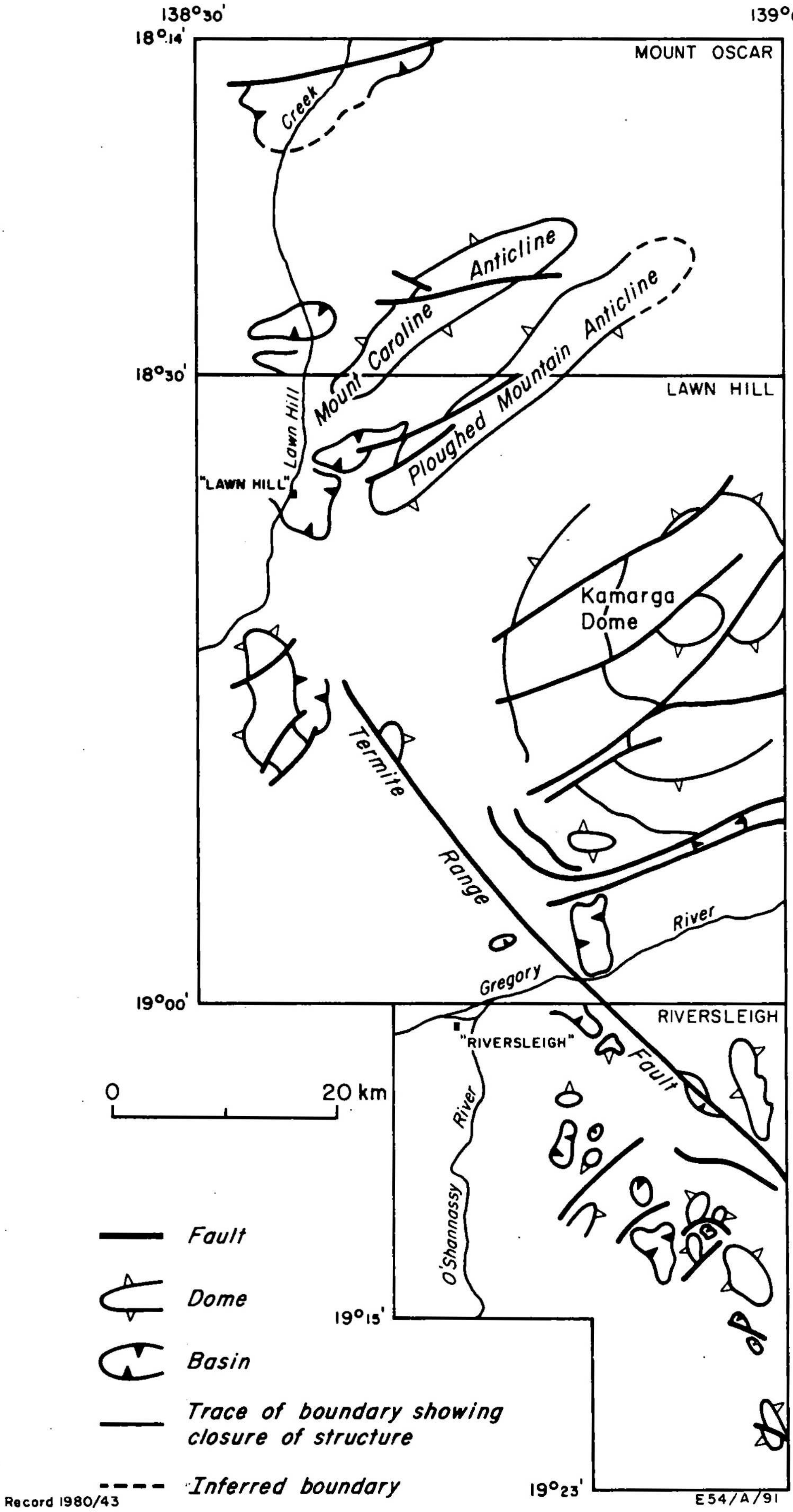

Fig. 24 Main structural features in the Lawn Hill/Riversleigh region

zinc-silver deposits. South of the Gregory River a series of small domes and basins are outlined mainly by Shady Bore Quartzite and Riversleigh Siltstone. The main fold axis direction is variable, but trends northerly to north-northwesterly in the south.

Termite Range Fault. The fault is a major northwest-trending lineament which can be traced from central MOUNT OXIDE, in the southeast, to near Lawn Hill Creek, in the northwest. The movement on the fault appears to be variable. If it were largely horizontal it should be possible to match the stratigraphy and structures at various points on opposite sides of the fault, and thereby to calculate displacements. Such features are absent, and although it does not prove that there was no horizontal movement, most of the separation of strata across the fault can be explained by vertical movements. For example, at the northern end of Termite Range, at LH494260, the fault coincides with an anticlinal axis in the Termite Range Formation. Emt_2 is in contact with Emt_3 and movement on the fault is probably less than 500 m. However, in the dome structure 6 km to the south-southeast, the Riversleigh Siltstone (Emr_{S2}) is adjacent to Emt_2, indicating vertical displacement of about 1000 m. Similar variations occur farther southeast. In northeastern RIVERSLEIGH the fault appears to form the axis of a syncline, and movement is again minimal.

The faults adjacent to the Termite Range Fault appear to terminate against it, but there is no evidence that they are older faults which have been displaced by it. On the contrary, the movement on both the Termite Range Fault and other faults appears to have been synchronous with the major folding episode in the region.

Origin of the Proterozoic structures

According to Hobbs & others (1976) 'the origin of dome and basin structure is imperfectly understood', and 'it is not clear... whether the domes and basins represent embryonic folds that are just starting to be amplified in a more-or-less undeformed sheet'. Duff & Wilson (1975) believe that dome-and-basin folding in the Mount Isa region, including Lawn Hill, is an early stage of deformation, and stated that 'early concentric buckling of rectilinear north-trending axes was succeeded by inhomogeneous flattening' and that ' different stages in the deformation are reflected in the appression of basins and domes which is accompanied by steepening of plunges'. The Lawn Hill region lies between the mainly east-northeasterly-trending structure of the

Westmoreland region (which includes the Murphy Inlier) and the northerly trending structures of the Mount Isa Orogen. The structures in the Lawn Hill-Riversleigh region appear to represent a combination of, or interference between, these two structural regimes and may reflect a change in the direction of the compressional or other forces which caused the folding. The McNamara Group appears to have been folded and faulted during only one major episode of deformation. Even transcurrent movement such as that displayed by the fault cutting the Mount Caroline Anticline could have formed during folding, and is not necessarily a reflection of later movements.

Structure of the Phanerozoic rocks

The Cambrian Thorntonia Limestone in the southwest of the region is flatlying or gently dipping. An outlier of the same rocks southeast of Lawn Hill homestead is, however, structurally quite distinct. Although the overall outcrop pattern of the outlier suggests that it is a virtually flat-lying, flattened-doughnut-shaped body, the rocks within it are actually quite intensely deformed. Fold axes trend in several directions, and there does not appear to be a main trend. De Keyser (1969) thought the folding was a passive reaction to faulting in the underlying Proterozoic rocks, but faults such as the Termite Range Fault show no evidence of post-Cambrian movement. Slumping or solution collapse in the limestones would probably have resulted in brecciation, and does not provide an explanation of the folding. The circular shape of the outlier, and the chaotic folding within it, superficially resemble some impact structures (Dr John Ferguson, BMR, personal communication), but as yet there is no other evidence to suggest such an origin.

The Mesozoic rocks in the region have been uplifted and warped slightly. They appear to be flat-lying, but the elevations of small mesas of such rocks range from about 150 m in eastern LAWN HILL to about 200-250 m in central and southwestern LAWN HILL and southern RIVERSLEIGH.

MINERAL RESOURCES

Economic lead-zinc-silver mineral deposits were first discovered in LAWN HILL by F.H. Hann in 1887. Several more discoveries followed and in 1899, the inappropriately named Burketown Mineral Field (Fig. 25) was proclaimed to cover these deposits. The field has been

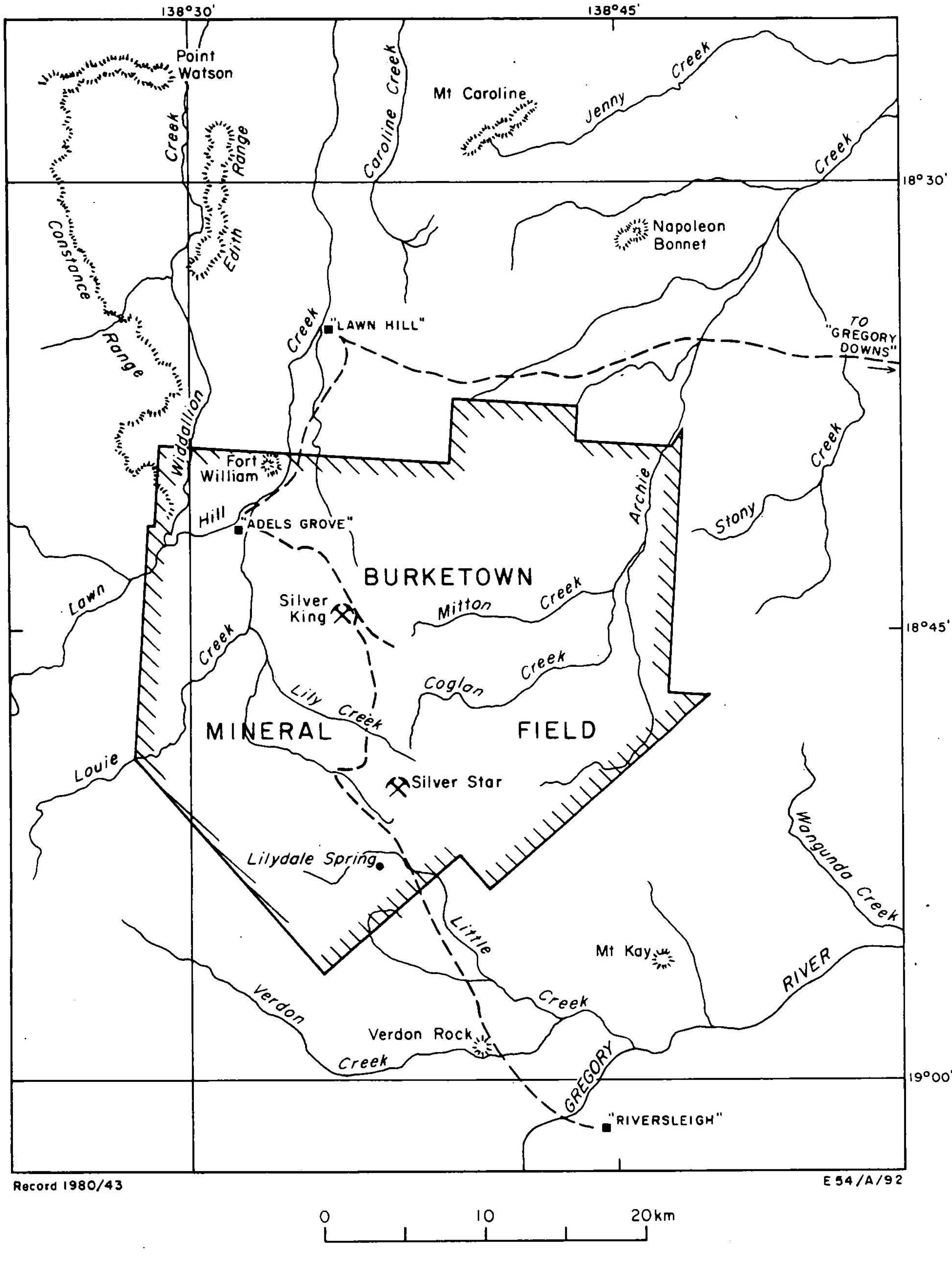

Fig. 25 Limits of the Burketown Mineral Field

worked intermittently since 1887 with peaks of production around the turn of the century, between 1914 and 1927, and between 1948 and 1958. The main problem with the operations on the field has been its isolation. During the 1930s plans for a rail link to the Gulf of Carpentaria were drawn up but the railway was not built. Between 1887 and 1970 37 small mines produced 6 174 tonnes of lead and 5.4 tonnes of silver (Syvret, 1975). The largest single mine on the field, Silver King, was worked until 1968 and yielded 2 603 tonnes of lead (Hutton, 1977).

The mineral deposits and prospective areas in the Lawn Hill region can be grouped as follows:

(1) known mineralisation and extensions to already mined areas within the Lawn Hill Formation in the Burketown Mineral Field (Fig. 25) and adjacent areas;

(2) potential stratiform lead-zinc deposits in the Gunpowder Creek, Paradise Creek, Esperanza, and Lady Loretta Formations; and

(3) phosphate in the Cambrian rocks of the Georgina Basin.

Mineralisation in the Lawn Hill Formation

The principal mines in the Lawn Hill Formation, all of which lie within the Burketown Mineral Field, have been listed in Table 12 along with their production figures and details of mineralogy, geology, and structure. Mineragraphic descriptions of selected samples are presented in Table 11.

The mineral deposits are associated with breccias occurring in northeast to east-northeast-trending tensional faults. Quartz and siderite gangue is present in many of these faults. Ore minerals present are galena and sphalerite with minor pyrite and chalcopyrite. Oxidation of these ores has produced cerussite, anglesite, malachite, azurite, cuprite, and covellite. The silver is bound up in the galena lattice, and, where silver concentrations are high, silver-bearing minerals such as tetrahedrite and tennantite may have exsolved from the structure (Bellis, 1973).

The source of the deposits at Lawn Hill is not known. The association of vein quartz and siderite gangue in a fault-bound lead-zinc sulphide ore body is commonly associated with hydrothermal activity. However, the nearest known igneous body is over 30 km to the east of the field and there is no other evidence of hydrothermal activity in the area. The association of quartz and siderite with sulphide minerals can also be produced by the escape of metal-bearing connate waters from underlying sediments. A third possibility for the origin of these deposits is that they represent remobilisation from a larger, hidden deposit, but evidence of such a deposit has not been found.

Mineralisation in the lower McNamara Group

A stratiform lead-zinc deposit has been found in the upper part of the Gunpowder Creek Formation in the southern part of the Kamarga Dome by a CRA-Newmont joint venture. The CRA Limited Annual Report for 1978 states that 'the mineralisation was found to be extensive, but grades continue to remain low at two to three percent combined lead and zinc'. No other information has been released. A low-grade copper deposit, associated with older beds in the Gunpowder Creek Formation, has also been discovered in the same area. Both the lead-zinc and copper concentrations may be genetically associated with the northeast-trending fault system which cuts the southern part of the Kamarga Dome.

In the Kingfisher Mine, at R700773, a malachite-rich gossan has been exposed in the Lady Loretta Formation at the unconformity with the Thorntonia Limestone. The Waanyee deposit, at LH540455, consists of a westerly-dipping vein of malachite, limonite, quartz, and siderite (Ball, 1911) in a fault-bounded outcrop of Riversleigh Siltstone in the Ploughed Mountain Anticline. Ore production from both deposits was probably only a few tens of tonnes.

Mineralisation in the Georgina Basin

A total of 241 million tonnes of phosphate, at an average grade of 15% P_2O_5, have been proved in the Middle Cambrian Border Waterhole Formation in LAWN HILL and MUSSELBROOK (Hutton, 1977). Deposits have been found at Mount Jennifer, near Lawn Hill homestead (20 million tonnes), at Phantom Hills 8 km south of Mount Jennifer (46 million tonnes), and in southwestern LAWN HILL (11 million tonnes). The main deposits, containing 164 million tonnes, are located in three deposits in MUSSELBROOK, west of LAWN HILL. The development of these deposits appears unlikely in the short term because of their isolation and the presence of much larger deposits at Duchess and Lady Annie, both of which are closer to main rail and road transport (Rogers & Keevers, 1976)

GEOLOGICAL HISTORY

The oldest rocks exposed in the Lawn Hill/Riversleigh region, the Kamarga Volcanics, were erupted on land or into shallow water. Their age is questionable: a single K-Ar isotopic age determination of 1532 ± 20 m.y. (Orridge & Dundas, 1974) should be regarded as a minimum age. They are tentatively correlated with the Fiery Creek Volcanics to the southeast, although they may be older - perhaps equivalent to the Eastern Creek Volcanics. An equivalent of the Fiery Creek Volcanics, the Carters Bore Rhyolite, has been dated by the U-Pb zircon method at 1678 ± 1 m.y., (Page, 1978) and this remains the best estimate of the minimum age of the Kamarga Volcanics.

The Kamarga Volcanics are intruded by the Weberra Granite, whose isotopic age has not been measured. The intrusion was probably associated with a tectonic event in which the volcanics were tilted and perhaps slightly folded. Uplift and erosion followed, and the sedimentary and volcanic pile was stripped from some areas, exposing the granite.

A major depositional episode began with a marine transgression through the area, and deposition of the basal formation of the McNamara Group, the Torpedo Creek Quartzite. A long period of shallow-marine and paralic sedimentation which followed is preserved as the Gunpowder Creek, Paradise Creek, Esperanza, and Lady Loretta Formations, and the Shady Bore Quartzite. The preserved facies seem to indicate mostly shallow subtidal, intertidal, supratidal, and lagoonal environments. They include pyritic, graded siltstone and sandstone, deposited in restricted marine or lagoonal environments; laminated, stromatolitic, intraclastic and oolitic dolomites deposited in a variety of peritidal environments; and well-sorted sandstone and orthoquartzite deposited in beach or shallow-marine environments. The supply of clastic material dwindled towards the end of Gunpowder Creek Formation time, probably due to a combination of distance from source areas, and to the relief of the source - a low, stable landmass. Carbonate and fine clastic sedimentation dominated until Shady Bore Quartzite time, when sand supply increased. This may have been the result of mild tectonism in a hinterland to the west or southwest, as suggested by an increase in thickness in central RIVERSLEIGH, and by its thinning eastwards. The sand is mineralogically and texturally mature, and is probably a recycled sandstone.

The Shady Bore Quartzite virtually marks the end of the main phase of shallow-water sedimentation in the region. The rate of subsidence increased, and although sedimentation locally kept pace with subsidence there was eventually an overall increase in water depth. The Riversleigh Siltstone reflects these changes. The younger part of the formation is carbonaceous and may represent a deep-water basin with restricted circulation and euxinic conditions.

Following deposition of the Riversleigh Siltstone the Termite Range Formation was laid down. The sandstones in the formation, although not classical turbidites, are believed to be deep-water deposits.

The depositional environments of the Lawn Hill Formation are not well understood but the presence of carbonaceous shale, siltstone, and tuffaceous sediments may indicate a continuation of relatively deep water and low-energy conditions; water circulation was restricted at times. The depositional basin either filled, or uplift occurred, because the Widdallion Sandstone Member of the Lawn Hill Formation is clearly of shallow-water origin. The presence of large-scale cross-beds and a glauconite-like mineral in some areas suggests that it may be an offshore sand body.

Deposition of the McNamara Group was probably terminated soon after the Lawn Hill Formation was deposited, and a major period of basin-and-dome folding, with associated faulting, ensued. During and after these episodes, erosion, particularly in eastern LAWN HILL, re-exposed older parts of the sequence. Farther north in HEDLEYS CREEK the Doomadgee Formation, a probable equivalent of the Lawn Hill Formation, is only gently tilted and is overlain disconformably by the South Nicholson Group (Sweet & Slater, 1975).

The age of the McNamara Group can be established within broad limits. It is younger than 1678 m.y., the age of the Carters Bore Rhyolite (Page, 1978). A recent U-Pb zircon age of 1670± 17 m.y. from the Mount Isa Group (Page, in press) is also considered to be the depositional age of the McNamara Group, because the two groups are equivalent (Plumb & Sweet, 1974; Cavaney, 1975). Lithostratigraphic correlations (Sweet, 1980) suggest that McNamara Group deposition may have continued later than in the Mount Isa Group. However younger age limits are provided by a glauconite date of 1390 m.y. (Plumb & Derrick, 1975) for parts of the Roper Group, a correlative of the South Nicholson Group. A greenschist facies metamorphic event which affected the Mount Isa Group between about 1620 and 1490 m.y. ago (Page, 1978) provides a slightly better younger age limit for the McNamara Group.

Following erosion of the McNamara Group, subsidence west of the Lawn Hill/Riversleigh region resulted in renewed deposition in fluvial and shallow-marine environments (South Nicholson Group). After folding and uplift of this sequence during the late Proterozoic (after 1390 m.y.; Plumb & Derrick, 1975) the region was probably eroded until the early Palaeozoic, when a thin veneer or phosphorites, cherts, and limestones (Georgina Basin sequence) was laid down. The region probably formed the northeastern margin of the Georgina Basin, and may have been a land area during much of the Palaeozoic and early Mesozoic. During the Late Jurassic to Early Cretaceous, fluvial sediments were succeeded by marine beds as widespread transgression occurred. Sedimentation probably ceased before the end of the Cretaceous, and deep weathering, with associated laterite formation, took place. Minor uplift occurred, and weathering continued, resulting in the ferruginisation of colluvial and alluvial gravel deposits. In the Late Tertiary the landscape and drainage assumed its present day appearance, and flood-plain deposition occurred on extensive plains marginal to the Gulf of Carpentaria.

Palaeogeography during McNamara Group time

Although the basic data are incomplete, some conclusions about basin shape and the positions of landmasses during McNamara Group time can be made.

The thinning of the Torpedo Creek Quartzite and a facies change from stromatolitic dolomite to coarse dolomitic sandstone in part of the Gunpowder Creek Formation, both towards the central and northern Kamarga Dome, suggest that the region may have been a structural high during deposition (Fig. 26). The Weberra Granite may have been a local sediment source initially, but was soon blanketed by the Torpedo Creek Quartzite. The main carbonate units - the Paradise Creek, Esperanza, and Lady Loretta Formations - were deposited on a broad platform whose limits cannot be determined until information from farther southeast is available (Fig. 25).

Thickness changes in the Shady Bore Quartzite are compatible with a source from the west or southwest (Fig. 26b). Evidence for the deeper-water basin, reflected in the Riversleigh Siltstone and younger formations, is best preserved in the Lawn Hill/Riversleigh region (Fig. 26c). A depocentre during Riversleigh Siltstone time developed just north of the Gregory River, where 3200 m of sediments were deposited. Preserved thicknesses west of the Kamarga Dome and in the Ploughed Mountain Anticline are less, and these and the lack of sandstone interbeds in the formation suggest a continuing sediment source to the west or southwest. The depocentre during deposition of the lower part of the Termite Range Formation was similar, but during deposition of the upper part of the formation it was farther north - up to 1000 m of Emt_3 is preserved at Ploughed Mountain compared with about 200 m west of the Kamarga Dome and 400 m in the type area. The Kamarga Dome area thus remained as a structural high, although its extent and shape cannot be determined.

The shape of the proposed turbidite basin or depocentre which formed during deposition of the Termite Range Formation can be deduced from the data available. Its eastern limit is roughly the Kamarga Dome; its southern limit may be in RIVERSLEIGH, as the formation appears to thin southwards. The western and northern basin margins can also be roughly defined (Fig. 26c) because turbidites are absent from the McNamara Group in the Carrara Range region to the west (Sweet & Mond, in preparation), and from the Fickling Group in HEDLEYS CREEK to the north (Sweet & Slater, 1975). The basin thus appears to be a north or northeast-trending structure no more than 60 by 120 km, centred in western LAWN HILL and MOUNT OSCAR (Fig. 26c). Unfortunately a complete lack of current structures (sole marks, cross-bedding) precludes any reconstruction of source areas for the basin. It is tempting to invoke a southeastern source area - tectonism, uplift and erosion in the Mountain Isa Orogen might have supplied the sediment - but this has not been substantiated.

The Lawn Hill Formation is also thickest in the north, and has correlatives in both HEDLEYS CREEK and the Carrara Range region. The lensing of the Bulmung Sandstone Member eastwards suggests a source to the southwest.

The only basin boundary which can be confidently predicted is the northwestern one, where the Murphy Tectonic Ridge formed a structural

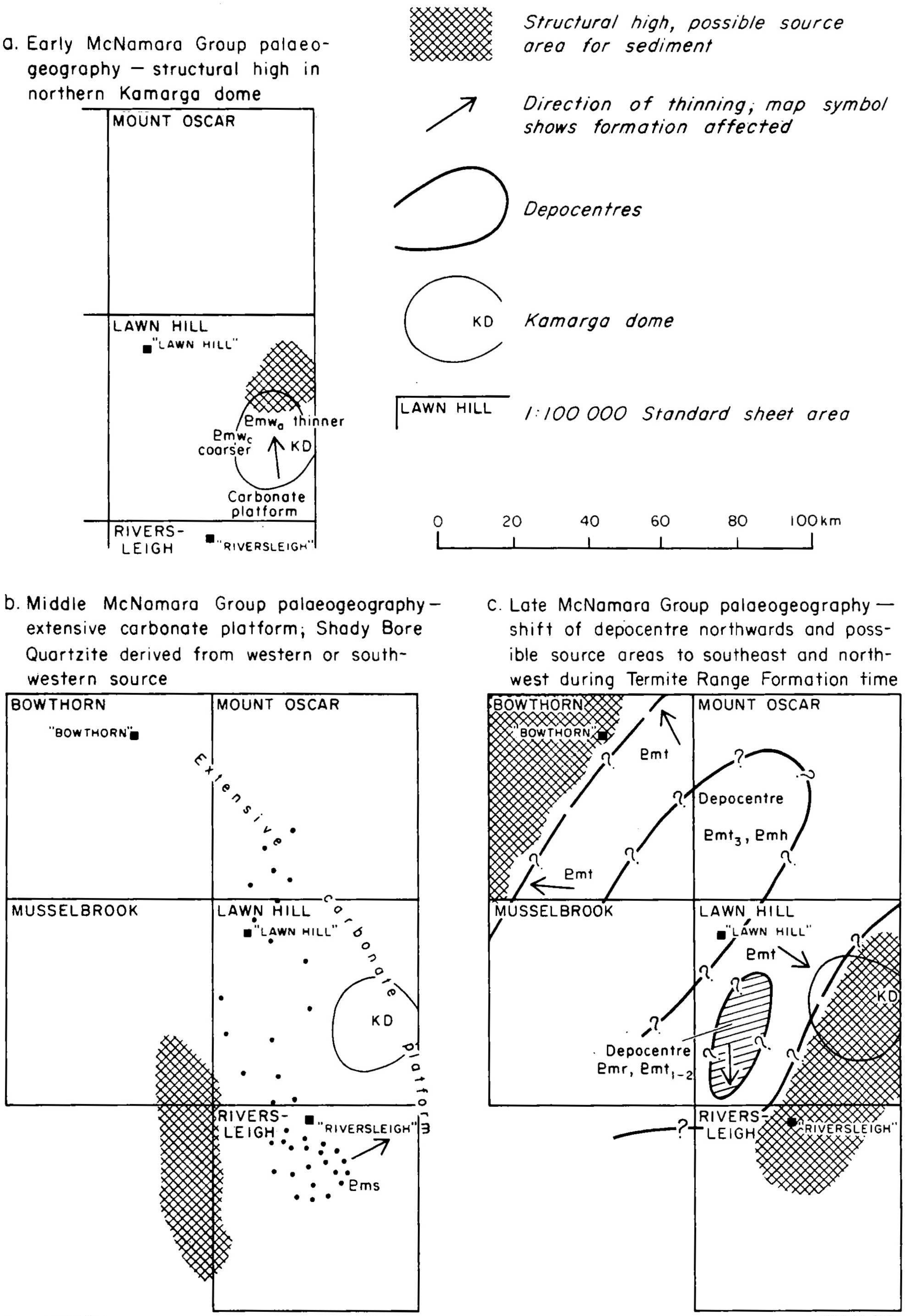

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Fig. 26 Palaeogeography during McNamara Group time high during much of the Carpentarian. It is unlikely to have supplied much sediment to the southeast; indeed for much of the period it was probably covered by thin incomplete sequences of rocks of the same age as the McNamara Group.

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Table 1. Summary descriptions of Proterozoic stratigraphic units

	Name of unit and symbol (members not shown)	Thickness (m)	Lithology	Stratigraphic relations and comments
SOUTH NICHOLSON GROUP	Mullera Formation (Ᵽsm)	50+	Siltstone, ferruginous sandstone	Conformably overlies Ᵽsc; contains major Fe deposits farther northwest
	Constance Sandstone (Ᵽsc)	250	Quartz sandstone, minor conglomerate	Overlies Lawn Hill Formation disconformably and with angular unconformity
McNAMARA GROUP	Lawn Hill Formation (Ᵽmh, Ᵽl$_0$ to Ᵽl$_4$)*	1800-2200+	Shale, siltstone, tuff, tuffaceous siltstone, sandstone, dolomite	Youngest formation preserved in McNamara Group; conformably overlies, and may intertongue with, Ᵽmt; divided into 6 members; 2 sandstone members formally named; host to Pb-Zn deposits
	Termite Range Formation (Ᵽmt, Ᵽm$_{11}$ to Ᵽm$_{13}$)*	200-1100	Feldspathic and lithic sandstone, quartzwacke, greywacke, siltstone, shale	Conformably overlies and intertongues with Ᵽmr; divided into 3 informal members
	Riversleigh Siltstone (Ᵽmr, Ᵽm$_8$ to Ᵽm$_{10}$)*	570-3200	Quartzose, dolomitic, and carbonaceous siltstone; shale, dolomitic sandstone, dolomite	Conformably overlies and intertongues with Ᵽms; contains 3 sandstone members
	Shady Bore Quartzite (Ᵽms, Ᵽm$_7$)*	70-590	Orthoquartzite, siltstone, dolomite, fine sandstone	Conformably overlies Ᵽml; proportion of quartzite varies from 25-100 percent; forms prominent ridges
	Lady Loretta Formation (Ᵽml, Ᵽm$_6$)*	2000	Laminated, stromatolitic, and intraclastic dolomite; dolomitic siltstone and sandstone; basal ferruginous breccia	Conformably overlies Ᵽmz; the basal breccia reflects ?pyritic rocks at depth
	Esperanza Formation (Ᵽmz, Ᵽm$_5$)*	200-250	Stromatolitic chert; siltstone, sandstone and dolomite	Conformably overlies Ᵽmx; forms ridges traceable as photogeological unit
	Paradise Creek Formation (Ᵽmx, Ᵽm$_4$)*	500	Dolomite, stromatolitic dolomite; minor siltstone, sandstone, and chert	Conformably overlies Ᵽmw; lower boundary poorly exposed in LAWN HILL but marked in southeast by Oxide Chert Member
	Gunpowder Creek Formation (Ᵽmw$_{b}$, c and d)	400-800	Carbonaceous shale, siltstone, ferruginous feldspathic sandstone, dolomite, dolomitic sandstone	Conformably overlies and intertongues with Ᵽmw$_a$; outcrop very altered due to weathering of pyrite and other sulphides
	Torpedo Creek Quartzite (Ᵽmw$_a$)	0-100	Conglomerate, feldspathic and quartzose sandstone; minor siltstone and shale	Basal formation of McNamara Group; unconformable on older units; overlain by and intertongues with Gunpowder Creek Formation
	Weberra Granite (Ᵽgb)		Medium-grained muscovite granite	Intrudes Kamarga Volcanics, nonconformably overlain by McNamara Group
	Kamarga Volcanics (Ᵽa)	1400	Amygdaloidal and massive basalt; feldspathic, ferruginous, and conglomeratic sandstones	Oldest rocks in LAWN HILL - base not seen; intruded by Ᵽgb, overlain unconformably by McNamara Group

* Symbols Ᵽm$_4$, Ᵽm$_5$, etc. are photointerpretation symbols. They appear only on MOUNT OSCAR. They have been replaced by formation symbols (Ᵽmx, Ᵽmz, etc.) on LAWN HILL and RIVERSLEIGH.

Table 2. Thin section descriptions, Kamarga Volcanics

BMR registered no. Field point Unit symbol	Rock name	Component	Percentage	Description and comments
76410121	Basalt	Feldspar	55	Sericitised laths, between 0.1 and 0.15 mm, may be oligoclase.
WC-1 - 427.8 m		Chlorite	15	Anhedral grains.
Ꝑa$_v$		Calcite	20	Crystalline, appears secondary.
		Opaques	10	Anhedral, up to 0.15 mm in diameter.
76410122	Basalt	Feldspar	55	Euhedral, up to 0.2 mm, oligoclase to andesine.
WC-1 - 436 m		Chlorite	30	Anhedral masses, up to 0.25 mm.
Ꝑa$_v$		Opaques	10	Subhedral to anhedral, some grains in excess of 0.3 mm.
		Calcite	5	Crystalline, appears secondary.
76410133	Weathered basalt	Sericite	85	Some outline of feldspar laths - no fresh feldspar some iron oxides.
LH5/04/4		Opaques	15	Anhedral, up to 0.2 mm.
Ꝑa$_v$				
76410135	Arkosic sandstone	Quartz	65	Grainsize between 0.04 and 0.4 mm, well rounded, poorly sorted.
LH5/04/2		Feldspar	25	Some fresh microcline and some altered plagioclase
Ꝑa$_s$		Lithic grains	5	Isolated grains, plutonic source.
		Matrix	5	Siliceous- in bands.
		Accessories		Opaques, tourmaline, muscovite.
76410138	Quartzose sandstone	Quartz	95	Most grains about 0.5 mm but down to 0.05 mm; overgrowths well sorted; quartz grains contain needle-like inclusions.
LH5/04/3		Opaques	5	Anhedral, up to 0.5 mm.
Ꝑa$_s$		Accessories		Tourmaline.
77410036	Vesicular basalt	Feldspar	40	Phenocrysts and groundmass; phenocrysts up to 1 mm; plagioclase.
LH8/24/2		Opaques	20	Up to 0.15 mm, anhedral.
Ꝑa$_v$		Zeolites	40	In vesicles, probably chabazite - short euhedral crystals.

Table 3. Thin section descriptions, Weberra Granite

BMR registered no. Field no. Unit symbol	Rock name	Component	Percentage	Description and comments
76410128 B	Greisen	Muscovite	65	Up to 3.2 mm long - parallel to strong schistosity.
LH6/102/3A		Quartz	20	Elongate anhedral crystals within schistosity.
Pgb		Opaques	10	Graphite.
		Tourmaline	5	Anhedral grains up to 0.15 mm.
76410137	Granite	Quartz	30	Subhedral; 1 to 5 mm size range.
LHB/22/7		Plagioclase	40	Altered & sericitised; subhedral; 1 to 5 mm size range.
Pgb		Orthoclase	20	Subhedral grains; up to 6 mm.
		Mica	10	Muscovite, up to 1 mm.
76410139	Granite	Quartz	25	Subhedral grains; 1 - 4 mm.
LH8/20/9		Plagioclase	35	Subhedral; extensively altered; up to 5 mm.
Pgb		Orthoclase	30	Subhedral; not as altered as plagioclase; 1 - 2 mm.
		Mica	10	Muscovite, up to 3 mm.
76410166	Quartz, hematite, muscovite schist	Quartz	75	Banded, some bands 100% and some 50%.
LH6/102/10A		Opaques	20	Bands with finer quartz crystals; mostly hematite, some graphite.
Pgb		Mica	4	Very fine-grained patches.
		Cherty material?	trace	Secondary silicification.
		Amphibole?	1	Sodic amphibole?.
76410167	Sheared hematitic granite	Quartz	10	Anhedral grains; up to 0.3 mm in diameter.
LH5/08/9A		Feldspar	50	Extensively altered and sericitised; cannot distinguish plagioclase and K-feldspar.
Pgb		Opaques	20	Hematite; elongated parallel to shearing.
		Secondary silica	20	Very fine-grained.
77410016	Granite	Quartz	34	Anhedral to subhedral; grains up to 3 mm in diameter (av 1-2 mm).
LH8/22/13		Microcline	26	Anhedral to subhedral; grains up to 3 mm in diameter (av 1-2 mm).
Pgb		Plagioclase	36	Andesine in composition; anhedral to subhedral; up to 3 mm.
		Mica	3	Muscovite.
		Altered ferro-magnesian minerals	1	Alteration after ferromagnesian minerals.

Table 4. Past and present nomenclature of the McNamara Group

de Keyser (1958)	Carter, Brooks, & Walker (1961)**		Cavaney (1975)		This Report	
Not observed	Lawn Hill Formation		McNAMARA GROUP	Lawn Hill Formation	McNAMARA GROUP	Lawn Hill Formation
	Ploughed Mountain beds			Gregory Quartzite		Termite Range Formation
				Riversleigh Siltstone		Riversleigh Siltstone***
Paradise Creek Formation				Carrier Quartzite		Shady Bore Quartzite
		Paradise Creek Formation		Lady Loretta Formation		Lady Loretta Formation
				Esperanza Formation		Esperanza Formation
				Paradise Formation		Paradise Creek Formation
Gunpowder Creek Formation		Gunpowder Creek Formation		Gunpowder Siltstone		Gunpowder Creek Formation
Myally beds		Myally beds		Torpedo Creek Quartzite Member		Torpedo Creek Quartzite*
				Mammoth Formation		Surprise Creek Formation

*Shown in LAWN HILL map reference as a member of the Gunpowder Creek Formation

**The relations shown are those we now know to be correct

***Shown incorrectly as 'Sandstone' in LAWN HILL map reference

Table 5. Thin section descriptions - Torpedo Creek Quartzite and Gunpowder Creek Formation

BMR no. Field no. symbol	Rock name	Component	Percentage	Description and comments
76410116	Sandy dolomite	Quartz	30	Size range from 0.05 to 0.5 mm; well rounded, graded, and cyclic bedding.
WC-1 - 89.0 m		Rock fragments	35	Microcrystalline silica; 70% of rock fragments are micritic intraclasts.
Ꞓmw$_d$		Matrix	35	Generally crystalline dolomite, stylolites; dolomitic mud in finer fractions.
76410117	Dolomitic pebble conglomerate	Quartz	20	Size range from 0.1 to 1.5 mm; v. poorly sorted; well rounded; quartz overgrowths.
WC-1 - 271.5 m		Rock fragments	60	Microcrystalline silica, granite fragments, micritic intraclasts up to 5 mm.
Ꞓmw$_c$		Matrix	20	Crystalline and micritic dolomite - crystalline dolomite is secondary.
76410118	Dolomitic sandstone	Quartz	80	Moderately well sorted up to 0.2 mm.
WC-1 - 313 m		Rock fragments	5	Microcrystalline silica.
Ꞓmw$_c$		Matrix	15	Crystalline dolomite.
76410119	Sandy dolomite	Quartz	40	Unevenly distributed; well rounded; poorly sorted; siltstone to fine sandstone.
WC-1 - 352 m		Feldspar	trace	Few grains of microcline feldspar
Ꞓmw$_c$		Rock fragments	5	Microcrystalline silica.
		Matrix	55	Dolomitic mud.
76410120	Dolomitic, arkosic sandstone	Quartz	50	Angular grains; ranges from 0.1 to 0.4 mm.
WC-1 - 370 m		Feldspar	15	Microcline; 0.2 mm.
Ꞓmw$_c$		Rock fragments	5	
		Matrix	30	Crystalline dolomite.
76410140	Conglomerate	Quartz	40	Ranges from 0.2 to 1 mm.
LH8/22/11		Rock fragments	50	Range from 0.5 mm to 15 mm: granite fragments (generally contain hornblende, quartz, and potash feldspar).
Ꞓmw$_a$		Matrix	10	Clay-grade material.

BMR no. Field no. symbol	Rock name	Component	Percentage	Description and comments
76410164 LH6/102/1 Ᵽmw$_{b}$	Mudstone	Clay	100	Clayey material with grains up to 0.02 mm; some grading in size of material; contains lens of very fine-grained sandstone; contains some mica flakes.
76410170	Polymictic pebble conglomerate	Rock fragments	30	Pebbles consist of multiple quartz grains; finer clasts after weathered volcanics.
Ᵽmw$_{a}$		Matrix	70	90% of matrix is quartz grains; 0.04 to 0.5 mm.
77410028 LH9/40/9 Ᵽmw$_{d}$	Mudstone			Isolated quartz grains; some very fine mica flakes; patches of recrystallised silica; banding due to ferruginous material.
77410031 LH8/24/1	Siltstone	Quartz	30	Poorly sorted; between 0.3 and 0.02 mm.
Ᵽmw$_{b}$		Mica	5	Flakes aligned parallel to bedding.
		Opaques	5	Some grains show crystal boundaries.
		Matrix	60	Clay-grade material.

Table 6. Thin section descriptions - Esperanza Formation

BMR no. Field no.	Rock name	Component	Percentage	Description and comments
76410123	Dolomitic Chert	Dolomite		Sparry cement.
WC.2-62M		Chert		Very fine-grained silica bands.
76410124	Dolomite	Opaques	15	Dolomitic mud; fine to
WC.2-85M		Matrix		medium silt-size.
76410125	Shale	Matrix	100	Clay-sized matrix of
WC.2-146.0M				silica dolomite and micas; laminated.
77410003	Dolomitic	Quartz	65	0.05 mm; rounded.
LH11/8/2	Siltstone	Feldspar	5	Albite or oligoclase.
		Matrix	30	Crystalline carbonate.
77410005	Siltstone	Quartz	75	0.02 to 0.08 mm.
LH12/6/5		Matrix	25	Very fine-grained siliceous matrix.
77410007	Oosparite	Ooids	80	0.4 to 0.5 mm in
LH12/4/6				diameter - quartz grains as nucleii.
		Matrix	20	Sparry cement and some very fine silica (chert?).
77410008	Siltstone	Quartz	80	Well-sorted, subangular, up to 0.05 mm.
LH12/8/2		Feldspar	2	Plagioclase
		Mica	3	
		Matrix	15	Iron-stained.

77410010	Siltstone	Quartz	65	Poorly sorted, subangular.
LH12/8/2		Feldspar	1	
		Lithic grains	4	
		Mica	3	
		Matrix	27	
77410013	Siltstone	Quartz	80	Well-sorted, subangular;
LH12/6/9		Feldspar	5	about 0.05 mm in size.
		Mica	3	Fresh.
		Matrix	12	Dense, ferruginised.
77410015	Sandy oolitic	Quartz	45	Very poorly sorted; grain-
LH9/36/7	wackestone	Ooids	15	size varies between 0.02
		Opaques	5	and 0.15 mm
		Matrix	35	Micritic dolomitic mud.

Table 7. Thin section descriptions - Lady Loretta Formation

BMR no. Field no. Unit symbol	Rock name	Components	Percentage	Descriptions and comments
76410003 LH2/98/6A Eml	Sandy dolomite	Quartz	10	Silt-size grains.
		Matrix	90	Clay-grade dolomitic.
76410005	Very fine grained sandy dolomite	Quartz	40	Coarse silt to very fine sand.
LH2/98/3		Mica	trace	Muscovite.
Eml		Matrix	60	Dolomitic mud.
77410002 LH13/4/3 Eml	Siltstone	Quartz	65	Medium to coarse silt.
		Opaques	25	Coating on grains and intergranular mass.
		Mica	5	Muscovite.
		Matrix	5	Masked by iron oxides.
77410023 LH12/14/5 Eml	Siltstone	Quartz	80	Medium grained silt.
		Feldspar	1	Plagioclase.
		Mica	2	Muscovite.
		Opaques	8	Small irregular blebs.
		Lithic fragments	9	Dense clayey grains.
77410033 LH10/82/5	Dolomite	Dolomite	100	Laminated with dolomitic mud (algal?). Channel of grainstone - dolomite mud grains in crystalline matrix.

Table 8. Thin section descriptions - Riversleigh Siltstone

BMR and field numbers; symbol of unit	Rock name	Component*	Percentage	Description and comments
76410008		C	95+	Possibly sericite.
LH 11/18/8	Silty	Q	5	Scattered medium silt grains.
Ꞓmr$_k$	claystone	A		Scattered muscovite flakes.
76410014	Fine clayey	Q	85+	Very fine sand, some quartz over-
LH 11/18/9	sandstone			growths but most are clay-rimmed.
Ꞓmr$_{S2}$		C	10+	Most may be discrete grains rather than interstitial; ?kaolin.
		F	5	Altered to clay along cleavages.
		A		Scattered muscovite, hematite goethite, rounded tourmaline and zircon.
76410165		O)	60+	Organic matter - dark brown/black;
Ꞓmr	Carbonaceous	)		amount not determined.
	Siltstone	C)		Low birefringence; intimately mixed with organic matter.
		Q	30+	Coarse silt.
		A	2	Muscovite flakes.
77410025		Q	75+	Very fine to fine sand; rounded;
LH 11/16/4	Dolomitic			quartz cement.
Ꞓmr$_{S1}$	Sandstone	D	10+	Dolomite - recrystallised or sparry, interstitial, irregular, acts as cement
		F	10	Probably mostly orthoclase; some microcline.
		R	1+	Claystone (?altered volcanics), sericite rock
		A		Muscovite flakes, tourmaline, zircon; opaques (interstitial, associated with dolomite).
77410029		Q	65+	Rounded, moderately sorted; course
LH 11/12/11	Dolomitic			silt to medium sand.
Ꞓmr$_{S1a}$	sandstone	D	20+	Fine(?micritic) aggregates, probably rock fragments; also some interstitial.
		F	10	Microcline and plagioclase more common than in 77410025.
		R		A few composite feldspar grains; dolomite (see above).
		A		Muscovite, clumps of Fe oxides, rounded tourmaline, zircon.

Table 8 (contd)

BMR and field numbers; symbol of unit	Rock name	Component*	Percentage	Description and comments
77410062		Q	60	Coarse silt to fine sand.
R4/90/10B	Clayey	C	40	Includes both interstitial material
$Emr_{Sla?}$	sandstone			and grains.
		A		Rare tourmaline and zircon.
77410065		Q,C		Similar to 0062; some clay defin-
R4/90/10C	Clayey			itely as grains, may be less matrix
Emr_{Sla}	sandstone			than 0062.
		F		Rare or absent.
		A		Muscovite, chlorite, Fe oxide
				staining.
77410066	Dolomitic	Q)		Difficult to estimate relative
R4/96/1	quartz	D)		percentages; Q and D in coarse silt
Emr	siltstone			range.
		C		Abundant muscovite; minor chlorite,
				biotite, zircon.
		A		Alignment of grains results in
				bedding fissility.
77410067		Q	1	Rare - fine silt-size.
R3/86/8B	Carbonaceous	C)	99+	Clay and organic matter form bulk
Emr	shale	O)		of rock; thin section almost opaque
				due to high proportion of organic
				material.
77410068		Q		Heterogeneous mixture of coarse
R4/90/13	Quartz	C	90+	quartz silt in matrix of clay and
Emr	siltstone	D		fine-grained dolomite.
		O		High proportion of opaque material,
				probably Fe oxides.

* C = Clay
Q = Quartz
F = Feldspar
R = Rock fragments
D = Dolomite
O = Opaques
A = Accessory minerals

Table 9. Thin section descriptions - Termite Range Formation

BMR and field numbers; symbol of unit	Rock name[1]	Component[2]	Percentage[3]	Description and comments
76410001 LH3/90/2A Emt_{3g}	Quartz wacke	Q	50+	Grains up to 1 mm.
		F) RF)	10	Mixed source.
		M	40	
76410004 LH3/90/2B Emt_{3g}	Quartz wacke	Q	50	Coarse silt to medium sand.
		M	50	Silt and clay; latter recrystallised owing to diagenesis.
76410006 LH3/90/1A Emt_3	Lithic greywacke	Q	70	0.5-1.0 mm; a few above 1 mm; well rounded; course silt and fine sand also present.
		F	5	
		RF	10	Mixed source.
		M	15	
76410009 LH11/18/3C Emt_3	Lithic greywacke	Q	75+	Some greater than 1 mm; average 0.2-0.5 mm; grains corroded by matrix.
		F	1-2	Slightly altered microcline.
		RF	8-10	Sedimentary, metamorphic, and igneous.
		M	15	Brown silt and clay; patchily recrystallised.
76410010 LH11/18/7A Emt_1	Sublithic arenite	Q	80	0.5 mm; some up to 1 mm, down to coarse silt.
		RF	10	Sedimentary, volcanic, and low-grade metamorphic; feldspar absent.
		M	5	Difficult to distinguish from some coarse silt grains; low-birefringence clay.
		A,V	5	Tourmaline, zircon, muscovite, limonite staining.
76410011 LH11/18/1C Emt_1	Quartz wacke	Q	75	Most grains less than 0.1 mm; ranges down into coarse silt.
		RF	5	Rare phyllite, volcanics; feldspar absent.
		M	20	Low-birefringenee clay.
76410012 LH11/18/1D Emt_1	Sandy siltstone	Q	40	Very fine sand and coarse silt.
		M	60	Silt and clay, muscovite flakes. No feldspar or rock fragments.

Table 9 (cont)

BMR and field numbers; symbol of unit	Rock name [1]	Component [2]	Percentage [3]	Description and comment
76410013 LH11/18/4 Emt_3	Sublith-arenite or subarkose	Q	80	Most less than 0.5 mm; cemented by quartz overgrowths.
		F) RF)	10	RF may be slightly more abundant than F; sedimentary and metamorphic.
		M	10	Clay outlines grain boundaries; a few larger patches.
		A		Zircon, tourmaline, rare opaques.
76410017 LH11/18/1B Emt_1	Quartz wacke	Q	70	2-0.5 mm; some overgrowth.
		RF	5	Sedimentary and volcanic; feldspar absent.
		M	25	Recrystallised clay or sericite in patches.
		A		Rare tourmaline, muscovite; limonite staining.
76410018 LH11/18/2B Emt_2	Sandy siltstone	Q	50	Coarse silt.
		C	25	Finer silt and clay minerals.
			25	Limonite - occurs as discreet grains; probably pseudomorphs after pyrite.
76410037 LH11/18/3A Emt_3	Lithic greywacke	Q	70	0.5 mm; some overgrowths.
		F	5	Microcline; fairly fresh.
		RF	5	Plutonic, volcanic, sedimentary, and metamorphic.
		M	20	Limonitic silt and clay; partly recrystallised.
		A		Tourmaline.
76410153 MOs6/91/12D Emt_3	Subarkose	Q	85+	Grains 0.1-0.5 mm.
		F	5+	Twinned (microcline) and untwinned; all fresh.
		RF	5	Mixed source, but chert predominates.
		M	5	Mostly quartz silt, no clay.
76410154 MOs6/91/12A Emt_3	Subarkose	Q	80	Grains 0.1-0.3 mm; interlocking mosaic.
		F	8	Tabular cleaved grains and subspherical twinned microcline; cloudy.
		RF	2	Mixed source.
		M		Trace only.
		C	10	Syntaxial quartz overgrowths.
76410155 MOs6/91/12E Emt_3	Sublith-arenite	Q	90	From coarse silt to 0.7 mm.
		F	2	
		RF	5	Mostly sedimentary
		M	3	Quartz silt.

Table 9 (contd)

BMR and field numbers; symbol of unit	Rock name [1]	Component [2]	Percentage [3]	Description and comments
76410156		Q	80	From coarse silt to 0.5 mm.
MOs6/91/12B		F	5	Well-rounded cleavage fragments.
Emt_3	Subarkose	RF	5	Sedimentary and metamorphic.
		M		Trace.
		C	10	Quartz overgrowths.
		A		Muscovite, tourmaline, zircon, opaques.
76410157		Q	70+	Just outside quartz wacke field; from coarse silt to 1 mm.
MOs6/91/12C	Feldspathic greywacke	F	5+	Fresh microcline.
Emt_{3g}		RF	5	Mixed source.
		M	15+	Difficult to distinguish from coarse silt.
76410160		Q	85	Up to 1 mm, but most less than 0.5 mm; some overgrowths.
MOs7/49/6	Sublith-arenite	F		None observed.
Emt_3		RF	5	Metamorphic and sedimentary.
		M	10	Small patches of white low-birefringence clay.
76410161		Q	85+	From coarse silt up to 1 mm; overgrowths and interlocking grains.
MOs7/49/7	Sublith-arenite	F	5	Rounded cleavage fragments; a few euhedral (authigenic) grains.
Emt_3		RF	5	Mixed source.
		M	5	
76410162		Q	50	A few grains over 1 mm; poorly sorted.
LH1/16/13	Feldspathic greywacke	F)	20	Abundant twinned and untwinned grains.
Emt_3		RF)		Igneous, metamorphic and sedimentary grains.
		M	30	Dark colour due to finely divided opaques.
76410163		Q	60+	
LH1/16/12	Quartz wacke	F)	10	
Emt_3		RF)		Sedimentary and metamorphic.
		M	30	Clay and quartz silt; scattered detrital micas.
76410173		Q	75	Grains up to 1 mm; moderate sorting.
LH2/00/7		F	10	Scattered coarse grains of potash feldspar, some altered.
Emt_3	Subarkose	RF	5	Muscovite-quartz schist predominates.
		M	10	
76410178		Q	85	
LH2/00/4	Sublith-arenite	F	1	
Emt_3		RF	4	Chert, quartz, volcanics, muscovite schist.
		M	10	Quartz silt and yellow to brown clay.
		A		Several rounded tourmaline grains.

Table 9 (contd)

BMR and field numbers; symbol of unit	Rock name [1]	Component [2]	Percentage [3]	Description and comments
76410179	Conglomeratic	Q	65	Subangular grains up to 5 mm.
LH2/00/4B	lithic	F	5	Altered; some intergrown with quartz (i.e., micrographic).
Emt_3	greywacke	RF	10	Igneous and metamorphic fragments.
		M	20	Clay.
		A		Rounded tourmaline; zircon, rare opaques.
76410180		Q	70	Up to 1 mm; some 2nd cycle overgrowths.
LH2/00/5	Lithic	F	5	A few large, rounded grains.
Emt_{3g}	greywacke	RF	10	Metamorphic and sedimentary.
		M	15	Heterogeneous mixture of sand, silt, and clay; scattered muscovite flakes.
76410181		Q	75	Poorly sorted sand; rare grains up to 5 mm.
LH2/00/6	Quartz			
Emt_3	wacke	F		A few grains.
		RF	5	Mostly sedimentary grains.
		M	20	Silt and clay; scattered muscovite, biotite, and chlorite flakes.

1. Classification of Pettijohn, Potter, & Siever (1973), p. 158

2. Q = Quartz, F = Feldspar, RF = Rock fragments, M = Matrix, C = cement, A = Accessories, V = Voids

3. Visual estimate

Table 10. Thin section descriptions - Lawn Hill Formation

BMR and field numbers; symbol of unit	Rock name[1]	Component[2]	Percentage[3]	Description and comments
76410002		Q	30	Angular grains - less than 0.5 mm.
LH1/18/2		F	4	Plagioclase - weathered.
Emh_4	Sandy tuff	Mi	5	Muscovite flakes.
		A	1	Tourmaline, sphene, zircon.
		M	60	Contains glass shards, iron oxide, and some calcite.
76410016		Q	20	Angular grains - less than 0.05 mm.
LH1/18/5C		F	Trace	Plagioclase - cloudy
Emh_2	Silty tuff	Mi	15	Biotite.
		A	5	Iron oxides.
		M	60	Clayey groundmass with glass shards.
76410134		Q	30	Angular grains - 0.1-0.3 mm.
LH1/26/4		F	5	Sericitised plagioclase.
Emh_2	Sandy tuff	Mi	Trace	Muscovite, biotite.
		A	Trace	Iron oxides, tourmaline, zircon.
		M	65	Glassy material with glass shards, and calcite.
76410130		Q	20	Angular grains 0.1-0.2 mm.
LH1/26/4A		F	5	Sericitised.
Emh_2	Sandy tuff	Mi	5	Muscovite and biotite.
		M	70	Glass shards - glassy material. Some clayey material; some concentration of oxide minerals
76410127		Q	30	Angular grains 0.2 mm.
LH1/26/4B		F	10	Sericitised - no fresh grains.
Emh_2	Sandy tuff	Ca	10	Large clusters of CaCo3 in rock.
		M	50	Glass shards - some matrix devitrifyied to form quartz clusters.
			Trace	Iron oxides around grains.
76410141		Q	20	Angular grains, 0.1-0.3 mm.
LH1/26/4C		F	Trace	Unaltered feldspar grains
Emh_2	Sandy tuff	Mi	5	Muscovite.
		M	75	Glassy with glass shards
76410021 LH1/26/1 Emh_2	Silty tuff			Rock consists of banded structure with bands of silt-size angular quartz grains making up to 10% of rock matrix; contains glass shards with accessory zircon.
76410028 LH2/92/4 Emh_2	Siltstone			Rock consists of isolated grains of quartz and fresh microcline; remainder of rock is very fine-grained

Table 10 (contd)

BMR and field numbers; symbol of unit	Rock name[1]	Component[2]	Percentage[3]	Description and comments
7610169 LH2/94/1 Emh_2	Tuff			Rock consists of angular grains of quartz in a matrix containing glass shards. Rock also contains biotite, muscovite, and calcite or dolomite.
76410168 LH2/96/8 Emh_2	Lithic arenite	Q	45	Subrounded grains up to 0.1 mm well sorted
		RF	10	Igneous rock fragments (?volcanics).
		A	40	Iron oxide grains and concentrations.
		Mi	5	Muscovite.
76410027 LH3/84/5g Emh_4	Sandy tuff	Q	10	Angular grains up to 0.1 mm.
		Mi	10	Muscovite
		M	80	Clay matrix with glass shards.
76410032 LH4/26/3A Emh_2	Lithic Arenite	Q	60	Subrounded, 0.1-0.3 mm.
		F	10	Well sorted-moderately sorted.
		RF	30	Plagioclase and microcline.
		A	Trace	Microcrystalline silica (?chert). Iron oxides and mica.
76410033 LH12/18/19A Emh_2	Sandy tuff	Q	30	Subrounded - less than 0.2 mm
		Mi	5	Biotite (green) and muscovite.
		F	Trace	Microcline.
		Ca	10	Massive concentrations.
		A	5	Zeolites in undistorted vesicles; some iron oxides.
		M	50	Clay material with spectacular examples of glass shards.
76410034 LH11/20/1 Emh_5	Lithic-arkosic arenite	Q	60	Subrounded 0.3-0.5 mm, moderately sorted.
		F	20	Both microcline and sericitised plagioclase.
		RF	20	Microcrystalline silica, and igneous rocks.
		A	Trace	Muscovite, tourmaline, and zircon.
76419935 LH9/56/5 Emh_5	Lithic-arkosic arenite	Q	50	Poorly sorted, larger grains rounded; varies between 0.05 and 0.5 mm.
		F	20	Both plagioclase and microcline.
		RF	20	Poorly sorted; microcrystalline silica and igneous rock fragments.
		A	Trace	Tourmaline and zircon.
		M	10	Clay-grade material with fine mica grains and iron oxides.

Table 10 (contd)

BMR and field numbers; symbol of unit	Rock name [1]	Component [2]	Percentage [3]	Description and comments
76410036	Calcareous	Q	30	Poorly sorted, angular 0.01-0.1 mm.
LH9/56/13	feldspathic	F	15	Plagioclase and microcline.
Ɛmh$_5$	arenite	RF	10	Microcrystalline silica.
		Ca	40	Masses of $CaCO_3$ up to 2 mm long.
		Mi	5	Green biotite.
76410038		Q	35	Subrounded grains, 0.1-0.5 mm,
LH11/22/1A	Lithic			moderately well sorted
Ɛmh$_5$	arenite	F	10	Plagioclase and fresh microcline.
		RF	55	Microcrystalline silica and igneous rock fragments.
			Trace	Iron oxide and mica flakes.
76410039				Rock consists almost entirely of a
LH11/22/2A				very fine-grained clayey matrix con-
Ɛmh$_6$	Mudstone			taining mica flakes and iron oxides, as well as clay-grade material.
76410040				Rock consists of clay-grade matrix
LH11/22/2B				which includes mica flakes and iron
Ɛmh$_6$	Mudstone			oxide grains up to 0.01 mm in diameter; mica flakes define laminations, which are disturbed by crystalline fragments.
76410041		Q	50	Subrounded grains, 0.1-0.5 mm, mod-
LH11/22/1B	Lithic			erately sorted.
Ɛmh$_6$	arenite	F	10	Fresh microcline and plagioclase.
		RF	40	Microcrystalline silica (?chert)and fine-grained igneous rock fragments.
		A	Trace	Iron oxides.
76410042		Q	60	Moderately well sorted, rounded
LH11/22/3	Lithic			grains, 0.1-0.5 mm.
Ɛmh$_6$	arenite	F	5	Plagioclase.
		RF	35	Microcrystalline silica (chert).
		Mi	Trace	Muscovite.
		A	Trace	Tourmaline and zircon.
76410030		Q	40	Some rounded grains, 0.1-0.5 mm,
LH3/84/9A	Feldspathic			poorly sorted.
Ɛmh$_5$	greywacke	F	15	Plagioclase and microcline.
		RF	5	Microcrystalline silica and igneous rocks.
		A	Trace	Tourmaline, sphene, and zircon.
		M	40	Very fine-grained, acicular clay and mica grains; clayey.

Table 10 (contd)

BMR and field numbers; symbol of unit	Rock name[1]	Component[2]	Percentage[3]	Description and comments
76410019 LH5/24/2A Ᵽmh$_2$	Silty tuff			Rock consists of a clayey matrix containing glass shards, zeolites, possibly scoria which is elongated and forms the layering; some very fine grains of quartz and feldspar.
76410022 LH4/26/3B Ᵽmh$_2$	Lithic arenite	Q	60	Angular grains about 0.1 mm.
		F	5	Sericitised plagioclase and some microcline
		RF	30	Fine-grained silica and igneous rock fragments
		A	5	Zircon, tourmaline, and some iron oxide and mica flakes.
76410023 LH5/24/2B Ᵽmh$_2$	Feldspathic greywacke	Q	15	Angular grains - 0.2 mm.
		F	5	Sericitised plagioclase.
		Mi	19	Muscovite.
		A	10	Iron oxides.
		M	60	Very fine-grained, clayey, with abundant fine-grained mica.
76410024 LH5/26/1 Ᵽmh$_5$	Feldspathic arenite	Q	40	Rounded grains less than 0.5 mm.
		F	30	Plagioclase and clear microcline up to 0.5 mm.
		Ca	10	Irregular grains.
		RF	10	Chert and igneous grains - less than 0.5 mm and angular.
		A	10	Iron oxides.
76410025 M/4/29/1* Ᵽmh$_5$	Lithic-feldspathic arenite	Q	60	Subrounded grains - 0.3 mm.
		F	15	Generally sericitised plagioclase.
		RF	15	Cherty fragments - subrounded grains less than 0.3 mm.
		Mi	5	Muscovite.
		A	5	Iron oxides, zircon, and tourmaline
76410026 LH4/24/4 Ᵽmh$_4$	Feldspathic greywacke	Q	50	Rounded grains up to 0.5 mm.
		F	10	Sericitised plagioclase and clear microcline up to 0.5 mm.
		RF	5	Cherty fragments.
		Mi	5	Muscovite.
		A	5	Iron oxides.
		M	25	Clayey.
76410029 LH3/84/9B Ᵽmh$_5$	Arkosic arenite	Q	50	Subrounded, up to 0.6 mm; well sorted
		F	30	Both microcline and plagioclase.
		RF	20	Chert.

*MUSSELBROOK

Table 10 (contd)

BMR and field numbers; symbol of unit	Rock name[1]	Component[2]	Percentage[3]	Description and comments
76410031 LH3/84/6B Emh_5	Lithic-feldspathic arenite	Q	60	Rounded grains 0.1-0.3 mm; well sorted
		F	10	Both microcline and plagioclase.
		RF	10	Microcrystalline silica (chert).
		A	10	Iron oxide, tourmaline, zircon, and micas.
76410129 LH3/94/4D Emh_4	Tuff			Rock consists of glass shards and abundant scoria in a now clayey matrix - minor isolated quartz grains and muscovite.
76410131 LH3/94/4E Emh_4	Sandy tuff	Q	20	Angular grains 0.1-0.2 mm in diameter.
		Ca	10	Irregular concentrations.
		A	Trace	Altered feldspar, zircon, and some mica.
		M	70	Clayey material containing glass shards scoria, and iron oxides.
76410132 LH3/94/4C Emh_4	Tuff			Rock consists of glass shards in a clayey matrix; also contains some quartz grains, vesicles filled with zeolites, and scoria.
76410142 LH3/94/4B Emh_4	Tuff			Rock consists of glass shards, vesicles containing zeolites, and scoria in a now clayey matrix.
76410143 LH3/94/4A Emh_4	Tuff			Rock consists of glass shards, vesicles with zeolites, and scoria in a clayey matrix.
76410171 LH3/90/7 Emh_1	Siltstone			Rock consists of silt-size matrix with some minor quartz grains abundant iron oxide and some ?calcium carbonate - section through a concretion in Emh_1.
76410175 LH3/88/2A Emh_4	Calcareous sandy tuff			Rock consists of subrounded quartz grains in a clayey matrix containing glass shards and scoria. Rock also contains about 40% $CaCO_3$ and some biotite grains.

Table 10 (contd)

BMR and field numbers; symbol of unit	Rock name [1]	Component [2]	Percentage [3]	Description and comments
76410176 LH3/88/2B Ꞓmh$_4$	Siltstone			Rock consists of some sandy bands with rounded quartz grains up to 0.1 mm. Majority of rock consists of fine clayey matrix containing aligned mica flakes. Sandy bands make up 10% of the rock.
76410177 LH3/88/2c Ꞓmh$_4$	Tuff			Rock consists of fine-grained clayey matrix containing glass shards, calcite, and quartz grains up to 0.3 mm .
76410183 B*10/14/1 Ꞓmh$_4$	Lithic arenite	Q	55	Rounded grains, 0.1-0.2 mm, well sorted.
		F	3	Microcline.
		RF	40	Microcrystalline silica (chert) and fine-grained igneous rock fragments.
		A	2	Iron oxide, tourmaline and muscovite.

1. Classification of Pettijohn, Potter & Seiver (1973) p. 158

2. Q - Quartz, F - Feldspar, RF - Rock fragments, Mi - Mica, M - Matrix, A - Accessories, Ca - Dolomite or calcite

3. Visual estimate only

* BOWTHORN

Table 11. Polished section descriptions - Burketown Mineral Field

BMR registered no. Mine name	Component	Description and texture
76410184 SILVER KING MINE	Galena	Grains in excess of 3 cm; also disseminated in a quartz gangue; exsolution of tetrahedrite and tennantite; recrystallisation of galena
76410185 SILVER KING MINE	Galena	Disseminated irregular grains up to 0.2 mm.
	Pyrite	Minute disseminated grains around 0.02 mm.
	Sphalerite	Small grains - 50 to 60% of specimen.
	Covellite	Isolated grains or as inclusions in galena and sphalerite - ?after chalcopyrite.
76410186 SILVER KING MINE	Sphalerite	Large grains in siliceous gangue cut by pyrite, galena; internal reflection.
	Pyrite	Cubic individual grains - veinlets through sphalerite and chalcopyrite.
	Chalcopyrite	Large grains up to 1 mm; contains grains of pyrite.
	Galena	Forms around outside of sphalerite grains; also as veinlets within sphalerite.
76410187 WATSONS LODE	Galena	Brecciated grains with oxidised coating of cerussite or anglesite; quartz gangue.
76410188 WATSONS LODE	Chalcopyrite	Main grains up to 2 cm in diameter; smaller grains in gangue.
	Galena	Small isolated clumps of grains and veinlets in chalcopyrite.
	Sphalerite	Isolated irregular grains in gangue and in chalcopyrite.
76410189 WATSONS LODE	Sphalerite	Large irregular masses; internal reflections (iron-poor variety); possible chalcopyrite exsolution.
	Chalcopyrite	Smaller irregular bodies up to 1 mm; possible exsolution from sphalerite (?or veinlet).
	Covellite	In cracks in sphalerite - after chalcopyrite.
76410190 STAR SPANGLED BANNER	Malachite	Malachite in 'box-like' network of iron oxides and hydroxides.
76410191 MENDED HILL	Galena	Large grains; recrystallisation textures around the edges; ?exsolution of argentite (or tetrahedrite).
	Pyrite	Minor altered grains in galena.
76410192 MENDED HILL	Galena	Large grains, recrystallisation textures; ?exsolution of argentite (or tetrahedrite) along crystallographic planes.
76410193 SILVER QUEEN MINE	Galena	Large grain - recrystallisation textures around edge of grain. Oxidation to cerussite and anglesite also at edge.
	Pyrite	Minor grains around edge of galena.

Table 11(cont.)

BMR registered no. Mine name	Component	Description and texture
76410196 SILVER QUEEN MINE	Pyrite	Both as large grains and fine grains in siderite gangue. Large pyrite mass is brecciated and infilled with galena and veinlets of chalcopyrite.
	Chalcopyrite	Large (2 cm) and small (0.5 mm) grains; larger grains twinned with grains of pyrite and veinlets of galena.
	Galena	Infilling between grains and veinlets cutting pyrite and chalcopyrite grains.
	Covellite	Alteration of ?chalcopyrite; veinlets through pyrite.
	Iron Oxides	Boxworks in altered sections.
76410196 TUNNEL HILL	Sphalerite	80% of rock; featureless; siliceous gangue.
	Pyrite	Cubic grains, generally as veins in sphalerite.
76410197 TUNNEL HILL	Sphalerite	Large grains, cracked and infilled with gangue; yellowish internal reflection; iron poor sphalerite.
	Pyrite	Clusters of grains up to 1 mm in diameter; grains are cubic; some veinlets in sphalerite.
76410198 STARDUST	Galena	Large grains; rock is banded with bands of disseminated galena and quartz gangue.

Table 12. Ore production from the Burketown Mineral Field since 1948

MINE NAME	ORE (TONNES)	Pb TONNES	Pb %	Ag GRAMS	Ag GRAMS/ TONNE	LOCATION	ORE MINERALS	FORM OF OREBODY AND ASSOCIATED MINERALS	LITHOLOGIES	REFERENCES
Star Spangled Banner (including Banner Group) Bull Ridge mine						LH441305	Sphalerite, galena, chalcopyrite, cuprite, malachite, azurite	Mineralisation largely oxidised - abundant cuprite and malachite; ore is brecciated but not associated with a quartz breccia	Shale and siltstone, tuff, of Ᵽmh$_1$ and Ᵽmh$_2$. Mineralisation associated with NE striking faults	Hutton, 1973 Ball, 1911 Jensen, 1941 Saint-Smith, 1925
Mended Hill mine	662	407	61	483 877	707.1	LH479245	Galena, pyrite tetrahedrite?, argentite? See Table 11. Nos. 76410101 and 7641092	Galena and pyrite in a quartz and siderite breccia. Galena in two forms: coarsely crystalline and finely crystalline. Galena has exsolution of silver minerals	Sandstone, siltstone, and tuff of Ᵽmh$_2$ and Ᵽmh$_3$. Associated with ENE striking faults	Bellis, 1973 Carter & others, 1961 Ball, 1911 Jensen, 1941 Cameron, 1900
Silver King mine	2653	1383	52	1 517 912	554	LH458255	See Table 11. Nos. 76410184, 76410185, and 76410186. Galena, sphalerite, chalcopyrite, pyrite, proustite, tetrahedrite, tennantite	Galena is primary ore with sphalerite in a quartz-filled breccia. Some exsolution of silver minerals from galena. Pyrite and chalcopyrite as disseminated grains	Sandstone, siltstone, and tuff of Ᵽmh$_2$ and Ᵽmh$_3$. Associated with NE-striking faults. No gossanous outcrop, but massive quartz-filled breccia	Carter & others, 1961 Bellis, 1973 Brooks, 1963 Ball, 1911 Jensen, 1941 Cameron, 1900 Saint-Smith, 1925
Silver Queen mine	33	15	44	5 225	150	LH433329	See Table 11. Nos. 76410193 76410195. Galena, sphalerite, chalcopyrite, covellite cerussite	Galena as band in hanging wall of fault. Chalcopyrite is later than the galena. Gangue minerals are quartz and siderite	Siltstone and sandstone of Ᵽmh$_3$. Associated with NE-striking faults	Hutton, 1973 Carter & others, 1961 Saint-Smith, 1925
Watsons lode (Lucky Dollar) (Wooden Duck)	152	82	52	16 329	186.7	LH460168	See Table 11. Nos. 76410187, 76410188 and 76410189. Galena, sphalerite, chalcopyrite, pyrite	Ore forms blocks in fault breccia. Mines spread along fault zone for about 1 km. Sphalerite is iron-poor variety; has chalcopyrite as ?exsolution	Shale, siltstone, and tuff of Ᵽmh$_4$. Associated with large fault which strikes NE. Fault has massive manganiferous quartz breccia	Carter and others, 1961 Ball, 1911 Cameron, 1900 Saint-Smith, 1925
Waanyee	?					LH40455	Chalcopyrite, pyrite, malachite, azurite, cuprite	Chalcopyrite and pyrite in fault breccia; no quartz breccia. 0.15 grams/tonne gold in ore	Unit [illegible] or [illegible] - interbedded dolomites and quartzose sandstone. Cut by NE-striking faults. In Ploughed Mountain Anticline	Carter & others, 1961 Ball, 1911 Jensen, 1941 Saint-Smith, 1925
Lilydale	172	74	43	23 919	134.7	LH463147	Galena, pyrite, cerussite, and malachite	Galena in fault breccia and as veinlets in sediments. Cerussite and malachite in oxidised zone. Siderite gangue	Siltstone, shale, and tuff of Ᵽmh$_4$. Ores associated with E-W fault	Carter & others, 1961 Ball, 1911 Cameron, 1900 Vernon & Edwards, 1958
Bell's lode	35	19	52	10 202	278.6	LH479255	Galena, tetrahedrite, proustite, pyrite, chalcopyrite, sphalerite	Galena in fault breccia; tetrahedrite, proustite as exsolution? in galena. Orebody strikes SE	Siltstone, sandstone, and tuff of Ᵽmh$_2$ and Ᵽmh$_3$. Associated with SE-striking fault zone	Carter & others, 1961 Bellis, 1973 Ball, 1911 Jensen, 1941 Cameron, 1925

Table 12. Ore production since 1948 (cont.)

MINE NAME	ORE (TONNES)	Pb TONNES	Pb %	Ag GRAMS	Ag GRAMS/ TONNE	LOCATION	ORE MINERALS	FORM OF OREBODY AND ASSOCIATED MINERALS	LITHOLOGIES	REFERENCES
Anglo-American (inc. Union Jack)	125	56	45	25 909	202	LH431295	Galena, pyrite, chalcopyrite, covellite, malachite	Galena in fault breccia; oxidation of ore at surface; galena associated with quartz breccia	Sandstone, siltstone and tuff of Emh_2 and Emh_3. Adjacent to NE-striking fault zone	Carter & others, 1961 Hutton, 1973 Ball, 1911 Jensen, 1941 Saint-Smith, 1925
Hann's mine (Axis Hill on Axis Ridge)	88	52	59	19 712	217.3	LH432328	Galena, anglesite, chalcopyrite, covellite	Galena in fault zones. Massive and strained galena. No quartz gangue	Sheared Emh_3 and Emh_2. Ore in ENE-striking fault plane	Carter & others, 1961 Hutton, 1973 Ball, 1911 Jensen, 1941
Stardust (East Star, Star of the East, Silver Star)	718	434	60	107 911	143.9	LH491155	Galena, anglesite, malachite, azurite. See Table 11. No. 76410198	Galena is fine-grained, in brecciated rocks; galena is also disseminated in a quartz gangue	Near boundary between Emt and Emh_1 and Emh_2 - in siltstone and shale of Emh. Associated with NE-striking faults	Carter & others, 1961 Ball, 1911 Cameron, 1900 Saint-Smith, 1925
Tunnel Hill	?					LH491263	Sphalerite, pyrite, chalcopyrite & galena. See Table 11. Nos. 76410196 and 76410197	Ore associated with massive manganiferous outcrop. Sphalerite is iron-poor variety. Chalcopyrite and pyrite may be ?exsolved from sphalerite structure	In shale, siltstone, and tuff of Emh_1 and Emh_2. In fault plane part of Termite Range Fault. Associated with massive manganiferous gossan	Bellis, 1973 Jensen, 1941