BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD

Record 1980/76

THE GEOLOGY OF THE CARRARA RANGE REGION, NORTHERN TERRITORY

by

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Abstract

The Carrara Range region lies in the Northern Territory, adjacent to the Queensland/Northern Territory border, between 18°30' and 18°47'S, and 137°11' and 138°E. It contains Early Proterozoic to Carpentarian rocks which form part of the North Australian Orogenic Province, Lawn Hill Platform, and South Nicholson Basin.

Quartz-veined schist, phyllite, quartzite, and siltstone of the 1860 m.y. or older Murphy Metamorphics basement are overlain unconformably by the Carrara Range Group, which contains basal fluvial sands (Don Creek Sandstone); basalt, trachyte, and interbedded sediments of the Mitchiebo Volcanics; and, at the top, rhyolitic lava or ignimbrite (Top Rocky Rhyolite).

Uplift and tectonism were followed about 1670 m.y. ago by transgressive deposition of sand, silt, and stromatolitic carbonate of the McNamara Group (Musselbrook Formation, Lawn Hill Formation), which are overlain unconformably by sandstone, siltstone, and ironstone of the South Nicholson Group (Constance Sandstone, Mullera Formation). Areas of Cambrian and Mesozoic strata overlie the Proterozoic sequences, which have been strongly altered in places by a Tertiary deep-weathering event.

The Murphy Metamorphics are tightly folded; Carrara Range and McNamara Groups are also folded, but characteristically are strongly faulted along east-northeast trends. South Nicholson Group rocks form open folds and basin-and-dome structures.

Prospectivity of the region is largely untested because of the effect of lateritisation on geochemical dispersion of metals. The McNamara Group, broadly equivalent to the Mount Isa Group, warrants further exploration, especially the Musselbrook Formation. Iron ore deposits in the region, and phosphatic beds at depth in the Cambrian sequences, are currently subeconomic.

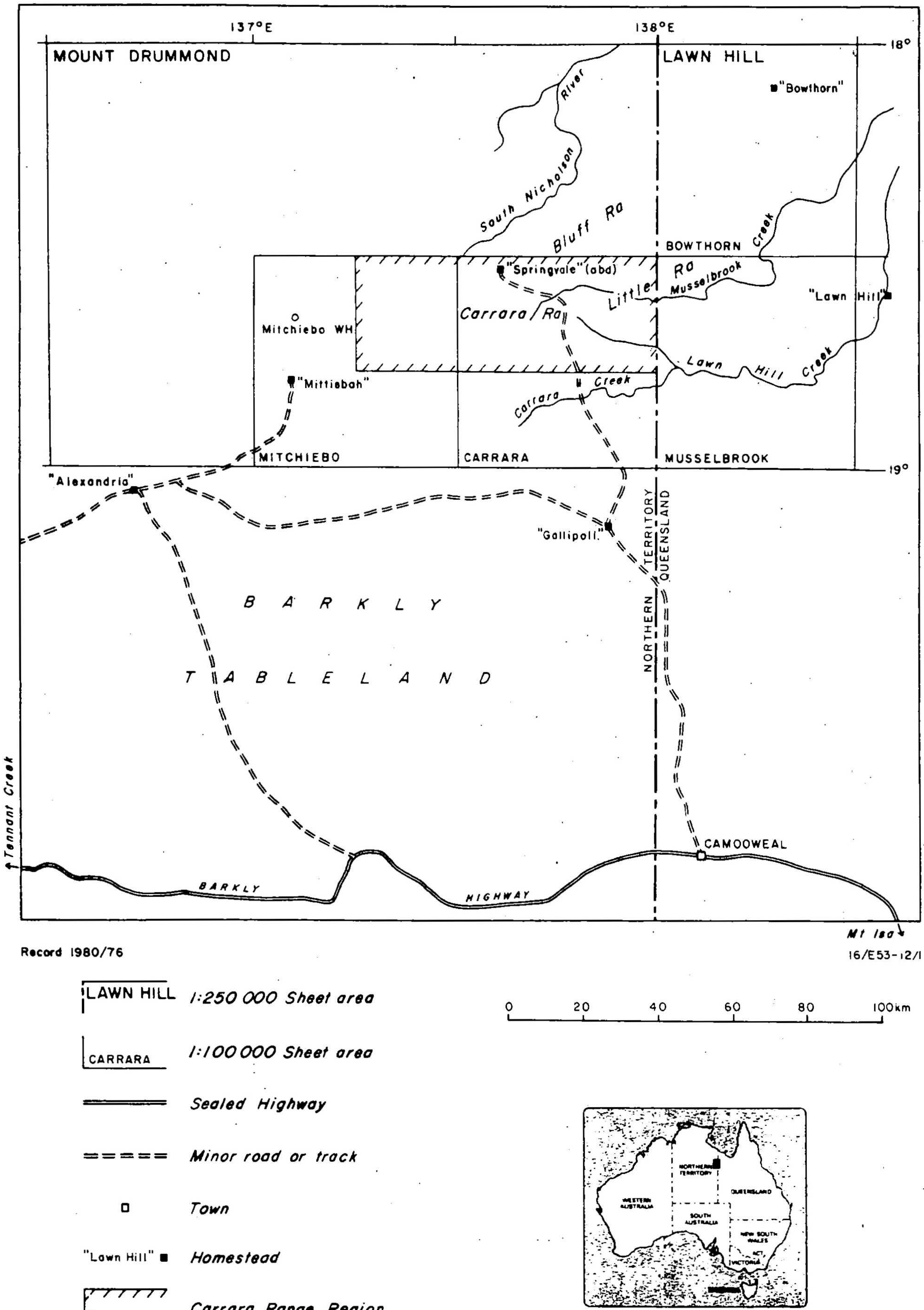

Fig 1: Location and access map

INTRODUCTION

Aims

This Record describes the results of an investigation undertaken in 1977 as part of a project to re-examine the stratigraphy, structure, and mineral potential of Proterozoic rocks of northwestern Queensland and adjacent areas.

Location and access

The Carrara Range region of this Record lies in the northeastern Northern Territory between latitudes 18°30'S and 18°47'S and longitudes 137°11'E and 138°E (the Northern Territory/Queensland border). It includes parts of two 1:100 000 Sheet areas of MITCHIEBO* and CARRARA (Fig. 1), and lies wholly within the Mount Drummond 1:250 000 Sheet area. The region includes a series of low ridges and plateaux (the Bluff, Carrara, and Little Ranges) which form the northeastern margin of the Barkly Tableland.

Access by road is from the south (Fig. 1). A well formed earth track links Camooweal, on the Barkly Highway, with Gallipoli homestead. North of Gallipoli a network of station tracks exists as far north as Carrara Creek, some 10 km south of the boundary of the Carrara Range region. The condition of these tracks, particularly over the blacksoil plains, is poor. North of Carrara Creek the access track to the now abandoned Springvale homestead is completely washed out. However, the route is still the best one by which to approach the region even though cross-country driving is necessary.

An alternative access, involving a greater distance of cross-country driving, is from the southwest via Alexandria homestead. A track runs north from Alexandria to Mittiebah homestead, and thence to Mitchiebo waterhole, about 15 km west of the map boundary (Fig. 1).

* 1:100 000 Sheet names are capitalised throughout this Record.

All station homesteads have airstrips suitable for light aircraft, and are served regularly by supply runs. Springvale homestead site, at grid ref. 747487, bears no sign of any buildings - the homestead was abandoned in about 1970, and the site is marked on the map for reference.

Climate and vegetation

The climate and vegetation of the Carrara Range region (part of the Barkly region) are described by Slatyer & Christian (1954) and Perry & Christian (1954). The climate is semi-arid tropical, and is characterised by a short summer wet season and a long dry season (generally April to October or November).

Thin skeletal soils developed on the Proterozoic rocks in the region support only a sparse vegetation cover in which spinifex (*Triodia* species) and snappy gum (*Eucalyptus brevifolia*) predominate. The surrounding sandy and ferruginous soils support a more varied flora, much of which is described by Horton (1976).

Habitation and industry

Since Springvale was abandoned the area has been uninhabited. Although the nearby pastoral properties extend into the area, surface water is scarce and the region supports few cattle.

Topography and drainage

The general elevation of the region is 300-400 m. Local relief of 50-80 m occurs in the numerous mesas, plateaux, and east to northeast-trending ridges. The main drainage is into coastal river systems - the Nicholson to the north, and Lawn Hill and Musselbrook Creeks to the east.

Creeks draining the western part of the region fade out in the sandy apron flanking the Proterozoic outcrops. Even the longest creeks, Rocky and Bull Creeks, extend no more than 10-15 km into the plains to the south.

Survey methods

Both vehicle and helicopter traverses were used to carry out the survey, and about 12 man-weeks' effort was required to fully cover the region. Observations and all geological information were plotted on 1:25 000 scale colour airphotos and transferred to bases supplied by the Division of National Mapping.

Previous investigations

Little was known of the geology of the Carrara Range region until BMR carried out a reconnaissance in 1958, and mapped the Mount Drummond 1:250 000 Sheet area in 1959 (Smith & Roberts, 1963). Few companies have prospected in the area and few surface indications of mineralisation are recorded; the most recent exploration in the Proterozoic rocks was carried out in 1967 (Dechow, 1967). The Cambrian rocks in the east were remapped by de Keyser (1969), and since then some exploration for phosphate has been carried out south of the Carrara Range.

Acknowledgements

L.J. Hutton, of the Geological Survey of Queensland, assisted in the field work in the Carrara Range region, and R.J. Bultitude examined and discussed thin sections of the volcanic rocks.

GEOLOGY

The basic geological framework of the Carrara Range region was described by Smith & Roberts (1963). As a result of the present survey a more detailed understanding of the stratigraphic sequence, requiring some revision of stratigraphic nomenclature, has been developed (Table 1). In addition, more precise correlations can be made with Proterozoic sequences to the north in the Westmoreland region, and to the east in the Lawn Hill region (Table 2). The stratigraphy of the Carrara Range region is summarised in Table 3.

Stratigraphic nomenclature

Table 1 summarises past and present stratigraphic nomenclature applied to the Proterozoic rocks in the Carrara Range region. Smith & Roberts (1963) recognised three major rock sequences - the Carrara Range Formation, the Bluff Range Beds, and the South Nicholson Group. The presence of two previously unrecognised unconformities within the Carrara Range Fromation has led to its redefinition as three formations, which form the Carrara Range Group. The uppermost part of the old Carrara Range Formation has now been included in the overlying sequence, the McNamara Group, and the term Bluff Range Beds has been abandoned. The McNamara Group crops out extensively in the Lawn Hill-Mount Isa region (Cavaney, 1975; Sweet & Hutton, 1980). The nomenclature of the South Nicholson Group has not been changed, except for the recognition of the Middle Creek Sandstone Member within the Mullera Formation.

Age and correlations

Smith & Roberts (1963) assigned the Bluff Range Beds and all older rocks in the Mount Drummond 1:250 000 Sheet area to the 'Lower Proterozoic', and the South Nicholson Group to the 'Upper Proterozoic'. Since 1966, when a threefold subdivision of the Australian Proterozoic was proposed (Dunn, Plumb & Roberts, 1966), the Murphy Metamorphics are the only rocks still assigned to the Lower (Early) Proterozoic. Plumb & Derrick (1975) assigned the Bluff Range Beds and Carrara Range Formation to the Carpentarian, and the South Nicholson Group to the Adelaidean or Carpentarian.

There have been no isotopic age determinations on rocks from the Carrara Range region, and the rocks in the region have therefore been assigned an age on the basis of correlation with other areas. The isotopic dates on which the ages of these rocks are based are discussed in the following descriptions of lithological units. Table 2 summarises the correlations and the ages of the rocks. The base of the Adelaidean is now believed to be much younger than previously thought (Preiss & Forbes, 1980, summarise the evidence) and thus by implication the upper boundary of the Carpentarian is also younger than previously thought. As a result the South Nicholson Group is now regarded as being wholly of Carpentarian age.

Table 1. Past and present stratigraphic nomenclature used in the Carrara Range region.

NOMENCLATURE USED BY SMITH & ROBERTS (1963)			NOMENCLATURE USED IN THIS RECORD		
SOUTH NICHOLSON GROUP	Mullera Formation		SOUTH NICHOLSON GROUP	Mullera Formation	Middle Creek Sandstone Member
SOUTH NICHOLSON GROUP	Constance Sandstone		SOUTH NICHOLSON GROUP	Constance Sandstone	
UNCONFORMITY			UNCONFORMITY		
	Bluff Range Beds		McNAMARA GROUP	Lawn Hill Formation	Widdallion Sandstone Member
	Bluff Range Beds		McNAMARA GROUP	Musselbrook Formation	
	Carrara Range Formation		UNCONFORMITY		
	Carrara Range Formation	unnamed volcanic member	CARRARA RANGE GROUP	Top Rocky Rhyolite	
	Carrara Range Formation	unnamed volcanic member	CARRARA RANGE GROUP	UNCONFORMITY	
	Carrara Range Formation	unnamed volcanic member	CARRARA RANGE GROUP	Mitchiebo Volcanics	
	Carrara Range Formation		CARRARA RANGE GROUP	Don Creek Sandstone	
UNCONFORMITY			UNCONFORMITY		
Murphy Metamorphics			Murphy Metamorphics		

Table 2. Correlation chart for Proterozoic rocks in the Carrara Range, Westmoreland, and Lawn Hill regions.

Age	Group	Carrara Range region (this Record)	Group	Westmoreland region (Sweet, Mock & Mitchell, in press)	Group	Lawn Hill region (Sweet & Hutton, 1980)
CARPENTARIAN		South Nicholson Group				
CARPENTARIAN		UNCONFORMITY				
CARPENTARIAN		Lawn Hill Formation		Doomadgee Formation		Lawn Hill Formation
CARPENTARIAN				UNCONFORMITY		Termite Range Formation
CARPENTARIAN	McNAMARA GROUP	Musselbrook Formation	FICKLING GROUP	Mount Les Siltstone	McNAMARA GROUP	Riversleigh Siltstone
CARPENTARIAN	McNAMARA GROUP		FICKLING GROUP	Walford Dolomite	McNAMARA GROUP	Shady Bore Quartzite
CARPENTARIAN	McNAMARA GROUP		FICKLING GROUP		McNAMARA GROUP	Lady Loretta Formation
CARPENTARIAN	McNAMARA GROUP		FICKLING GROUP		McNAMARA GROUP	Esperanza Formation
CARPENTARIAN	McNAMARA GROUP		FICKLING GROUP		McNAMARA GROUP	Paradise Creek Formation
CARPENTARIAN	McNAMARA GROUP		FICKLING GROUP		McNAMARA GROUP	Gunpowder Creek Formation
CARPENTARIAN	McNAMARA GROUP		FICKLING GROUP	Fish River Formation	McNAMARA GROUP	Torpedo Creek Quartzite
CARPENTARIAN		UNCONFORMITY				
CARPENTARIAN	CARRARA RANGE GROUP	Top Rocky Rhyolite		Peters Creek Volcanics (upper)		?
CARPENTARIAN	CARRARA RANGE GROUP	UNCONFORMITY				Kamarga Volcanics
CARPENTARIAN	CARRARA RANGE GROUP	Mitchiebo Volcanics		Peters Creek Volcanics (lower)		?
CARPENTARIAN	CARRARA RANGE GROUP	Don Creek Sandstone		Wire Creek Sandstone		
		UNCONFORMITY		UNCONFORMITY		
Early Proterozoic		Murphy Metamorphics		Murphy Metamorphics		

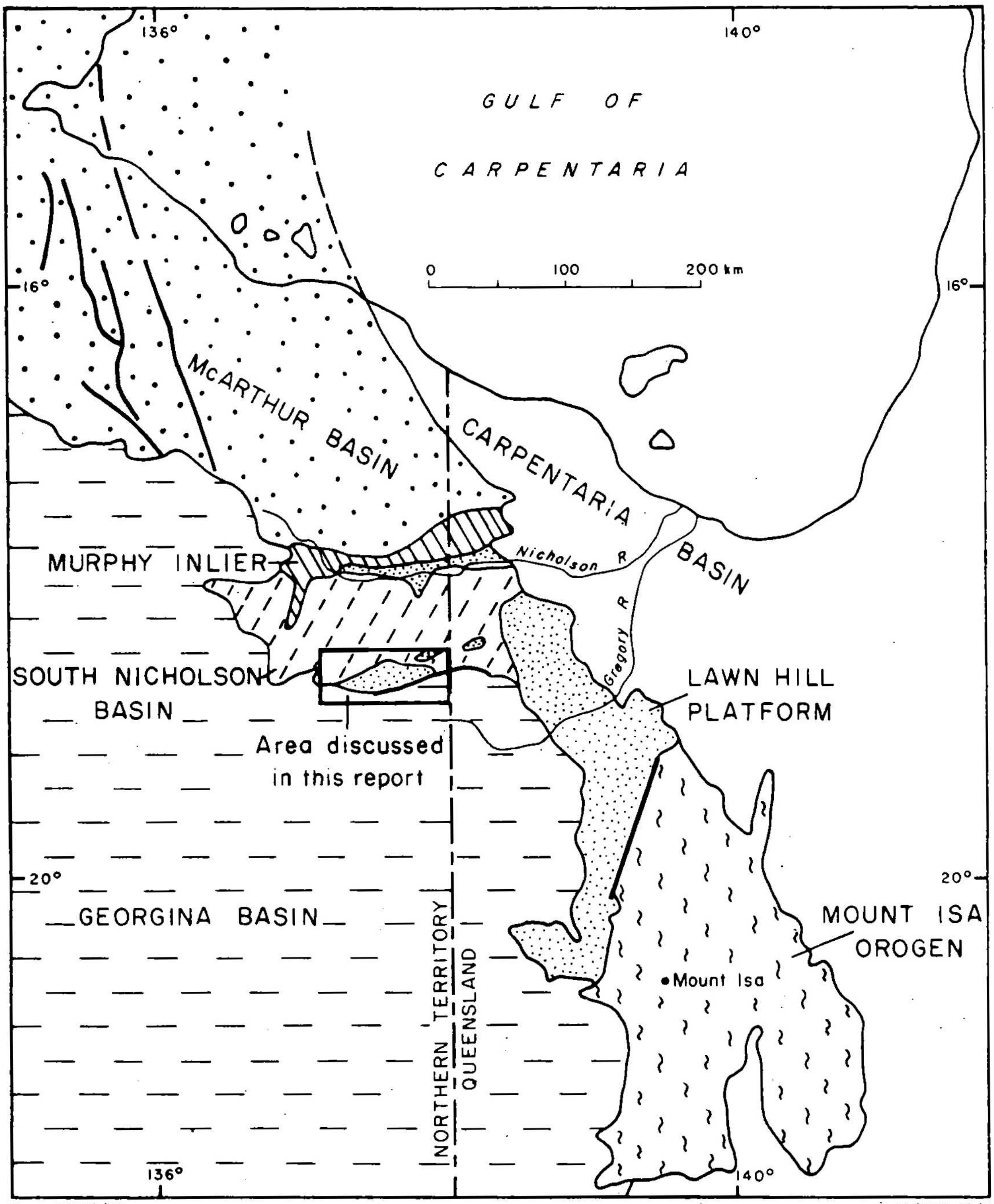

Fig 2: Regional distribution of major tectonic units

(modified from GSA, 1971)

Regional tectonic setting

The rocks of the Carrara Range region belong to five main tectonic entities.

The oldest rocks, the Murphy Metamorphics, are probably part of an extensive belt of rocks of early Proterozoic age which crop out in northern Australia; they have been assigned to the North Australian Orogenic Province (GSA, 1971).

The Carrara Range and McNamara Groups are assigned to the Lawn Hill Platform, a Carpentarian Middle Proterozoic volcanic and sedimentary sequence which extended over a vast area between the McArthur Basin to the north and the Mount Isa Orogenic Province to the southeast (Plumb & Derrick, 1975).

The South Nicholson Basin, a younger Carpentarian basin, overlies the Lawn Hill Platform, and the Early Palaeozoic Georgina Basin flanks it to the south. Scattered outcrops of early Cretaceous rocks, which crop out throughout the region, are part of an extensive but thin cover assigned to the Northern Territory Shelf by Grimes (1974).

Figure 2 shows the main tectonic entities and their classification using the terminology of the GSA (1971).

EARLY PROTEROZOIC(?)

Murphy Metamorphics

Smith & Roberts (1963) mapped poorly outcropping 'schist and sheared shale' south of the Carrara Range as part of the Murphy Metamorphics, the main outcrops of which are 110 km to the northwest, in the Calvert Hills 1:250 000 Sheet area. The rocks are similar to those in Calvert Hills, and although there is no unequivocal evidence that the southern outcrops are Murphy Metamorphics, the name has been retained for convenience. If the rocks are Murphy Metamorphics they must be older than about 1860 m.y., the age of the oldest phases of the Nicholson Granite Complex which intrude the Metamorphics in eastern Calvert Hills (Sweet, Mock & Mitchell, in press).

<u>Stratigraphic relations</u>. The contact between the Murphy Metamorphics and the Don Creek Sandstone is not exposed, but the lack of metamorphism or foliation in the Sandstone and its uniform northerly dip suggest that it overlies the Metamorphics unconformably.

<u>Lithology</u>. Weathered phyllite or fine schist, with a northwest-dipping schistosity and cut by numerous quartz veins, crops out at grid ref. 787272. A quartzite ridge 100 m to the south and several low outcrops of sandstone and probable siltstone up to 5 km to the east-northeast have also been assigned to the Murphy Metamorphics.

The grade of metamorphism of the Murphy Metamorphics is probably lower greenschist facies. A sample of quartzite from the ridge referred to above displays some recrystallisation of quartz into elongate grains displaying a preferred orientation, but most original grain boundaries are still visible. The rock (sample 77410059) was originally a medium-grained, well-sorted feldspathic sandstone.

CARPENTARIAN

LAWN HILL PLATFORM

The sequence now assigned to the Carpentarian was thought by Smith & Roberts (1963) to be of early Proterozoic age. The rocks assigned to the Lawn Hill Platform - the Carrara Range and McNamara Groups - have not been dated directly, but have been correlated with the type-Carpentarian by Plumb & Derrick (1975). The Mitchiebo Volcanics and Top Rocky Rhyolite are correlated with the Peters Creek Volcanics to the north, and to the Kamarga Volcanics (Sweet, in press), Fiery Creek Volcanics and Carters Bore Rhyolite to the east and southeast. The Carters Bore Rhyolite has been dated at 1678 ± 1 m.y. (Page, 1978), which gives some idea of when sedimentation and volcanism began. Because the McNamara Group is equivalent to the Mount Isa Group it is probably about the same age: 1670 m.y. (Page, in press).

CARRARA RANGE GROUP

The Carrara Range Formation was not formally defined by Smith & Roberts (1963), but as mapped by them it consists of a basal sandstone overlain by volcanics, which are in turn overlain by sandstone. Two unconformities have now been recognised within the sequence. The older unconformity, within the volcanics, is believed to be a local one, but the younger one, between the volcanics and the upper sandstones, is regional in extent. The Carrara Range Formation below the regional unconformity has been redefined as the Carrara Range Group and the younger sandstone, comprising less than 25 percent of the total thickness of the former formation, has been included in the McNamara Group.

Don Creek Sandstone

The Don Creek Sandstone was previously mapped by Smith & Roberts (1963) as the basal sandstone of the Carrara Range Formation.

Derivation of name. From Don Creek, which drains the eastern end of the Carrara Range and flows southeastwards into Carrara Creek.

Distribution. Scattered outcrops along the southern margin of the Carrara Range, in CARRARA, total about 10 km^2.

Type section. The base is at grid ref. 833292 and the top is at grid ref. 835301. It consists of 420 m of pebbly quartz sandstone.

Stratigraphic relations and boundary criteria. Neither the lower nor the upper contact is exposed, but stratigraphic relations can be inferred from the outcrop pattern of the sandstone. The oldest beds of the Don Creek Sandstone dip uniformly north at the base of the type section, and therefore would appear to overlie the Murphy Metamorphics. The complete lack of evidence of metamorphism or foliation within the Don Creek Sandstone suggests that the contact is an unconformity.

Amygdaloidal basic volcanics crop out within a few metres of the uppermost Don Creek Sandstone in its type section, and although the contact is sharp it is probably conformable, as sandstone similar to the Don Creek Sandstone is interbedded with the volcanics.

Lithology and thickness. The type section of the Don Creek Sandstone, about 420 m thick, is one of only two unfaulted sections of the formation. The other one, about 4 km west of the type section, is of similar thickness. The Don Creek Sandstone consists of massive, medium to coarse and gritty quartz sandstone with scattered quartz pebbles, and stringers and lenses of conglomerate. Most of the conglomerate fragments are subangular to well rounded quartz pebbles up to above 5 cm across. Scattered clayey and iron oxide-stained grains are present, and some beds are cross-bedded. The sandstone is irregularly silicified, and structures such as cross-bedding are partly obliterated.

Discussion. The Don Creek Sandstone records the beginning of a major depositional phase. Little is known of its provenance, but the uniform lithology, lack of siltstone interbeds, and presence of quartz pebbles suggest that it may be a fluvial deposit, possibly part of a braided stream system which eroded a quartz-rich (acid igneous or metamorphic) terrain.

The formation is similar to, and is correlated with, the Wire Creek Sandstone and Westmoreland Conglomerate to the north (Sweet, Mock & Mitchell, in press). Both of those formations contain cobbles and boulders which suggest local derivation, probably from the Murphy Tectonic Ridge, but the Don Creek Sandstone is finer-grained, and is probably a more distal deposit. There is no evidence that it was derived from the Murphy Tectonic Ridge.

Mitchiebo Volcanics

The Mitchiebo Volcanics include most of the basic to intermediate volcanics of the former Carrara Range Formation, and the sediments interbedded with them. The remainder of the volcanics, which overlie the basic ones, have been assigned to the Top Rocky Rhyolite.

Derivation of name. From the Mitchiebo 1:100 000 Sheet area, which contains the westernmost outcrops of the Volcanics.

Distribution. The main outcrops, of about 50 km^2, form an arcuate belt extending from 5 km southwest of, to about 15 km east of, Mount Drummond (at grid ref. 744304).

Type section. About 900 m of basic to intermediate volcanics, sandstone, and siltstone. The base of the type section, at grid ref. 833292, is the same locality as the top of the type section of the Don Creek Sandstone. The section extends northeastwards for 2 km to grid ref. 853313.

Stratigraphic relations and boundary criteria. The lower contact, with the Don Creek Sandstone, is sharp but conformable.

The upper boundary of the Mitchiebo Volcanics is an unconformity surface. In the east the Volcanics are concordant with the overlying Top Rocky Rhyolite, but the Volcanics have clearly been eroded, and the surface is a disconformity. The sandstone at the top of the Mitchiebo Volcanics, Ꝑcm$_s$, has been eroded into a series of narrow ridges and valleys whose direction may be largely joint and fault controlled. These topographic irregularities were buried by lava or tuff, and the whole sequence tilted to about 35^{o}. The contact is now sharply defined by differential erosion.

In most outcrops northwest of Mount Drummond the Top Rocky Rhyolite was eroded before deposition of the McNamara Group, which thus overlies the Mitchiebo Volcanics with angular unconformity.

Lithology and thickness. Vesicular and amygdaloidal basalt or trachyte predominate in the lower part of the formation in the type section (Ꝑcm$_b$), and quartzose and feldspathic sandstone predominates in the upper part (Ꝑcm$_s$). The lavas are generally poorly exposed, and outcrops in the vicinity of the type section are restricted to creek beds incised into a mantle of Cainozoic gravel and conglomerate (Czg) 2-3 metres thick. Around Mount Drummond the lavas are more massive, and less vesicular, than elsewhere and they are cut by several northwest-trending reddish-brown dykes of more acid composition. Highly weathered amygdaloidal volcanics are poorly exposed in several fault-bounded outcrops 5-15 km northwest of Mount Drummond. Quartz-rich and lithic (probably volcanigenic) sandstone and siltstone are interbedded with the lavas.

The sandstone, Ꝑcm$_s$, which has been delineated on the map (Plate 1), is massive to blocky, well-sorted, medium to coarse quartzose and feldspathic sandstone; it is cross-bedded on a large scale in some outcrops. At least two lenses of sandstone, separated by a thin basalt flow, are present in the type section.

Thickness. The type section appears to be unfaulted and is about 900 m thick. The lower 700 m is predominantly basalt or trachyte and the upper 200 m mainly sandstone. Southwest of Mount Drummond between 500 and 800 m of sandstone is preserved beneath the Top Rocky Rhyolite, indicating that less sandstone was eroded from this area than from the east. Assuming that the volcanic component has not decreased in thickness the total thickness in the west is therefore about 1500 m.

Petrography. Descriptions of five thin sections are presented in Table 4. Samples 77410035, 0056, and 0057 are characteristic of the lavas in the Mitchiebo Volcanics. They consist of strongly altered feldspar laths of unknown composition set in an iron oxide and secondary quartz-rich groundmass. Ferromagnesian minerals are absent and there is no evidence to suggest that they were ever present in significant amounts. Sample 77410019 is redder and contains red feldspar phenocrysts, some of which display Carlsbad twinning; it is almost certainly a trachyte.

Sample 77410020 is the only sandstone from the Mitchiebo Volcanics to be examined in thin section. It is a medium to coarse lithic sandstone with a heterogeneous assemblage of grains. Recognisable basalt or trachyte grains are absent, but the very ferruginous grains may be derived from highly weathered volcanics.

Discussion. The lavas in the Mitchiebo Volcanics are invariably strongly altered and their primary composition is therefore unknown. However, the probable lack of ferromagnesian minerals and the occurrence of Carlsbad twinning suggest that some may be trachytes. The volcanics are correlated with the Peters Creek Volcanics to the north (Sweet & Mond, 1978) which are potash-rich, a feature which seems to be a regional characteristic. The rocks have not been analysed because of the alteration and the presence of secondary minerals in amygdales. Parts of the Kamarga Volcanics (Sweet, in press) and Fiery Creek Volcanics (Cavaney, 1975) to the east resemble the Mitchiebo Volcanics, and may be correlatives.

The environment into which the volcanics were extruded is not known, but the presence of cross-bedded sandstone and siltstone suggests that it may have been subaqueous.

Table 3: Summary of Proterozoic stratigraphy

Group name	Formation and member names and symbols	Thickness (metres)	Lithology	Stratigraphic relations and comments
SOUTH NICHOLSON GROUP	Mullera Formation (Ᵽsm)	400+	Siltstone, shale, sandstone and ironstone	Unconformably overlain by Cambrian rocks outside of map area; youngest Proterozoic unit; conformable on Ᵽsc
	Unnamed member (Ᵽsm$_s$)	150+	Feldspathic sandstone	May be equivalent to the Mittiebah Sandstone west of map area
	Middle Creek Sandstone Member (Ᵽsm$_m$)	20	Fine to medium sandstone with siltstone and shale interbeds	Two main lenses or tongues
	Constance Sandstone (Ᵽsc)	300-400	Medium to coarse quartz sandstone; conglomeratic lenses	Unconformable on McNamara Group
	Unnamed member (Ᵽsc$_c$)	0-8	Pebble to boulder conglomerate; well-rounded clasts of quartz, quartzite and chert may be equivalent to the Maloney Formation, north of the Carrara Range area	Lenses at base of Ᵽsc
McNAMARA? GROUP	Lawn Hill Formation (Ᵽmh)	1800+		No undivided Lawn Hill Formation on map - three unnamed members described below
	Widdallion Sandstone Member (Ᵽmh$_w$)	300	Micaceous, medium quartz sandstone	Overlain disconformably by Ᵽsc; conformable on Ᵽmh$_b$
	Unnamed member (Ᵽmh$_b$)	1000-1500	Siltstone and shale, minor dolomite and dolomitic siltstone	Conformable on Ᵽmh$_a$; crops out poorly
	Unnamed member (Ᵽmh$_a$)	400-650	Micaceous siltstone and shale interbedded with fine to medium sandstone; thin grit and pebble bands	Conformable on Ᵽmb$_s$

Table 3: Summary of Proterozoic stratigraphy (contd)

Group name	Formation and member names and symbols		Thickness (metres)	Lithology	Stratigraphic relations and comments
McNAMARA GROUP	Musselbrook Formation (Ᵽmb)		1350+		No undivided Musselbrook Formation on map - four unnamed members described below
	four unnamed members	Ᵽmb$_{s}$	50	Fine to medium orthoquartzite	May thicken eastwards; may be present in eastern and northeastern outcrops but not recognised; conformable on Ᵽmb$_{3}$
		Ᵽmb$_{3}$	400	Siltstone, stromatolitic chert, sandstone	Conformable on Ᵽmb$_{2}$; most outcrops are highly altered, and may be dolomitic at depth
		Ᵽmb$_{2}$	280+	Siltstone, claystone, stromatolitic chert and sandstone	Conformable on Ᵽmb$_{1}$; proportion of chert and sandstone higher than in Ᵽmb$_{3}$; outcrops are more altered than Ᵽmb$_{3}$
		Ᵽmb$_{1}$	630	Orthoquartzite; minor siltstone, stromatolitic chert, conglomerate and dolomite	Unconformable on Carrara Range Group; further subdivided into 5 units - Ᵽmb$_{1a}$ to Ᵽmb$_{1f}$
CARRARA RANGE GROUP	Top Rocky Rhyolite (Ᵽct)		100-400	Feldspar porphyry, probably rhyolite	Very altered, but probably rhyolitic; bound at top and base by unconformities; basal one believed to be a local unconformity

Table 3: Summary of Proterozoic stratigraphy (contd)

Group name	Formation and member names and symbols	Thickness (metres)	Lithology	Stratigraphic relations and comments
CARRARA RANGE GROUP	Mitchiebo Volcanics (Ᵽcm)	900-1500		No undivided Mitchiebo Volcanics
	Ᵽcm$_s$	200-800	Medium to coarse, quartzose and feldspathic sandstone; minor basalt/trachyte interbeds	Several interbeds within Ᵽcm$_b$ and a major band at top of formation; it is therefore not a single member
	Ᵽcm$_b$	700	Vesicular and amygdaloidal basalt or trachyte	Mainly in the lower part of Ᵽcm; contains several sandstone and siltstone interbeds; very altered, probably trachytic but may include basalt; contact with Ᵽcd is sharp but probably conformable
	Don Creek Sandstone (Ᵽcd)	420	Medium, coarse, and gritty quartz sandstone; thin conglomeratic lenses	Inferred to lie unconformably on Murphy Metamorphics; most pebbles are of quartz
	Murphy Metamorphics (Ᵽlm)	-	Phyllite or fine schist, quartzite, siltstone	Low grade metasediments tentatively assigned to the Murphy Metamorphics; they crop out poorly; probably of early Proterozoic age

Table 4: Thin section descriptions - Mitchiebo Volcanics.

BMR and field numbers	Location (grid ref.)	Rock name	Description
77410019 C6/22/8	737 297	TRACHYTE(?)	Completely altered brown rock. Feldspar laths with diffuse boundaries, some laths show Carlsbad twinning; set in indeterminate iron oxide-laden groundmass, possibly altered glass. Numerous thin quartz veins.
77410020	597 375	LITHIC (VOLCANIGENIC?) SANDSTONE	Heterogeneous mixture of fine to medium rounded and angular quartz grains; opaque, iron-oxide rich tabular grains; chert, clay, acid volcanic matrix (rare), altered feldspar. Cemented by chalcedony and iron oxide.
77410035	746 325	AMYGDALOIDAL BASALT OR TRACHYTE	Purplish-brown altered rock; randomly oriented laths of feldspar, 0.05-0.5 mm, set in iron-oxide rich groundmass. Vesicles 5-10 mm across lined or filled with chlorite and zeolite. Carlsbad twinning in one feldspar lath.
77410056	837 316	AMYGDALOIDAL BASALT OR TRACHYTE	Brown altered volcanic, sparsely vesicular. Texture similar to 0035; some larger iron-oxide grains in groundmass could be replacing a primary iron-rich mineral; 10+ percent of interstitial secondary quartz.
77410057	835 302	AMYGDALOIDAL BASALT OR TRACHYTE	Similar to 0035, 0057, but finer grained, groundmass almost completely opaque, and much more vesicular - 30-40 percent vesicles and amygdales. Vesicles lined with clay or chlorite, chalcedony, coarse-grained quartz, minor calcite.

Top Rocky Rhyolite

The Top Rocky Rhyolite is the uppermost formation of the Carrara Range Group, and includes all the volcanics above the disconformity recognised in the former Carrara Range Formation.

Derivation of name. From Top Rocky Waterhole, a permanent waterhole in Musselbrook Creek at grid ref. 852387.

Distribution. The Top Rocky Rhyolite crops out as a belt up to about 1 km wide extending from 6 km southwest of Mount Drummond to about 20 km east of it; total outcrop area is about 20 km^2.

Type section. The base is at grid ref. 750324 and the top is 500 m north at 750329. The section comprises about 250 m of massive feldspar porphyry.

Stratigraphic relations and boundary criteria. The Top Rocky Rhyolite is bounded at the top and base by unconformities. It overlies sandstones in the Mitchiebo Volcanics disconformably in all outcrops except one 4 km northwest of Mount Drummond, where there appears to be angular discordance. Relief on the disconformity surface is quite marked (Fig. 3), and must have been of the order of 100 m. The upper contact here is also a disconformity or a slight angular unconformity which is also apparent on a regional scale.

The boundaries are everywhere sharp and easily mapped because of the distinct photo-patterns of the adjacent units and the effects of differential weathering.

Lithology. The Top Rocky Rhyolite is almost solely light to dark reddish-brown, massive, structureless feldspar porphyry. Scattered dark brown feldspar phenocrysts up to 5 mm across are set in a fine-grained groundmass; quartz phenocrysts are rare. In the type section a prominent joint set dipping 30° north is probably a flow parting. At grid ref. 738315 steep, variably dipping banding may be primary flow-banding, and a few kilometres southwest, at grid ref. 709291, prominent spherical structures in the volcanics give the rock a pisolitic appearance; the structures are probably spherulites.

The Rhyolite seems to be a single massive body - either a flow or an ignimbrite sheet, with very little variation laterally or vertically except in an outcrop 1 km northwest of Mount Drummond, where thin bands of basalt or trachyte are interlayered with rhyolite. The interbeds are identical to volcanics in the Mitchiebo Volcanics and suggest that both units may belong to one episode of volcanism despite their separation by a disconformity.

The only obviously fragmental rocks in the Top Rocky Rhyolite are at the base, adjacent to the disconformity surface shown in Figure 3. The contact with the Mitchiebo Volcanics is marked by a 1 m-thick layer of conglomerate or breccia containing angular clasts of silicified sandstone 10-20 cm across set in a poorly sorted clayey and sandy matrix.

Thickness. Because the Top Rocky Rhyolite is massive its dip is difficult to determine, and its thickness has therefore been computed using the dips from the underlying and overlying units. The thickness thus calculated varies from over 400 m in the east, to 250 m at the type section, to about 100 m in the southwest. It is not possible to say whether this is a primary decrease in thickness, or a secondary one due to subsequent erosion.

Petrography. Descriptions of five thin sections of Top Rocky Rhyolite are presented in Table 5. The rocks are characterised by the presence of potash(?) feldspar phenocrysts and spherulitic or perlitic textures, the lack of feldspar laths and vesicles, and pervasive iron-staining. Sample 77410061 differs from the other samples in that it is vesicular.

Discussion. The original composition of the rocks is not definitely known, and the name 'rhyolite' is applied mainly on the basis of the similarity of the unit to rhyolites in the Peters Creek Volcanics in HEDLEYS CREEK.

The Peters Creek Volcanics include rocks ranging in composition from basic to acid (Sweet and others, in press) and the Mitchiebo Volcanics and Top Rocky Rhyolite are believed to represent the same episode and compositional range. The disconformity between them is thought to be a local one.

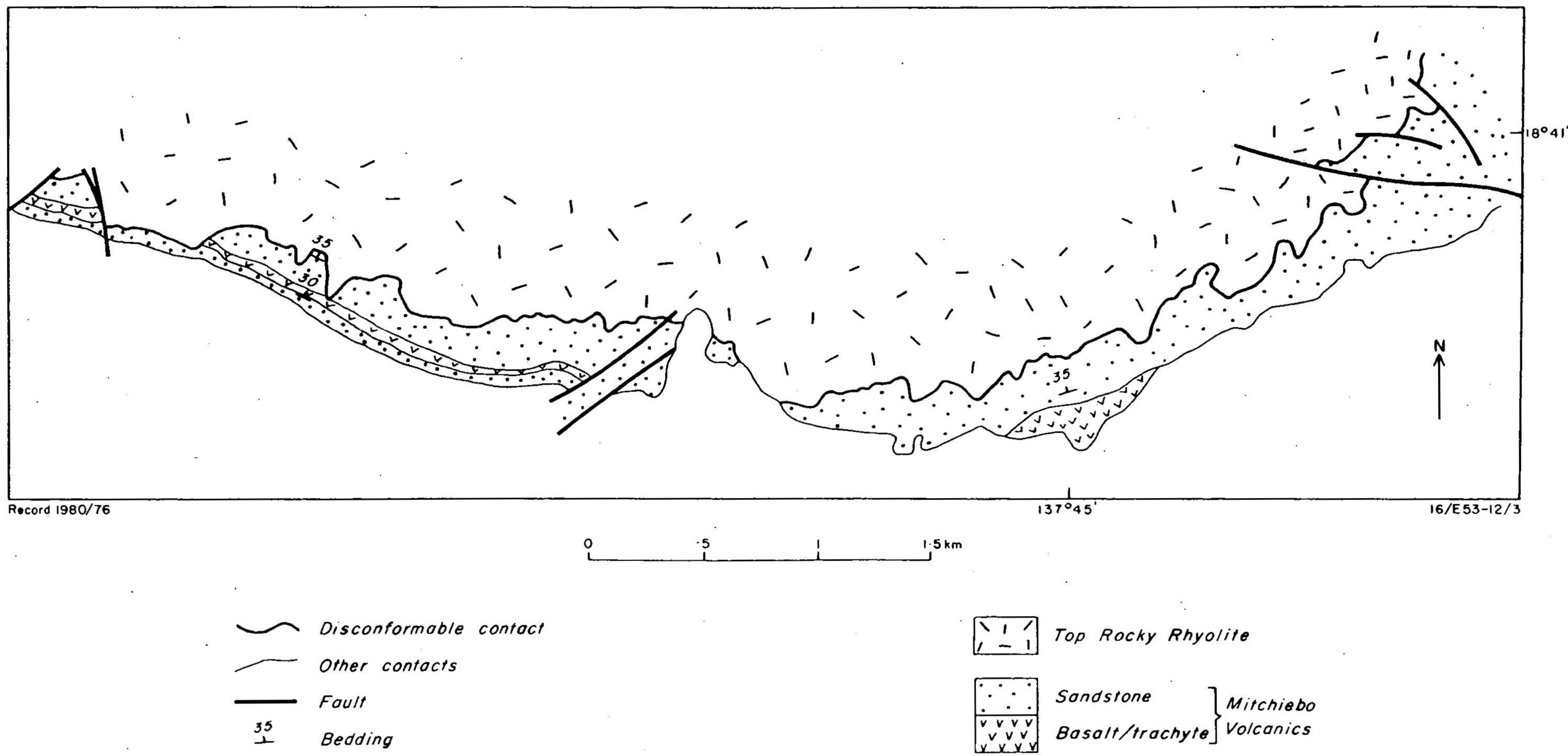

Fig 3: Disconformable contact between the Mitchiebo Volcanics and the Top Rocky Rhyolite

Table 5. Thin section descriptions - Top Rocky Rhyolite.

BMR and field numbers	Location (grid ref.)	Rock name	Description
77410017 C6/22/12	738 308	RHYOLITE(?)	Feldspar - scattered euhedral phenocrysts, some show Carlsbad twinning; mafic phenocrysts - rare, altered to iron oxide and ?chlorite; groundmass - altered, ferruginised mass of reddish-brown circular patches (?spherulites) with areas between filled by quartz and small, iron-stained, euhedral feldspar crystals; ?spherulites are strongly iron-stained, quartz-rich areas less so.
77410021 C7/22/1	717 254	RHYOLITE(?)	Similar to 0017; some hint of radial texture within spherulites.
77410037 C6/24/3	710 290	RHYOLITE(?)	Large spherulites - 0.5 to 2 cm across consist of fibrous, radiating, iron-stained, indeterminate minerals with scattered coarse quartz grains; interstitial material is a lightly iron-stained granular mosaic of quartz and feldspar, and voids are filled by chalcedony and coarse quartz.
77410058 C6/18/3A	865 309	RHYOLITE(?)	Feldspar - scattered phenocrysts; set in dark brown matrix full of ?perlitic cracks which are outlined by heavier iron-staining; matrix lacks spherulites and is a fine-grained, indeterminate mosaic.
77410061 C5/78/8	720 335	TRACHYTE(?)	Scattered feldspar phenocrysts in structureless groundmass - no laths, no cracks or spherulites; scattered small vesicles (1-2 mm) filled with chlorite and quartz.

It is not known whether the Top Rocky Rhyolite is ignimbrite or lava. Probable flow-banding near Mount Drummond suggests lava, but evidence of either alternative is lacking in other outcrops.

The strongly ferruginous nature of the Rhyolite, and the lack of interbedded sediments, suggest subaerial extrusion.

McNAMARA GROUP

The McNamara Group includes all of the Bluff Range Beds as mapped by Smith & Roberts (1963), and the top 25 percent of their Carrara Range Formation. The term Bluff Range Beds has been abandoned to avoid the confusion which could arise if it were to be used for a constituent formation in the McNamara Group.

The McNamara Group has been divided into the Musselbrook Formation - a sandstone/chert (carbonate at depth?)/siltstone unit; and the Lawn Hill Formation - a siltstone/sandstone unit first recognised in LAWN HILL, 80 km east of CARRARA.

Musselbrook Formation

The Musselbrook Formation is a sandstone/chert/siltstone unit which is probably dolomitic at depth. It has been subdivided into four informal members on the basis of photogeology and dominant lithology - they are Emb_1, Emb_2, Emb_3, and Emb_s. Emb_1, which is predominantly sandstone, was previously mapped as part of Smith & Roberts's (1963) Carrara Range Formation. It has been subdivided into six units (Emb_{1a} to Emb_{1f}).

<u>Derivation of name</u>. From Musselbrook Creek, which drains much of the area underlain by the formation north of the Carrara Range.

<u>Distribution</u>. The Musselbrook Formation is the most widely distributed Proterozoic unit in the Carrara Range region. It forms low strike ridges and valleys extending from the eastern end of the Carrara Range westwards to No Mans Creek; the total outcrop area is about 500 km^2.

<u>Type section</u>. The type section is composite, comprising two components. The lower component, the holostratotype (ISSC, 1976) extends from grid ref. 754 331 (3 km north-northeast of Mount Drummond) northwards to grid ref. 753 342. The upper component, the parastratotype, extends from grid ref. 603 401 (17 km northwest of Mount Drummond) northwards to grid ref. 603 422. The 2-component type section has been used because complete, unfaulted sections of the formation are not present in any one locality. The parastratotype is cut by one fault, but its displacement is minor - probably a few tens of metres.

<u>Stratigraphic relations and boundary criteria</u>. The Musselbrook Formation unconformably overlies the Carrara Range Group. In the east it overlies the Top Rocky Rhyolite disconformably, in central outcrops it overlies the Rhyolite with angular unconformity, and in the west it overlies the Mitchiebo Volcanics also with angular unconformity. The base of the Musselbrook Formation is conglomeratic in many areas.

The Musselbrook Formation is overlain conformably by the Lawn Hill Formation. The boundary between them is somewhat arbitrary, and has been placed at the top of a prominent orthoquartzite bed (Ꝑmb$_s$) above which siltstone predominates and chert is absent. Siltstone occurs below the orthoquartzite but it is interbedded with chert and sandstone.

<u>Lithology and thickness</u>. The Musselbrook Formation has been divided into four informal members mainly on the basis of photo-interpretation. Ꝑmb$_1$ and Ꝑmb$_s$ are predominantly sandstone, but Ꝑmb$_2$ and Ꝑmb$_3$ contain a variety of rock types; a combination of faulting, poor outcrop and possible facies changes has rendered their identification somewhat difficult, particularly east of the holostratotype.

<u>Ꝑmb</u>$_1$

Figure 4 is a composite stratigraphic column for the Musselbrook Formation - its total thickness is about 1350 m. The basal conglomerate, <u>Ꝑmb</u>$_{1a}$, consists of a series of lenses of which only the thicker ones are shown on the map. It reaches a maximum thickness of 65 m at a point 4 km northwest of Mount Drummond. Well rounded pebbles and cobbles of quartzite and quartz sandstone are the most common clasts in the conglomerate, but

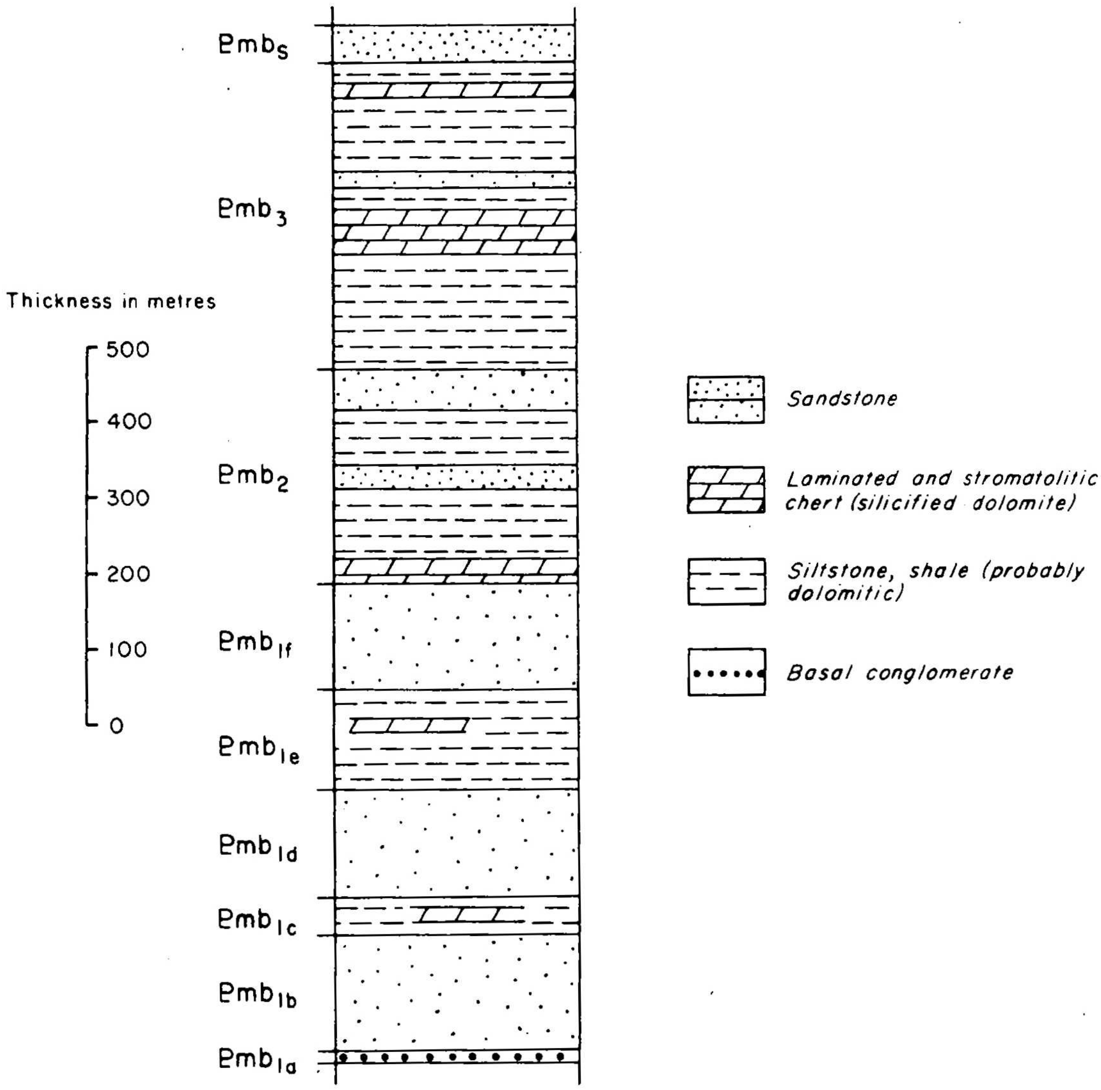

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Fig 4: Composite section of Musselbrook Formation—total thickness about 1350m

1.5 km north of Mount Drummond there are boulders up to 40 cm across, of both quartzite and acid volcanics (identical to Top Rocky Rhyolite), in the basal few metres. This conglomerate, which is friable and easily weathered, is overlain by more resistant, better sorted conglomerate and conglomeratic sandstone in which there are only quartzite clasts 5-10 cm across. The conglomerate is in some localities cross-bedded on a large scale, and some beds are crudely graded.

In the westernmost outcrops of Musselbrook Formation, for example at grid ref. 590 390, a basal sandy arkose is overlain by conglomerate in which over 90 percent of the clasts are subrounded quartz pebbles up to about 5 cm across; quartzite clasts are well rounded and generally 10-30 cm across.

Emb_{1a} grades upwards into Emb_{1b}, the oldest of three sandstone units which are separated by siltstone, dolomite, and chert beds. The three sandstones, Emb_{1b}, Emb_{1d}, and Emb_{1f}, are similar in most respects and are distinguishable only when the complete sequence is present. They are flaggy to massive, medium-grained, well sorted orthoquartzites. Many are cross-bedded on a medium scale (in units 10-30 cm thick), ripple marks and mud flakes are common, particularly in Emb_{1d} and Emb_{1f}, and mudcracks were observed in one outcrop.

Emb_{1c} is a poorly outcropping subunit 50-75 m thick. It is unexposed in the holostratotype but friable clayey sandstone, siltstone, and wavily laminated and domal stromatolitic dolomite crop out 2-3 km to the west. The stromatolite domes are pseudocolumnar types up to 10 cm across and 20 cm high. This was the only unaltered dolomite observed in the Proterozoic outcrops by us, although Dechow (1967) reported several other outcrops; all other rocks which were originally carbonates are severely altered and leached or replaced by chert.

Emb_{1e} is also a poorly outcropping subunit. Only one outcrop has been observed - stromatolitic chert at the base of Emb_{1e}, at grid ref. 650 401. The remainder of the subunit is believed to be highly weathered siltstone or shale. Its thickness decreases from 135 m in the holostratotype to 85 m in western outcrops.

<u>Undivided Ᵽmb$_1$</u>

Both the easternmost and westernmost outcrops of Ᵽmb$_1$ are undivided or only partly subdivided. Ᵽmb$_{1c}$ and Ᵽmb$_{1e}$ are probably present in all the western outcrops but their boundaries cannot be readily photo-interpreted. In the east softer, probably silty interbeds are visible on airphotos but they cannot be definitely related to the known subunits.

<u>Ᵽmb$_2$</u>

Ᵽmb$_2$ consists of limonitic and leached siltstone and claystone, stromatolitic chert, and sandstone. All outcrops except the sandstones are severely altered, and although their original composition is not known, they were probably dolomitic. The leached and limonitic rocks are probably dolomitic at depth - below the zone of weathering - but the stromatolitic cherts, although originally dolomites, may have been silicified during diagenesis and may be chert even at depth.

A faulted section of Ᵽmb$_2$ occurs in the area north of the holostratotype of the Musselbrook Formation. It includes finely laminated ferruginous silty rocks, several massive orthoquartzites similar to those in Ᵽmb$_1$, and two steeply-dipping massive goethite layers which appear to be concordant with bedding. The goethite could be related to faulting or to weathering of sulphide-rich rocks. Possible malachite staining was noted 10 km to the west, but no signs of primary sulphides were recorded.

Around the parastratotype faulting is insignificant and the outcrop is slightly better than elsewhere. White laminated chert interbedded with sandstone near the base of Ᵽmb$_2$ is overlain by fine-grained recessively weathering rocks. At the top of Ᵽmb$_2$ is a flaggy to blocky, thin to medium bedded, medium to coarse sandstone with gritty bands overlain by a conglomerate bed containing tabular angular clasts, 10-20 cm across, of white chert similar to that cropping out lower in the member.

The highly weathered, poorly outcropping rocks between Wild Cow and Rocky Creeks, in the southwest, have been tentatively mapped as Ᵽmb$_2$. Several relatively unaltered sandstone beds are cross-bedded, and contain mudflakes and mudcracks.

Ɛmb$_2$ is about 280 m thick in the parastratotype, including 125 m of sandstone at the top. To the east, just north of the holostratotype at grid reference 777 356, sandstone tentatively mapped as the top beds of Ɛmb$_2$ is 280 m thick, and the recessive beds below it, although faulted, are probably of similar thickness. The member therefore seems to thicken eastwards.

Ɛmb$_3$

Ɛmb$_3$ crops out even less than Ɛmb$_2$. It appears to consist of fine-grained silty, possibly dolomitic rocks, with a resistant band of stromatolitic chert in the upper part. The parastratotype is about 400 m thick, including a 100 m band of chert. The best siltstone outcrops are at grid ref. 778 358, where flaggy and fissile white, leached siltstone with some micaceous and ferruginous laminae crops out.

The chert bed in the parastratotype contains columnar stromatolites 2-3 cm across and some larger columns - up to 10 cm across. The chert is interbedded with thin claystone and sandstone bands.

Ɛmb$_s$ is a massive sandstone unit, the top of which has been defined as the top of the Musselbrook Formation. It consists of fine to medium-grained orthoquartzite which varies from structureless to strongly cross-bedded, in units up to 1 m thick. The unit is about 50 m thick in the west, and may thicken eastwards.

Discussion

The outstanding characteristic of the Musselbrook Formation is its highly altered nature. Virtually all outcrops of Ɛmb$_2$ and Ɛmb$_3$ are silicified, ferruginised, or altered to a porous silty or clayey rock, and the dominant land forms associated with these rocks are low mesas resulting from a resistant duricrust layer. The weathering and formation of duricrust are believed to have been caused by early to mid-Tertiary weathering events which resulted in laterite formation, some of which is still preserved. The Musselbrook Formation is believed to be dolomitic at depth, but leached entirely of carbonate at the surface.

The association of orthoquartzite and carbonate rocks is a common one (Pettijohn, 1957), although the Musselbrook Formation probably has more silt or clay in it than Pettijohn believed to be the norm. The lower part of the McNamara Group in the Lawn Hill region (below the Riversleigh Siltstone) is lithologically similar to that in the Carrara Range region (Sweet & Hutton, 1980), although the ratio of carbonate to sandstone is probably higher. The depositional environments in the Carrara Range and Lawn Hill regions are believed to be similar - shallow marine and shoreline environments adjacent to a stable landmass, in an arid region. These conditions led to the deposition of dolomites, many of them stromatolitic. Evidence of evaporite minerals has been preserved at Lawn Hill, but at Carrara weathering has destroyed most fine structures, and no such remnants have been found.

Lawn Hill Formation

The rocks now mapped as Lawn Hill Formation in the Carrara Range region were previously mapped as the upper part of the Bluff Range Beds by Smith & Roberts (1963). It became obvious during examination of outcrops in LAWN HILL, BOWTHORN, and CARRARA that the Lawn Hill Formation extends throughout the whole region, and that the term Bluff Range Beds is therefore redundant. The main features identifying Lawn Hill Formation in CARRARA are: (a) the presence of a thick sequence of fine siltstone and shale overlain by a friable cross-bedded micaceous sandstone; (b) the structural continuity of the outcrops with those in BOWTHORN; and (c) the occurrence of siltstone concretions similar to those in the basal part of the formation in LAWN HILL.

Distribution. The Lawn Hill Formation crops out in four main 'belts' in the Carrara Range region (Fig. 5): the northern belt, between No Mans Creek and Springvale; the central belt, south of Springvale; the northeastern belt; and the eastern belt - south of Little Range. The total area of outcrop, or shallow subcrop beneath Cainozoic deposits, is some 300 km^2.

Type section. In LAWN HILL, 38 km south of Lawn Hill homestead. Six members, including two named sandstone members, are recognisable in the type section, but only the uppermost one, the Widdallion Sandstone Member, is recognised in the Carrara Range region. Here, the sequence below the Sandstone Member is divided into two informal members, Emh_a and Emh_b, whose relation to those in LAWN HILL is not known.

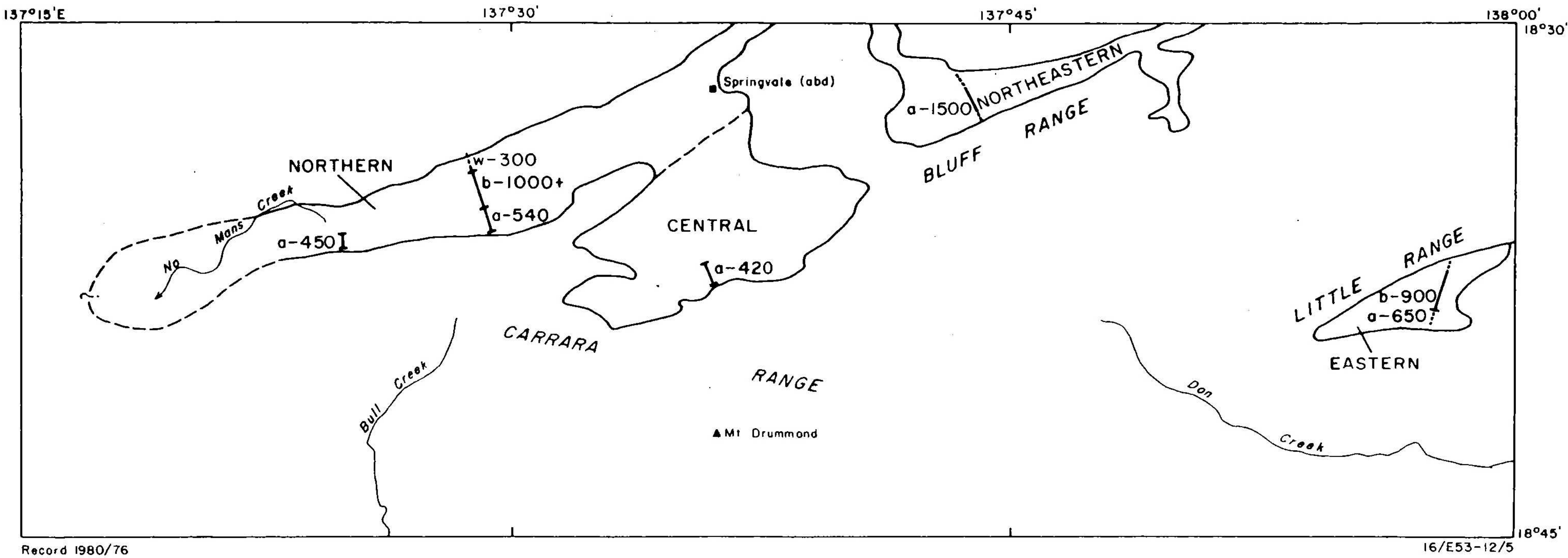

Fig 5: The four main outcrop belts of the Lawn Hill Formation in the Carrara Range region, showing thicknesses, in metres, of its members (a=Pmh_a, b=Pmh_b, w=Pmh_w). Dotted lines indicate that the sections are incomplete.

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Stratigraphic relations and boundary criteria. The Lawn Hill Formation lies conformably on the Musselbrook Formation in the northern and central belts. The positioning of the boundary between the two formations is somewhat arbitrary as the proportion of siltstone increases gradually upwards in the sequence and sandstone and carbonate decrease. The lower boundary has not been mapped in the northeastern and eastern belts - the rocks have all been mapped as Lawn Hill Formation but it is possible that Musselbrook Formation is present.

The upper contact is, in all localities, an unconformity - in the northern belt the Constance Sandstone lies disconformably on the Widdallion Sandstone Member, but in other belts the Widdallion is absent, and the Constance Sandstone overlies, with marked angular unconformity, Ɇmh$_a$ and Ɇmh$_b$. In the eastern belt Cambrian rocks also overlie both members with angular unconformity.

Lithology and thickness. The Lawn Hill Formation consists of an interbedded sandstone/siltstone sequence (Ɇmh$_a$) overlain by a shale/siltstone sequence (Ɇmh$_b$) which is, in turn, overlain by the Widdallion Sandstone Member (Ɇmh$_w$). Isolated outcrops of khaki-green shale and siltstone in the Bluff Range, tentatively assigned to Ɇmh$_a$, contain (e.g. at grid ref. 028 465) siltstone concretions similar to those in the basal member (Ɇmh$_1$) of the Lawn Hill Formation in LAWN HILL. Since they are separated from other Ɇmh$_a$ outcrops by a fault, their relative stratigraphic position is not known.

Ɇmh$_a$

Sandstone and siltstone dominate this unit. The sandstones are flaggy to blocky, fine to medium, well-sorted and quartz-rich, with micaceous partings, and the lowermost sandstone is generally manganese-stained on joint surfaces. Thin grit and pebble bands are present, particularly in the eastern belt where thin conglomerate layers contain chert pebbles up to 3 cm across in a fine to medium sandstone matrix. Sedimentary structures in the sandstones include cross-bedding, ripple marks, mudflakes, and rare mudcracks. The interbedded siltstones and shales, which comprise perhaps 60-70% of the total thickness of Ɇmh$_a$, are flaggy to fissile, laminated and micaceous. They contain thin interbeds of fine-grained, ripple-laminated sandstones.

Complete sequences of Emh_a, present in the northern and central outcrop belts, are 400-500 m thick. The northeastern belt appears to be about 1500 m thick, but this may be an overestimate because of the possibility of strike faulting and the presence of unidentified Musselbrook Formation. About 650 m of Emh_a is present in the eastern belt, and as its base is not exposed, the member may thicken eastwards.

Emh_b is poorly exposed except in the eastern belt, where over 900 m of leached pale green shale and fissile siltstone crops out. Two interbeds of laminated and intraclastic dolomite and dolomitic siltstone are present towards the top of the exposed sequence. Although Emh_b is poorly exposed in the northern belt it appears that a complete, unfaulted sequence is probably present beneath a thin cover of Cainozoic gravels. Between 1000 and 1500 m of siltstone and shale is present, depending on which dip values are used in the calculations.

The Widdallion Sandstone Member (Emh_w) crops out only in the northern outcrop belt. It is difficult to distinguish from the Constance Sandstone on airphotos, but it is redder weathering, more friable, and micaceous. The boundary with the Constance Sandstone is placed at the base of white indurated orthoquartzites which overlie the friable micaceous ones.

A sequence of about 300 m preserved north of grid ref. 630 457 consists of blocky to massive, thick-bedded, medium-grained quartz sandstone rich in muscovite flakes, clayey matrix, and iron oxide-stained quartz grains. The sandstones are cross-bedded on a large scale, and primary current lineations and slumped foreset laminae suggest a high energy environment and rapid deposition.

Discussion

The Lawn Hill Formation in the Carrara Range region is very similar to that in BOWTHORN and LAWN HILL, but lacks the tuffaceous rocks and carbonaceous shale present in the latter areas. The sandstones at the base and top of the formation indicate shallow-water, relatively high-energy deposition, with some evidence for erosion of rocks similar to the Musselbrook Formation (chert conglomerates) and evidence of desiccation (mudflakes and mudcracks). The Widdallion Sandstone Member could be a fluvial deposit, but the remainder of the Formation is probably marine, including tidal-flat environments at the base (Emh_a). The siltstones and shales were deposited in very low-energy conditions but there is no evidence that euxinic conditions developed, as they did farther east.

The most complete section, of 1750 m, in the northern belt, is not significantly different from that in LAWN HILL, although Emh_a does appear to thicken eastwards.

SOUTH NICHOLSON GROUP

The South Nicholson Group crops out extensively in the Carrara Range region. Smith & Roberts (1963) recognised four formations in the Group, two of which - the Constance Sandstone and the Mullera Formation - crop out in the region. The Maloney Formation, a basal conglomeratic facies which crops out north of the Carrara Range region, may be equivalent to thin conglomerates (Esc_c) at the base of the Constance Sandstone within the region.

Constance Sandstone

The Constance Sandstone overlies the Lawn Hill Formation disconformably in the west and with angular unconformity elsewhere. Its distribution is somewhat less extensive than that indicated by Smith & Roberts (1963) - the ENE-trending belt extending from No Mans Creek in the west to Basin Spring, south of Springvale, is not Constance Sandstone but Musselbrook Formation. However, outcrops at the western end of this belt, at grid ref. 490 372, are included in the Sandstone.

The Constance Sandstone is dominantly fine to medium quartz sandstone, although some coarse-grained and conglomeratic beds are present. Lenses of basal conglomerate (Esc_c) up to 8 m thick consist of angular to well-rounded pebbles of quartz, quartzite, and chert set in a poorly-sorted fine to coarse silicified quartz sandstone. Boulder conglomerates, containing well-rounded quartz clasts up to 45 cm across, are also present.

Siltstone beds and members, which have been mapped to the north and west, lens out southwards and eastwards, and are not present in the Carrara Range region (Smith & Roberts, 1963; Sweet & others, in press).

The Constance Sandstone is 300-400 m thick in the Carrara Range region.

Mullera Formation

The Mullera Formation consists of siltstone, shale, sandstone, and ironstone. Dark grey and greyish-green siltstone and shale are probably the dominant rock-types in the Carrara Range region, as elsewhere, but they crop out poorly. Two sandstone members have been delineated on the Carrara Range region map, but an ironstone/sandstone member has not been shown. Several ironstone beds, up to 20 m thick, crop out in the southern limb of a syncline west-northwest of Springvale and grade west into ferruginous sandstone. Their stratigraphic position - near the base of the Mullera Formation, suggests that they may be equivalent to the Train Range Ironstone Member which crops out to the east in the Constance Range region.

The Middle Creek Sandstone Member (Esm_m) has been mapped only in a syncline in the eastern part of the region. Two main lenses or tongues of sandstone each about 10 m thick, separated by siltstone and shale, have been delineated. They consist of grey and light brown, flaggy to massive, fine to medium sandstone.

Another sandstone member, Esm_s, crops out in a syncline about 14 km west-northwest of Springvale. It consists of at least 150 m of sandstone, much of it clayey or feldspathic. Although it is mapped as Mullera Formation it may be equivalent to the Mittiebah Sandstone which overlies the Mullera Formation in the southwest of the Mount Drummond 1:250 000 Sheet area (Smith & Roberts, 1963).

Overall the Mullera Formation is about 400 m thick in the Carrara Range region, but the sequence is incomplete or faulted in many areas. The estimate of 3800 feet (1160 m) by Smith & Roberts (1963) appears to be too great.

CAMBRIAN

Middle Cambrian rocks (Smith & Roberts, 1963; de Keyser, 1969) deposited in the Georgina Basin, crop out only in the southeast of the region and were not examined during this survey.

Phosphate exploration drilling has revealed Cambrian rocks beneath a cover of 2-20 m of Mesozoic and Cainozoic sediments south of the Proterozoic outcrops. The cover thins southwards, and Camooweal Dolomite is present beneath 1-2 m of black residual soil in the southwest and southeast of the region.

MESOZOIC

Smith & Roberts (1963) delineated several outcrops of Mesozoic rocks in the Carrara Range region. They were subsequently included in the Mullaman Beds by Skwarko (1966) who identified early Cretaceous fossils in many outcrops. The outcrop of Mullaman Beds around Top Rocky Waterhole is more extensive than that mapped by Smith & Roberts (1963), and several small outcrops have also been recognised in other areas. All of the outcrops shown occupy valleys, and are probably fluvial deposits. They include highly weathered clayey sandstone and claystone which appear to lie within a lateritic weathering profile; many outcrops are capped by ferruginous laterite.

CAINOZOIC

Cleanskin Beds

The oldest Cainozoic unit may be the Cleanskin Beds - light grey limestones which occupy the valley of Tin Creek around grid ref. 930 410. Their relation to the nearby laterite outcrops is unknown, although Smith & Roberts (1963) believed them to be older than the laterite. If, as suggested by Smith & Roberts (1963), the Cleanskin Beds are the same age as the Carl Creek Limestone near Riversleigh (Tedford, 1967) in the Lawn Hill region, then they are of Late Oligocene or Early Miocene age.

Czf and chemically altered sediments (stippled)

The stippled areas, and those labelled Czf, are those which have been severely affected by a Tertiary deep-weathering event. The event was a lateritisation process, and ferruginous, mottled, and pallid zones are developed in many outcrops. The stippled areas are those in which the weathered bedrock is exposed at the surface, indicating that the ferruginous laterite at the top of the profile has been stripped off by later erosion. Areas marked Czf are those in which the ferruginous zone is still present.

The weathering event and the ancient land surface with which it is associated is probably the one described by Hays (1967) as the Tennant Creek Surface. Smart & others (1980) have described the Aurukun Surface, of early to mid-Tertiary age, which affects Mesozoic rocks of the Carpentaria Basin, as equivalent to the Tennant Creek Surface. If the surface did develop during the 'early to mid-Tertiary' it is doubtful that the Cleanskin Beds of supposed late Oligocene to Miocene age are older than it.

Czg

Limonite-cement conglomerates, obviously related more closely to present-day topography and drainage than to the Tertiary lateritisation event, are marked Czg. The conglomerates commonly form a terrace 2-5 m above present drainage channels, and are probably alluvial fan deposits and colluvium. The ferruginous cement is probably largely reworked, or leached, from Czf.

Czb

Grey clayey soil, commonly known as 'black soil', is developed on Cambrian carbonate rocks in the south. It is mainly a residual soil, but may include some alluvium, for example that deposited on Proterozoic rocks around grid ref. 910 400.

Czs

Czs includes all residual soils, aeolian sands, alluvium, colluvium, and fan deposits which cannot be definitely assigned to any of the other Cainozoic units. The predominantly sandy deposits south of the Proterozoic outcrops are outwash deposits carried by streams which die out within a few kilometres of their sources. The areas marked Czs which mask the McNamara Group, particularly the Lawn Hill Formation, include much Czg which was not delineated on the map because its boundaries are either diffuse, or are not easily recognisable even on colour airphotos.

Qa

Qa is alluvium associated with larger drainage channels. As the region is largely an area of erosion, not deposition, little Qa is present.

STRUCTURE

Parts of three distinct Proterozoic tectonic provinces, each with a distinct structural style, are preserved in the Carrara Range region. They are the North Australian Orogenic Province, the Lawn Hill Platform, and the South Nicholson Basin (Plumb, 1979).

North Australian Orogenic Province

The Murphy Metamorphics are part of the extensive North Australian Orogenic Province which contains rocks deposited and deformed during the early Proterozoic (Plumb, 1979). The Metamorphics are probably tightly folded, but their outcrop is poor and structural trends are not evident. The strike of the only foliation measured is roughly northeast. The quartzites assigned to the Metamorphics strike parallel to the Little Range Fault Zone, on which the major movements were mid to late Proterozoic; i.e. unrelated to early Proterozoic deformation.

Lawn Hill Platform

The Carrara Range and McNamara Groups occupy the Lawn Hill Platform, an intracratonic mid-Proterozoic basin (Plumb, 1979). The rocks are only moderately folded, but strongly faulted. Apart from a syncline in the south, near the Little Range Fault Zone, the Carrara Range and McNamara Groups dip north or north-northwest through practically the whole region. This uniformity of dip directions suggests that the rocks lie in the south-southeastern flank of a broad syncline. Both the bedding trends and the more prominent of two fault trends parallel the east-northeast trend of the Murphy Inlier, a narrow basement ridge 100 km to the north (Sweet & others, in press), flanked both north and south by rocks correlated with the Carrara Range and McNamara Groups. The prevailing north-northwesterly dips in the Carrara Range region are similar to those on the northern flank of the Murphy Inlier, which was also a basement high during sedimentation, and it is possible that there is a similar ridge south of the region.

Faults

The main feature of the rocks in the Lawn Hill Platform in the Carrara Range region is the degree to which they are faulted. The main fault direction is east-northeast, but there is also a northwest-trending set of faults. Several faults are curved, and appear to represent a combination of the two directions. The northwest set appears to be displaced by the east-northeast set, and may therefore be older. However, the curved nature of some faults suggests that the sets may be conjugate, and thus to have developed at the same time.

Many of the east-northeast set of faults have large vertical displacements. The sense is generally north-block-up, and displacements vary - from a few hundred metres up to 2 km on the fault running through grid ref. 680410.

The Little Range Fault Zone, called the Little's Range Fault by Smith & Roberts (1963), may have a displacement (north-block-up) of up to 5 km, assuming that the rocks around grid ref. 866285, south of the fault zone, are Musselbrook Formation (they are tentatively mapped as such).

There is no definite evidence of transcurrent movement on the east-northeast faults.

South Nicholson Basin

The South Nicholson Group was deposited in the South Nicholson Basin, an ENE-trending crustal downwarp between the Murphy Inlier and the Little Range Fault Zone. The Group may extend south of the Fault Zone, but it is now hidden beneath the Cambrian rocks of the Georgina Basin.

Faults and fold axes trend east-northeast in the South Nicholson Group. The structural style is different from that of the older rocks, however: the folds are open, with dips in the limbs rarely over 30°, and there are few faults. East of the Carrara Range region, in the Constance Range region, deformation appears to have been slightly more intense, and a series of basins and domes have formed.

The faults cutting the South Nicholson Group have small vertical displacements, probably in the range 10-200 m. There was further movement on the Little Range Fault Zone, but it was considerably less than the 5 km referred to previously; it may have been only a few hundred metres.

The region has been stable since the deformation which affected the South Nicholson Group, and the Cambrian rocks have been affected by only minor movement on the Little Range Fault Zone, and gentle tilting and uplift. The Cretaceous rocks appear to have only been uplifted.

ECONOMIC GEOLOGY

There are no mines or prospects in the Proterozoic rocks in the Carrara Range region. The two 'unexploited iron deposits' shown by Smith & Roberts (1963) on the Mount Drummond 1:250 000 Sheet have been shown on the 1:100 000 Sheet as 'minor mineral occurrences', as there is no evidence available to suggest that they are potentially workable deposits.

Apart from the work of Battey (1959) the only company exploration of the Proterozoic rocks has been reported on by Dechow (1967). A stream sediment and outcrop sampling program did not reveal any mineralisation, although a gossanous zone was found in the Murphy Metamorphics, and manganese-rich zones in the Bluff Range Beds (now Lawn Hill Formation).

The major problem in prospecting in the area is the lack of knowledge of the effect of the lateritisation event on the dispersion of metals and other pathfinder elements. For this reason the prospectivity of the Proterozoic rocks should be regarded as largely untested. The McNamara Group is highly prospective in other areas and warrants further attention in the Carrara Range region. The main target should probably be the Musselbrook Formation, as it contains the highest proportion of carbonate rocks in association with fine-grained silicoclastics. The possibility exists that some of the alteration of the formation is the result of the weathering of sulphides rather than simply the leaching of carbonates.

Phosphatic beds in the Border Waterhole Formation extend into the eastern part of the Carrara Range region from Musselbrook 100 000 Sheet area. They also occur at depth below the Camooweal Dolomite in the southern part of the region, and although some exploration has been carried out, no deposits have been discovered.

GEOLOGICAL HISTORY

Most conclusions about the geological history of the Carrara Range region have been arrived at by examining it in conjunction with adjacent regions - mainly the Westmoreland region (Sweet & others, in press), and the Lawn Hill region (Sweet & Hutton, 1980). The following sequence of events can be deduced:

(1) Deposition, folding, and metamorphism of a thick sedimentary sequence in the early Proterozoic (Murphy Metamorphics). The Metamorphics were intruded by syntectonic granites in the Calvert Hills 1:250 000 Sheet area about 1860 m.y. ago (Sweet & others, in press).

(2) Erosion, then renewed sedimentation, mostly of fluvial sands, during the early Carpentarian (Don Creek Sandstone). Fissure eruptions along major crustal fractures led to the outpouring of basalt and trachyte over a vast area (Mitchiebo Volcanics). Fluvial or shallow marine sedimentation continued, resulting in the interbedding of sandstone, siltstone, and lava.

(3) Minor uplift, causing erosion of some of the already indurated sandstone. A sheet of rhyolitic ignimbrite or lava then blanketed the uneven sandstone surface (Top Rocky Rhyolite).

(4) Further uplift, and possibly minor faulting, occurred and the Top Rocky Rhyolite was eroded completely from some areas. A marine transgression around 1670 m.y. ago resulted in the deposition of sand, silt, and stromatolitic carbonate over a vast area, including the Westmoreland, Lawn Hill, and Mount Isa areas. Shallow marine and paralic sedimentation continued for several tens of millions of years, but the exact age of termination is not known. It was, however, before about 1490 m.y., the time at which isotopic closure occurred in metamorphic micas in the Mount Isa Group and may have been as early as 1620 m.y. ago (Page, 1978).

The event which terminated sedimentation was probably the one which caused the folding and extensive faulting of the rocks of the Lawn Hill Platform. The reaction of the rocks, particularly the Carrara Range Group, by faulting rather than tight folding or shearing suggests that they were deformed under low confining pressures - i.e. at very shallow depth.

(5) During and following deformation further erosion took place and a new phase of subsidence and sedimentation was initiated. Sand, silt, mud, and iron-rich sediments were laid down in fluvial and shallow marine environments (South Nicholson Group).

(6) An episode of mild deformation, into broad domes and basins, took place probably before 1300 m.y. ago. (The Mullera Formation has yielded a Rb-Sr total-rock shale age of 1510 $\pm$ 120 m.y., and the Roper Group, the correlative of the South

Nicholson Group, was intruded by dolerite between 876 and 1280 m.y. ago; Plumb & Derrick, 1975).

(7) Apart from relatively brief episodes of sedimentation in the early Palaeozoic and Cretaceous, the region has been stable, and has probably undergone erosion from the time of deformation of the South Nicholson Group to the present.

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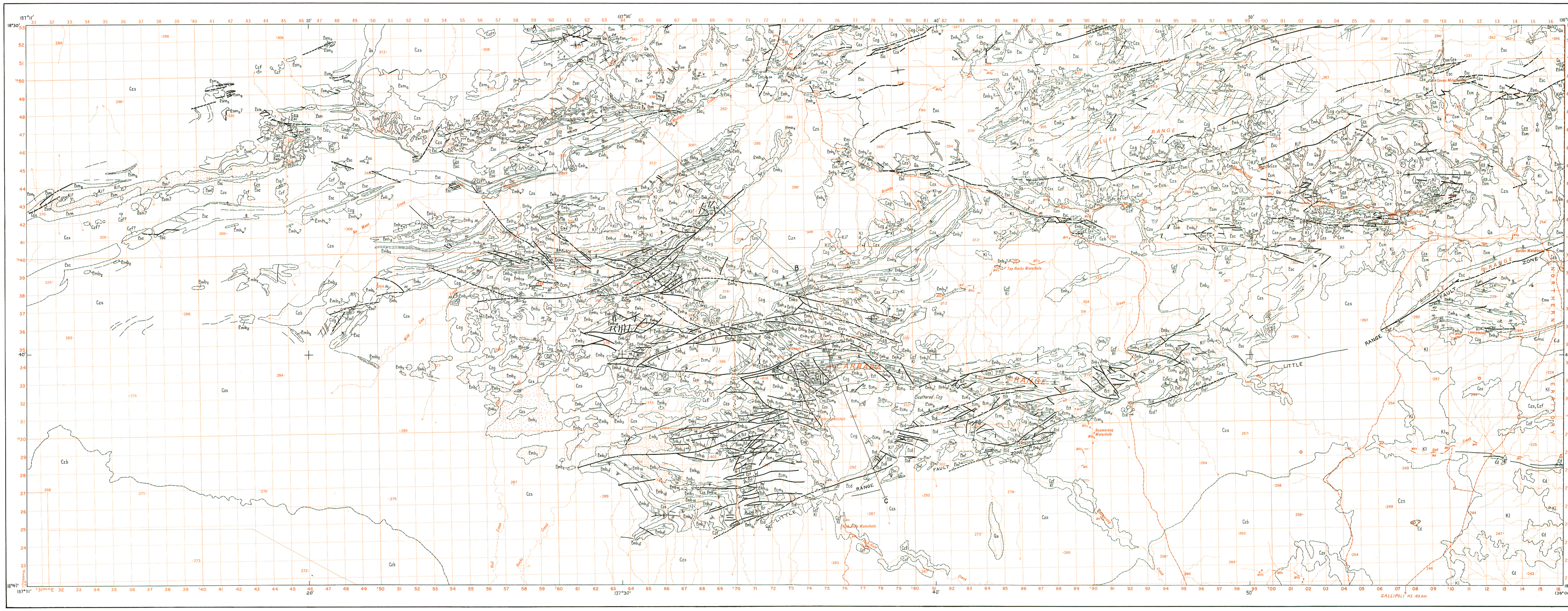
AUSTRALIA 1:100 000 GEOLOGICAL SPECIAL

GEOLOGY OF THE CARRARA RANGE REGION

NORTHERN TERRITORY

PARTS OF SHEETS 6360, 6460



CAINOZOIC	QUATERNARY		Qa	Silt, sand, and gravel: alluvium
			Czs	Clay, silt, sand, gravel, and limonite-cemented conglomerate: colluvium and residual soils; some alluvium
			Czb	Grey clayey soils: residual and alluvial soils
			Czg	Limonite-cemented pebble and cobble conglomerate: colluvium, alluvial fan deposits
			Czf	Ferruginous laterite
				Chemically altered (ferruginised, silicified or kaolinised) sediments
	TERTIARY	Cleanskin Beds	Tl	Light grey limestone
MESOZOIC	EARLY CRETACEOUS	Mullaman Beds	Kl	Clayey sandstone, claystone, conglomerate
PALAEOZOIC	MIDDLE CAMBRIAN	Camooweal Dolomite	Ɛd	Thin-bedded to massive dolomite
		Currant Bush Limestone	Ɛmc	Thin-bedded grey limestone with lenses and interbeds of marl and sandy dolomite
		Border Waterhole Formation	Ɛmo	Chert, siltstone, chert breccia, phosphorite
PROTEROZOIC	CARPENTARIAN	SOUTH NICHOLSON GROUP: Mullera Formation	Ᵽsm$_s$	Massive to flaggy feldspathic sandstone
			Ᵽsm	Siltstone, shale, sandstone and ironstone
		Middle Creek Sandstone Member	Ᵽsm$_m$	Grey and light brown, massive to flaggy, fine to medium sandstone with some interbedded siltstone and shale
		Constance Sandstone	Ᵽsc	Fine to medium quartz sandstone, some coarse grained; conglomerate beds
			Ᵽsc$_c$	Basal lenses of pebble to boulder conglomerate
		McNAMARA GROUP: Lawn Hill Formation, Widdallion Sandstone Member	Ᵽmh$_w$	Blocky to massive, thick-bedded, micaceous, cross-bedded medium quartz sandstone
			Ᵽmh$_b$	Siltstone and shale; minor dolomite and dolomitic siltstone
			Ᵽmh$_a$	Fissile to flaggy, micaceous siltstone and shale with thin interbeds of ripple laminated sandstone and thicker interbeds of flaggy to blocky, fine to medium, well-sorted sandstone with thin grit and pebble bands
			Ᵽmb$_s$	Massive, fine to medium orthoquartzite
			Ᵽmb$_3$	Fissile to flaggy siltstone and stromatolitic chert, minor sandstone
		Musselbrook Formation	Ᵽmb$_2$	Siltstone, claystone, stromatolitic chert, sandstone
			Ᵽmb$_1$	Orthoquartzite, minor siltstone, stromatolitic chert and conglomerate
			Ᵽmb$_{1f}$	Flaggy to massive, medium orthoquartzite
			Ᵽmb$_{1e}$	Siltstone, stromatolitic chert
			Ᵽmb$_{1d}$	Flaggy to massive, medium orthoquartzite
			Ᵽmb$_{1c}$	Siltstone, fine clayey sandstone, laminated and stromatolitic dolomite
			Ᵽmb$_{1b}$	Flaggy to massive, medium orthoquartzite
			Ᵽmb$_{1a}$	Massive conglomerate containing cobbles and boulders of quartzite: quartz sandstone, acid volcanics, and pebbles of quartz
		CARRARA RANGE GROUP: Top Rocky Rhyolite	Ᵽct	Massive reddish-brown feldspar porphyry, probably rhyolite
		Mitchiebo Volcanics	Ᵽcm$_s$	Massive to blocky, medium to coarse, well sorted, quartzose and feldspathic sandstone with minor basalt/trachyte interbeds
			Ᵽcm$_b$	Purplish-brown to reddish-brown vesicular and amygdaloidal basalt and/or trachyte; strongly altered
		Don Creek Sandstone	Ᵽcd	Massive, medium to coarse and gritty quartz sandstone; scattered quartz pebbles and thin conglomeratic lenses
	EARLY PROTEROZOIC	Murphy Metamorphics	Ᵽlm	Phyllite or fine schist, quartzite, siltstone

- Geological boundary
- Syncline
- Anticline
- Fault

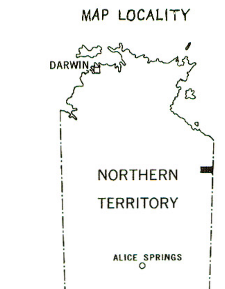
Where location of boundaries, folds and faults is approximate, line is broken, where inferred, queried, where concealed, boundaries and folds are dotted, faults are shown by short dashes.

- Sedimentary facies change; Unconformity — section and diagrams only
- Strike and dip of strata
- Strike and dip of strata, dip not measured
- Vertical strata
- Horizontal strata
- Strike and dip of strata, dip < 5°; Strike and dip of strata, dip 5°–15°; Strike and dip of strata, dip 15°–45°; Strike and dip of strata, dip > 45°; Trend-line; Lineament; Joint pattern — airphoto interpretation
- Strike and dip of foliation
- Stromatolite locality
- Type section
- Quartz dyke
- Minor mineral occurrence; Fe–Iron
- Waterholes
- Sinkhole
- Vehicle track
- Building
- Yard
- Fence
- Elevation in metres

SCALE 1:100000

1 0 1 2 3 4 5 6 7 8 9 10 Kilometres

MAP LOCALITY



UNIVERSAL GRID REFERENCE

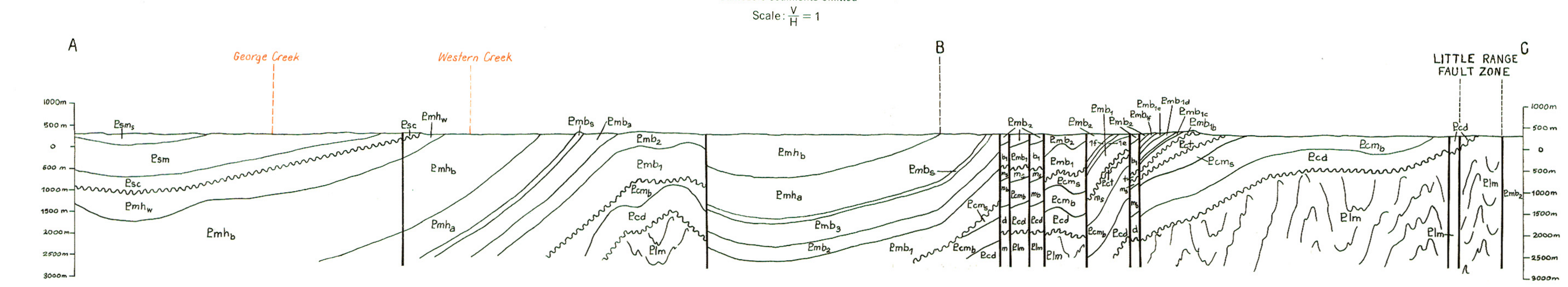
Brown numbered grid lines are 1000 metre intervals of the Australian Map Grid, Zone 53. Grid values are shown in full only at the southwest corner of the map. Transverse Mercator Projection.

Compiled by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development and Energy. Issued under the authority of the Minister for National Development and Energy. Base map compiled by the Division of National Mapping from aerial photography at 1:80 000 scale.

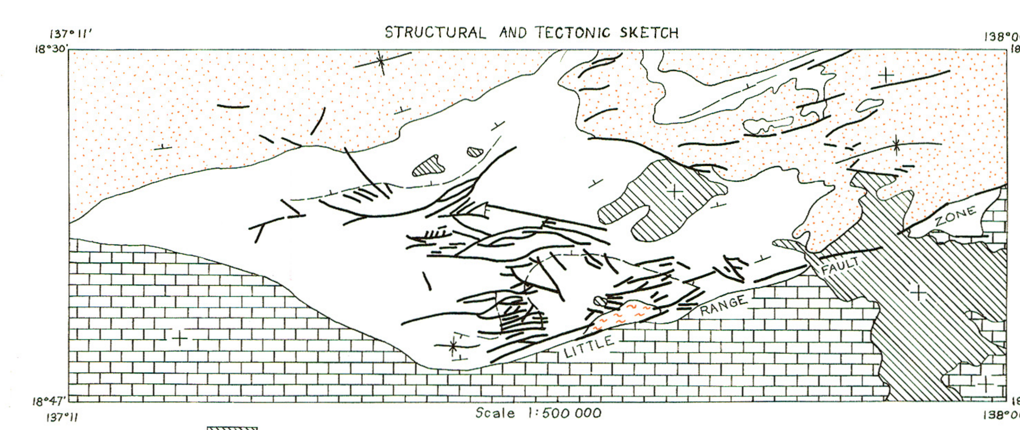
Geology 1959 by J.W. Smith, H.G. Roberts BMR
1968 by R. Thieme, F. de Keyser BMR
1977 by I. Sweet, A. Mond BMR; L. Hutton GSQ
Compiled 1978 by I. Sweet, A. Mond, J. Stirzaker BMR
Design and drafting by Cartography Section, BMR
Drawn by J. Stirzaker, H. Apps BMR

SCHEMATIC SECTION

Cainozoic sediments omitted



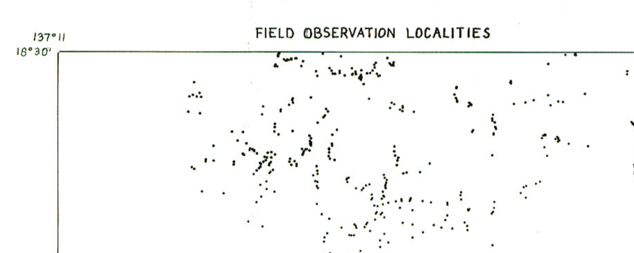
STRUCTURAL AND TECTONIC SKETCH



Scale 1:500 000

- Northern Territory Shelf
- Georgina Basin
- South Nicholson Basin
- Lawn Hill Platform
- Murphy Metamorphics
- Boundary of tectonic unit
- Trend-line and prevailing dip
- Horizontal or sub-horizontal strata
- Syncline
- Fault

FIELD OBSERVATION LOCALITIES



Scale 1:750 000

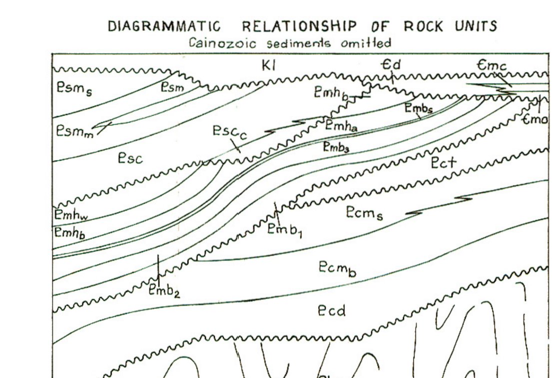
INDEX TO 1:100 000 MAPS

1:250 000 maps shown in brown

RANKEN 6258	LIGNUM 6358	MIKADO 6458	CAMOOWEAL 6558	UNDILLA 6658	MAMMOTH MINES 6758

DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS

Cainozoic sediments omitted



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SUBJECT TO AMENDMENT

GEOLOGY OF THE
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PARTS OF SHEETS 6360, 6460