REPORT 154

The Geology of the Charnley 1:250 000 Sheet Area Western Australia

D. C. GELLATLY, G. M. DERRICK, R. HALLIGAN,
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SUMMARY

The Charnley Sheet area lies in the West Kimberley Division in the northern part of Western Australia. This Report describes in detail both the older Precambrian (Archaean? to Lower Proterozoic) igneous and metamorphic rocks, the overlying Kimberley Basin succession of Carpentarian age, and late Adelaidean glacial rocks, and includes brief notes on Palaeozoic and Cainozoic sediments.

The oldest rocks in the Sheet area are the Halls Creek Group, a series of flysch sediments of Archaean? age, which have been strongly folded and metamorphosed in the greenschist, and locally in the almandine-amphibolite, facies. They have been intruded in pre-Carpentarian time by the Woodward Dolerite, which has been metamorphosed together with the Halls Creek Group.

The Whitewater Volcanics (of Lower Proterozoic age) consist of quartz and feldspar-phyric rhyodacite tuffs and lavas. They overlie the Halls Creek Group with inferred unconformity and are intruded by high-level quartz-feldspar porphyry and granite (Mount Disaster Porphyry and Mondooma Granite) and by later granites. The later granites comprise the porphyritic Lennard and Kongorow Granites, and minor leucocratic granite (Mount Amy Granite) which may have been derived from the Lennard Granite by fractionation.

The older Precambrian rocks are overlain unconformably by the Kimberley Basin succession (Speewah and Kimberley Groups) of lower Carpentarian age. This succession comprises about 2200 m of sandstone, 600 m of basic volcanics, and minor siltstone and conglomerate. The Kimberley Group is overlain unconformably by the Adelaidean Mount House Group consisting of tillite, sandstone, and minor dolomite, and shale.

Palaeozoic rocks, forming part of a Devonian limestone reef complex, lie unconformably on the older Precambrian in the southeast corner of the Sheet area.

Cainozoic sediments include laterite of probable Tertiary age, superficial soils and alluvium, and intertidal recent marine sediments.

Strong folding along axes plunging southeast and southwest and gentle folding along northeasterly axes have affected the area; several periods of folding are represented. Major faults in the area trend mainly north, northwest, and northeast, and include faults with a transcurrent component. Prominent joints and associated faults trend north, northeast, or northwest; the latter trend predominates in the older Precambrian in the southeast. The main metamorphism probably antedates the Whitewater Volcanics. Two main phases are recognized: an early low-stress phase in which andalusite was widely developed, and a high-stress phase in which andalusite was destroyed and garnet developed. Zonal distribution of andalusite, staurolite, and garnet has been mapped.

The only economic minerals that have been worked in the area are cassiterite and wolfram. A small deposit of kyanite, with associated corundum, diaspore, and topaz, has been found recently. Minor amounts of chalcopyrite, scorodite, and fluorite have also been recorded. Laterites in the area may be bauxitic but have not been examined in detail. Water from surface pools, shallow bores, and wells is used for cattle.

INTRODUCTION

Location

The Charnley 1:250 000 Sheet area SE/51-4 lies between latitudes 16° and 17° South, and longitudes 124°30′ and 126° East. It falls within the Kimberley Land Division of the northern part of Western Australia. The southeast corner of the Sheet area is about 100 km from the port of Derby. Parts of Walcott Inlet and Doubtful Bay lie in the western part of the Sheet area.

Object

The work described in this Report is part of a program of regional reconnaissance mapping at a scale of 1:250 000 carried out jointly by the Geological Survey of Western Australia (GSWA) and the Bureau of Mineral Resources (BMR), and designed to map all the Precambrian rocks of the Kimberley region. Since the program started in 1962, the following Sheet areas have been mapped: Montague Sound, Drysdale-Londonderry, Medusa Banks, Prince Regent/Camden Sound, Ashton, Cambridge Gulf, Mount Elizabeth, Lissadell, Lansdowne, Dixon Range, Mount Ramsay, Gordon Downs, Yampi, and Lennard River.

The aim of this Report is to provide a preliminary description of all the rock units in the Charnley Sheet area.

The results of the Kimberley mapping program is being published in four Bulletins describing the 'Precambrian Geology of the Kimberley Region'; Bulletin 106, East Kimberley (Dow & Gemuts, 1969); Bulletin 107, Lamboo Complex (Gemuts, 1971); Kimberley Basin (Plumb, in prep.); and West Kimberley (Gellatly, Sofoulis, & Derrick, in prep.). The Kimberley Basin Bulletin will incorporate information on the Carpentarian and Adelaidean rocks, and the West Kimberley Bulletin will include that on the older Precambrian. In addition, Explanatory Notes summarizing the geology will be published with each coloured 1:250 000 Sheet; some have already been issued.

Access

The main access route to the Sheet area is the Derby/Gibb River/Kalumburu road, a formed earth road which crosses the southeast corner. Graded tracks lead from it to Mount Hart, Mount Barnett, and Beverley Springs homesteads. Minor tracks radiate from the homesteads to cattle watering points and yards. Sporadically maintained station tracks from both Kimberley Downs and Napier Downs stations give access to the southwest corner of the Sheet area. Rough bush tracks lead from Oobagooma in the Yampi Sheet area to Hawkestone Creek in the southwest, and to King Creek yard near the western boundary of the Sheet area; vehicle access eastwards and southeastwards from these points is possible for about 24 km. About 80 percent of the area is inaccessible even to four-wheel-drive vehicles.

The airstrip at Beverley Springs is suitable for DC3 aircraft and that at Mount Hart for light aircraft.

Population and industry

The only known population of the area is centred at the cattle stations of Mount Hart, Mount Barnett, and Beverley Springs. The total population on these stations is probably around 100, most of whom are Aboriginals. Morgan (1955) found Aboriginals not previously contacted in the Drysdale Sheet area, and it is possible that a few Aboriginals not yet contacted may live in the rugged inaccessible northwest part of the Sheet area.

Raising of beef cattle is the only industry. Small-scale mining was carried on for short periods around 1911-1912 at the King Sound Tin Mine, but apart from the efforts of a lone prospector (J. Stewart) no work has been done there since.

Climate

The area has a moderately dry tropical monsoonal climate with a marked wet season during the summer period from December to March. There are no published rainfall and temperature figures. Extrapolated isohyets (Slatyer, 1960) indicate that the northwest corner of the Sheet area has an average rainfall of more than 1000 mm per annum and the southeast corner less than 750 mm. About 75 percent of the Sheet area lies in the 750-1000 mm rainfall belt; the centre of the area probably has about 850 mm.

The temperature data for Derby and Halls Creek (Fitzpatrick & Arnold, 1964) provide guides to temperatures of the coast and inland. Derby has mean monthly maxima of 29°C (July) to 36°C (November and December) and minima of 14°C (July) to 27°C (December). Halls Creek has maxima of 27°C (July) to 38°C (November) and minima of 8°C (July) to 24°C (January).

Vegetation and pastures

The typical vegetation of low-lying ground is grassy open eucalyptus woodland. Sandstone plateaux and ridges support mainly spinifex and stunted wattle, eucalypts, and cypress pine. Low sandstone hills in the coastal areas have a thick tangle of cane grass (annual sorghum) and creepers. Dolerite and basalt hills generally support blue grass or white grass, and black soil areas mostly wire grass and flinders grass. Pandanus and paperbarks fringe waterholes in river courses; elsewhere along the drainages eucalypts and baobabs predominate. Dense mangrove swamps fringe the tidal bays, inlets, and estuaries.

Previous work

The earliest explorers in the Sheet area were Alexander Forrest (1879), who examined the King Leopold Range in the vicinity of Mount Matthew, and Hann (1901) and Brockman (1902), who both followed the Hann and Charnley Rivers. They were concerned largely with the pastoral potential of the area, but also made brief geological observations. The journeys of the early explorers are charted in Feeken & Feeken (1970).

The King Sound (Clara Hill) Tin Mine was mentioned briefly by Campbell (1909). It has been described in detail by Blatchford (1914), and summarized by Finucane (1939), who made a detailed map of the deposit, and by Simpson (1948).

More recently, Harms (1959, 1965) and Speck et al. (1960, 1964) have furnished good general accounts of the geology and geomorphology of the whole of the North and West Kimberley areas.

Present investigations

Before fieldwork started, a photogeological map was prepared by Perry (Perry & Richard, 1965); it has formed the basis for much of the present map.

Field work on the Carpentarian and Adelaidean rocks was carried out by R. Halligan (GSWA) in June and July 1965. The Lower Proterozoic rocks in the southwest corner and the adjacent Carpentarian sediments were mapped in 1966 and 1967 jointly by BMR and GSWA.

Detailed ground traverses were made only in the southwest; the remainder was given only a rapid reconnaissance, partly by helicopter.

A short report on the Hawkstone Creek kyanite has already been published (Derrick & Morgan, 1966). Data on palaeocurrents collected from the Charnley Sheet area have been incorporated in a report on palaeocurrent data for the whole Kimberley region (Gellatly et al., 1970).

The present Report, together with similar reports on the Yampi (Sofoulis et al., 1971) and Lennard River (Gellatly et al., 1968) 1:250 000 Sheet areas, and the Oscar Range of the Lennard River Sheet area (Derrick & Gellatly, 1971), will form the basis for a Bulletin on the geology of the West Kimberley.

At the time of the present investigation the following aerial photographs and maps were available:

1. Vertical aerial photographs—1:50 000 (approx.); 1949 photography by RAAF;
2. Topographic base maps (unpublished) at 1:50 000 scale and
3. Topographic map at 1:250 000 scale, compiled by the Royal Australian Survey Corps in 1962 and 1963, respectively;
4. Photomosaics at 1:63 000 compiled by the W.A. Department of Lands and Surveys from 1949 photography;
5. Photomosaic at 1:250 000 compiled in 1950 by the Commonwealth Division of National Mapping, Department of National Development;
6. Topographic map at 4 miles to 1 inch by W.A. Department of Lands and Surveys;
7. Geological map of the Kimberley Region (10 miles to 1 inch) by J. E. Harms (1959).

Since the geological mapping described in this Report was carried out, vertical aerial photographs (RC-9 Series) on a scale of 1:85 000 (approx.) have become available for the whole of the Sheet area.

PHYSIOGRAPHY

The physiography is essentially that of an irregular dissected plateau which occupies the whole of the area, except the southwestern corner, which consists of low rocky granite hills separated from the plateau by the King Leopold Ranges (Wright, 1964).

The principal landforms are grouped into three physiographic provinces and six subprovinces (Fig. 1). Two provinces, the Kimberley Plateau and the Kimberley Foreland, fall within the North Kimberley Division of Jutson (1950); the third province, the Lamboo Hills, falls within Jutson's Fitzroyland Division.

The two subprovinces of the Lamboo Hills are underlain by older Precambrian crystalline rocks, the others by Carpentarian sediments.

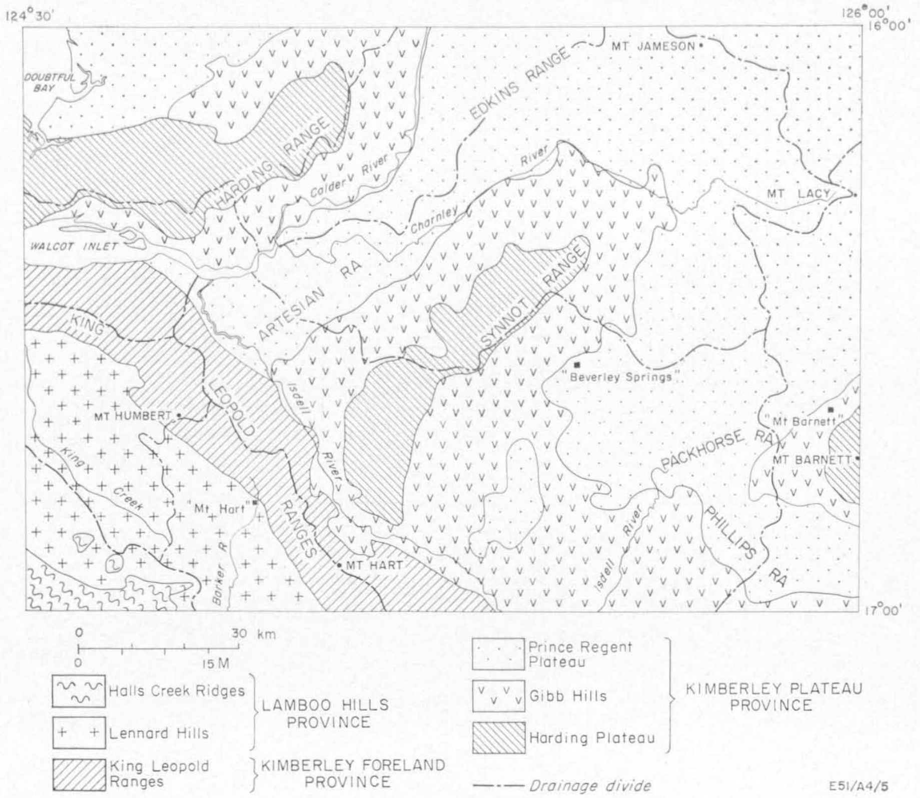

Fig. 1. Physiographic map.

Drainage

Parts of the catchment areas of seven major rivers fall within the Sheet area. The central part—more than half—of the area is drained by the Calder, Charnley, and Isdell Rivers, which converge and debouch into Walcott Inlet. The eastern border includes parts of the catchments of the Drysdale River which drains northwards, and the Hann River which drains southwards, into the Fitzroy. In the southwest the Barker River (a tributary of the Lennard River) and the Robinson River drain southwestwards and westwards to King Sound; and King Creek (known locally as King River) and Humber Creek drain northwestwards and westwards into Secure Bay. Other rivers along the western margin have short courses and drain directly into Doubtful Bay or Walcott Inlet.

Geological structure has played a part in controlling the courses of the major rivers. Broad anticlines of King Leopold Sandstone, and remnant plateaux of Warton Sandstone in the centre of broad synclines, generally form the divides between catchment areas. For as much as 80 km at a stretch major rivers follow closely the contact between the Carson Volcanics and the King Leopold Sandstone. Where rivers break through the anticlines spectacular gorges are developed, for example on the Isdell and Charnley Rivers. A notable feature is the deflection of the Isdell River by the King Leopold Ranges. It flows initially southwestwards, but is deflected northwestwards by the ranges and for the rest of its length runs parallel to them. This is in direct contrast to the breaching of the King Leopold Ranges by the Fitzroy River at Diamond Gorge to the southeast of the Sheet area.

The courses of tributary streams are closely controlled by geology and are described under each physiographic subprovince.

Coastal features

The small coastal areas in the Charnley Sheet area are part of the drowned ria-type coastline that surrounds the Kimberley region on its northern and western sides. Spectacular narrow rocky rias are found at the mouths of rivers draining into Doubtful Bay, especially the Sale River. Walcott Inlet is a broad drowned valley. It is 32 km long, up to 12 km wide, and has a mean effective tide of 11 m (Gordon, 1964). Echo soundings show that the floor of the inlet is irregular, being deeper (over 60 m below sea level) near its northern shore, where steep slopes and cliffs forming the southern edge of the Harding Plateau rise to about 120 m above sea level. At its mouth, in the adjacent Yampi Sheet area, the floor of the inlet is 85 m below sea level.

Lamboo Hills Province

The Lamboo Hills Province occupies the southwestern corner of the Charnley Sheet area.

In the *Lennard Hills* subprovince the principal landforms are rugged bouldery granite hills and tors, whalebacks characterized by smooth exfoliation surfaces, broad sandy pediments with isolated monadnocks, and narrow alluvium-filled valleys. Minor watercourses are closely spaced and commonly follow joints or faults. Elevations range from sea level to 370 m; local relief is generally 120 m to 150 m.

The *Halls Creek Ridges* which cover a small area in the southwest, consist of small hummocky rounded hills and ridges of easily eroded phyllite and schist, and of intervening clay-soil plains. Minor streams are closely spaced and commonly have a dendritic pattern, but where they traverse plains they are incised and meandering. Elevations range from 90 m to 300 m; local relief is generally about 60 m.

Kimberley Foreland Province

The *King Leopold Ranges* are a narrow belt of parallel, steep-sided, commonly flat-topped ridges, which form the steeper western edge of the Kimberley Plateau. They are separated by more easily eroded dolerite valleys, especially along the southern margin. The topography is strongly controlled by the structure, and typically consists of long strike ridges with subsequent and consequent minor streams. The ranges have been deeply dissected, and form the divide between the streams draining into Walcott Inlet, and those which drain into Secure Bay to the west, or through the Barker and Lennard River systems into the Fitzroy River and King Sound. No major watercourses cross the ranges. The impressive peaks of Mounts Hart, Humbert, and Hepple form the highest points of the ranges in the Sheet area.

Kimberley Plateau Province

The *Prince Regent Plateau* is underlain entirely by the King Leopold Sandstone. It is gently undulating, and has rocky butte topography and deeply incised drain-

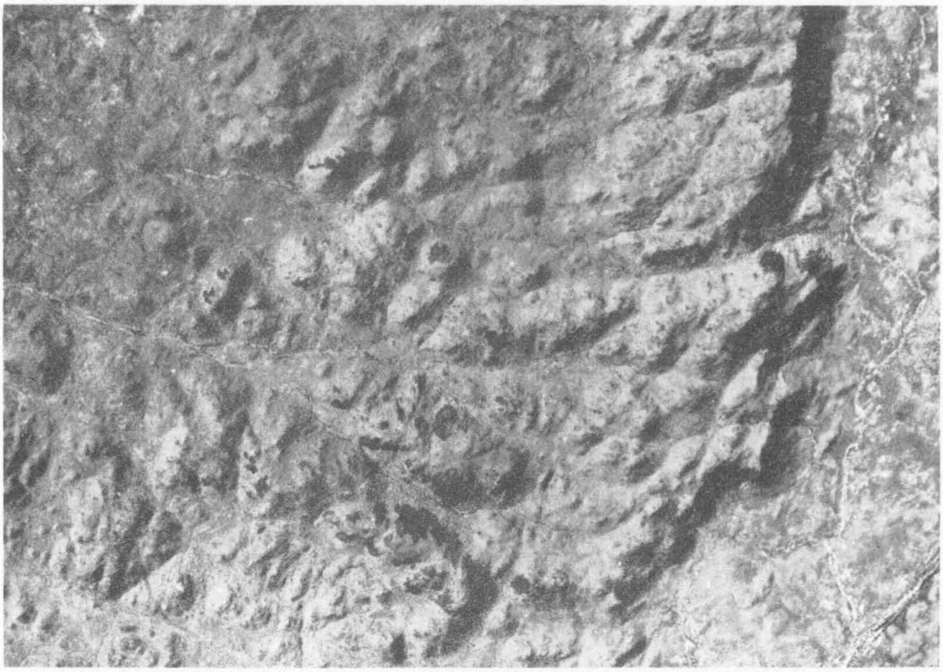

Fig. 2a. Typical physiography of Mondooma Granite. Vertical aerial photograph. Note black boulder scree and well defined joint pattern. Lennard Granite forms low ground at base of photo. Centre point of photograph is 6 km east-northeast of King Creek yard. GA 1292. (Photograph by RAAF.)

Fig. 2b. Physiography of Kimberley Plateau. Mesas of Warton Sandstone (in distance) overlying Carson Volcanics which are cut by quartz-filled north-trending fault (foreground). Looking northeast from near Byrnes Hill. G1885.

age. It differs from the Harding Plateau subprovince in its lack of escarpment and cuesta topography. Local relief is mostly around 60 to 150 m but is as much as 300 m in places, for example at the lower end of the Isdell Gorge. Elevations range from sea level to 760 m at Mount Lacy, the highest point in the Sheet area.

Minor drainage is closely controlled by faults and joints, and tends to have a rectilinear pattern following northwest and southwest fractures.

The *Gibb Hills* are a series of low, generally smooth, rounded hills formed on basalt. In the centre of the Sheet area, near Beverley Springs homestead, the hills are capped by small laterite mesas. Elevations range from sea level to over 500 m. Local relief seldom exceeds 150 m. Quartz-filled major faults form prominent narrow ridges. Joint fractures, in contrast to those in the Prince Regent Plateau, are not deeply eroded, and minor drainage is dendritic rather than rectilinear.

The *Harding Plateau* subprovince consists of escarpment-bounded plateaux. It includes the Harding Range, the Synnot Range, and part of the Mount Barnett plateau. The surfaces of the plateaux are broken by scattered mesas and cuestas; in the Harding Range cuestas are a dominant feature of the topography. Local relief is mostly 60 m to 120 m. Elevations range from sea level to over 500 m.

Minor drainage is irregular. It is partly controlled by fault and joint fractures, partly subsequent controlled by strike ridges, partly consequent flowing down dip slopes, and partly dendritic.

The Harding Plateau is similar physiographically and geologically to the Karunjie Plateau subprovince in the eastern part of the Kimberley Plateau.

STRATIGRAPHY

The stratigraphy of the Charnley Sheet area is summarized in Table 1. Most rock units exposed are Precambrian. The older Precambrian rocks—Halls Creek Group and Lamboo Complex—are assigned to the Archaean(?) and Lower Proterozoic respectively. The younger rocks of the Kimberley Basin succession are assigned to the Carpentarian System. They are overlain by Upper Adelaidean sediments including tillite. The subdivision of the Precambrian of the Kimberley region into Archaean(?), Lower Proterozoic, Carpentarian, and Adelaidean is based on isotopic age determinations (Bofinger, 1967; Miss R. Bennett, unpubl. data*). In addition, the Lamboo Complex has been informally subdivided into three parts on the basis of field relationships (Gellatly et al., 1968) and the Whitewater Volcanics have been included in it. The Whitewater Volcanics are now placed in the Lower Proterozoic at the base of the middle unit of the Lamboo Complex, instead of the base of the Carpentarian as previously (Dunn et al., 1966; Dow & Gemuts, 1969).

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* As used in this Report the Lower Proterozoic ranges from 2300 m.y. to about 1800 m.y., the Carpentarian System from about 1800 m.y. to 1400 m.y., and the Adelaidean System from 1400 m.y. to 600 m.y. The subdivisions of the Precambrian used by the Geological Survey of Western Australia differ from these and are shown separately on the accompanying map.

[Ages assigned to rock units have been modified by Plumb & Derrick (in press) in accordance with new data obtained since preparation of the Charnley 1:250 000 geological map and this Report. The Lamboo Complex, Speewah and Kimberley Groups, and the Hart Dolerite are now assigned to the Lower Proterozoic.—Ed.]

Stratigraphic nomenclature of the Precambrian units is defined fully in Dow & Gemuts (1969); Gemuts (1971); Gellatly, Sofoulis, & Derrick (in prep.); Plumb (in prep.).

The Precambrian is overlain by sediments of Devonian age and by Tertiary laterite and other superficial Cainozoic deposits.

ARCHAEAN(?)

HALLS CREEK GROUP

The Halls Creek Group, the oldest exposed unit, is a sequence of phyllite, schist, and quartzite. The unit is named after Halls Creek, in the East Kimberley. The derivation of the name is documented in Dow & Gemuts (1969).

Stratigraphic relations

The base of the Halls Creek Group is not exposed. The Group is overlain by ash-flow tuff of the Whitewater Volcanics and by Devonian conglomerate, and is intruded by the Woodward Dolerite, Mondooma Granite, Mount Disaster Porphyry, and Lennard Granite.

Field occurrence

The Halls Creek Group is exposed mainly in an east-trending belt in the far southwest, near the headwaters of Hawkstone and Alexander Creeks; in three inliers 1 to 5 km across, a few kilometres north of this belt, near the headwaters of the Pardaboora River; and in a small area at the western edge of the Sheet area, about 5 km west of the abandoned Federal Downs homestead.

Lithology

Phyllite, porphyroblastic mica schist, and impure quartzite are the dominant rock types in the Halls Creek Group, with minor amounts of hornfels.

Sericite phyllite is the most abundant rock type; it is generally buff to grey, laminated to flaggy and thin-bedded, with both cleavage and bedding in most places. Locally the phyllite contains small spots of andalusite.

Mica schist is also widespread, and generally contains porphyroblasts of one or more of the following: andalusite, chloritoid, staurolite, garnet, and kyanite. Andalusite and chloritoid are abundant, but the remainder are confined to schist in the southwest. Most andalusite is 1 mm to 1 cm long, and is commonly pseudomorphed by sericite aggregates. In the Hawkstone Creek area andalusite locally forms up to 10 percent of the gravels; crystals 2 to 6 cm by 1 to 2 cm predominate, but specimens up to 12 cm long have been found. In this area it is pseudomorphed by kyanite. Staurolite in schist is present as both stubby and elongate crystals, the latter occuring in the more strongly deformed zones with garnet. Garnet porphyroblasts ranging from 2 mm to 1 cm in diameter appear to be restricted to the more highly cleaved schists and show well developed pressure shadows in some places. Kyanite schist is found near the headwaters of Hawkstone and Alexander Creeks, in association with lenses of coarse kyanite rock, corundum rock, and kyanite-topaz rock. This kyanite deposit, at the lower contact between Woodward Dolerite and phyllite of the Halls Creek Group, is about 400 m long.

TABLE 1. STRATIGRAPHIC TABLE

Era	*Age*	*Rock Unit and Symbol*	*Thickness (m)*	*Lithology*	*Distribution*	*Topography*	*Remarks*
CAINOZOIC	QUATERNARY	Qa	Variable	Alluvium; unconsolidated silt, sand and gravel	Along principal watercourses, especially Hann, Sale, and upper Isdell Rs, Bamboo and Maurice Crs	Flood plains and river channels	
		Qc	Unknown	Sand, silt and mud; thin salt crust locally	Around Doubtful Bay and Walcott Inlet	Tidal mudflats	Seaward fringes mangrove-covered
		Czs	Variable	Soil, sandy soil, eluvium	Widespread, especially in SE and extreme SW	Plains, pediments, and debris-slopes	Includes large areas of pale grey sandy soil over King Leopold Sandstone, and red-brown soils over Carson Volcanics
		Czb	About 6 (from bore data)	Black soil	Small scattered areas mainly in SE	Intensely cracked and pitted (gilgai) treeless plains	Mainly Carson Volcanics
		Czl	Variable	Ferruginous, pisolitic, sandy soil	Small areas N of Beverley Springs and SW of Tabletop Mountain	Plateaux and alluvial fans	Overlies or borders laterite. Suitable for unsealed roads
	TERTIARY	Tp	Up to 10	Ferruginous pisolitic laterite	Synnot Ra; also 15 km south of Beverley Springs	Small mesas	Overlies mainly Carson Volcanics, locally overlies Beverley Springs Member
UNCONFORMITY							
PALAEOZOIC	DEVONIAN — FAMENNIAN TO FRASNIAN?	Pillara Limestone Dp	Unknown	**Back-reef facies***:* yellow to light grey, bedded stromatoporoid limestone and oolite; calcarenite and calcilutite; localized areas of possible reef limestone	Small area in extreme SW	Low rocky rise; scattered jagged ridges of ?reef limestone	
		Napier Formation Dn	Unknown	**Fore-reef and inter-reef facies***:* grey to red-brown calcarenite and calcirudite; local scattered blocks of reef limestone	Small area in extreme SW	Gentle rocky rise	
	DEVONIAN — FRASNIAN? TO GIVETIAN	Van Emmerick Conglomerate Dv	About 15	Boulder, pebble, and cobble conglomerate with arkose matrix	Small area in extreme SW	Low conical hill	Granitic clasts predominate
UNCONFORMITY							

PROTEROZOIC	ADELAIDEAN	MOUNT HOUSE GROUP	Throssell Shale Ꝑht	?	Grey-green shale; buff and grey-green fine sandstone interbeds	Small area in extreme SE	Shale-strewn pediments and gentle debris slope	Light-toned, mottled photo-pattern. Probably only a few metres of section preserved
			Traine Formation Ꝑha	About 60	Green to brown coarse lithic sandstone. Minor sandy dolomite and dolomitic sandstone. Scattered glacial erratics	Small area in extreme SE	Low rounded hills and rises	Dark-toned photo-pattern
			Walsh Tillite Ꝑhw	About 50	Tillite, pink fine pebbly sandstone, pink to brown dolomite. Minor purple-brown siltstone and algal dolomite	Extreme SE	Scarp (tillite) and dip-slope (dolomite)	Topography distinctive. Interfingers with and overlies Beverley Springs Member
			Beverley Springs Member Ꝑhb	50	Poorly-sorted pebbly quartz sandstone	Low conical hills	S and W of Beverley Springs	Unconformable on Kimberley Group. Fills in ancient lowland
			UNCONFORMITY					
	CARPENTARIAN	KIMBERLEY GROUP	Hart Dolerite Ꝑdh	Up to about 3000, mostly ca 1200	Dark grey and grey-green tholeiitic dolerite; granophyre	Widespread, mainly along SW flank of King Leopold Ra	Valleys and ridges; steep slopes beneath sandstone escarpments	At least two main sills; in SW granophyre is more prominent at top of lower sill
			Pentecost Sandstone Ꝑkp	About 225	White to pale brown well sorted quartz sandstone; minor pale red-brown feldspathic sandstone and arkose with thin red-brown siltstone interbeds	Extreme W between Doubtful Bay and Walcott Inlet	Resistant sandstone cuestas; feldspathic beds form smooth rounded hills	Feldspathic beds form upper part of sequence and may be unconformable on lower part
			Elgee Siltstone Ꝑke	30-60	Red-brown shale, siltstone, and fine-grained sandstone. Minor pebble conglomerate at base	Extreme W between Doubtful Bay and Walcott Inlet	Valleys and scarp-slopes	Very poorly exposed. Lithology from adjacent parts of Yampi Sheet area
			Warton Sandstone Ꝑkw	450-600	White to pale-brown well sorted quartz sandstone; minor feldspathic sandstone	Harding, Synott, and Barnett Ras	Broad plateaux bordered by cliffs; rugged scarp and dip slope topography in W	Top eroded except in far W
			Carson Volcanics Ꝑkc	500-900?	Tholeiitic basalt and spilite; minor agglomerate, feldspathic sandstone, and siltstone	Surrounding Harding, Synnot, and Barnet Ras	Broad rolling lowlands with isolated hills and ridges	Agglomerate well developed in W and siltstone in Barnet Ra
			King Leopold Sandstone Ꝑkl	About 900-1000	White medium to coarse-grained quartz sandstone	King Leopold, Artesian, Edkins, Packhorse, and Phillips Ras; Sale and upper Charnley Rs	Rugged hills and ranges; butte topography locally. Deeply dissected by fault and joint valleys	Overlies Speewah Group conformably

TABLE 1. STRATIGRAPHIC TABLE.—*(cont.)*

Era	*Age*		*Rock Unit and Symbol*	*Thickness (m)*	*Lithology*	*Distribution*	*Topography*	*Remarks*
PROTEROZOIC	CARPENTARIAN	SPEEWAH GROUP	Luman Siltstone Ꝑpl	About 40	Purplish red siltstone and fine micaceous sandstone	King Leopold Ras SE of Mt Humbert	Steep slopes below King Leopold Sandstone	Poorly exposed; grades into sandstone to NW
			Lansdowne Arkose Ꝑpo	30-150	White to cream medium quartz sandstone; minor feldspathic sandstone and quartz granule conglomerate	King Leopold Ras SE of Mt Humbert	Prominent ridges	Well developed festoon cross-bedding locally
			Valentine Siltstone Ꝑpv	About 15	Green and purple shale, siltstone, and phyllite	King Leopold Ras SE of Mt Humbert	Low ground below Lansdowne Arkose	Rarely exposed
			Tunganary Formation Ꝑpt	60-90	White, medium to coarse quartz sandstone and feldspathic sandstone; minor siltstone and quartz granule conglomerate	King Leopold Ras	Prominent strike ridge	
			O'Donnell Formation Ꝑpn	100-170	Coarse quartz sandstone and pebble conglomerate; minor grey-green siltstone and shale	King Leopold Ras	Basal strike ridge of the Kimberley Basin rocks	Unconformably overlies Lamboo Complex
	UNCONFORMITY							
	LOWER PROTEROZOIC	LAMBOO COMPLEX — UPPER	Mount Amy Granite Ꝑbka		Fine, even-grained muscovite granite; aplite and tourmaline-muscovite pegmatite	Small outcrops in extreme SW, and 20 km S of Mt Hart homestead	Low hills and pavements cut by more resistant dykes	Intrudes Mondooma Granite, Halls Creek Group, and Lennard Granite. Some beryl in pegmatite
			Kongorow Granite Ꝑbkk		Dark grey coarse-grained porphyritic granite	Dykes, veins, and sheets in the Lennard Granite SW of Pardaboora R	Domes, pavements, and low whale-backs in hills of Lennard Granite	Equivalent to younger phase of Kongorow Granite in Yampi Sheet area. Forms large scale intrusion breccia with Lennard Granite
			Lennard Granite Ꝑbkl		Massive to foliated coarse, even-grained to porphyritic granite; local xenolith-rich zones, and contaminated zones	Along and E of Barker R; Swift Cr, King Cr headwaters; immediately S of Pardaboora R; S of Hawkstone Cr	Elongate whale-backs and bouldery hills in far SW. Elsewhere massive rounded bouldery *hills and tors with* large sandy pediments	Intrudes Mondooma Granite. Massive nature in NE of basement area contrasts with gneissose *nature in* SW. Xenolith swarm contains abundant blocks of ?Halls Creek Group

PROTEROZOIC	LOWER PROTEROZOIC	LAMBOO COMPLEX	MIDDLE	Mondooma Granite Ᵽbko		Medium - grained granite; porphyritic microgranite and microgranodiorite	Most of basement belt, except S margin	Massive, rounded bouldery hills, moderately rugged	Contains patches resembling Mount Disaster Porphyry. Bipyramidal quartz phenocrysts present in some areas. Marked joint control of drainage
				Mount Disaster Porphyry Ᵽbkd		Coarse pale pink to grey quartz feldspar porphyry, minor porphyritic granite	Extreme W, in headwaters of Hawkstone Cr, along Barker R, and flanking O'Donnell Formation SW of Mt Hepple	Bouldery hills similar to Mondooma Granite. Near Mt Hepple forms whalebacks, domes, and low pavements with intervening sand	Intruded by Lennard Granite. Dyke intrudes Whitewater Volcanics in SW
				Whitewater Volcanics Ᵽw	About 5000	Undifferentiated grey and grey-green rhyodacitic and dacitic ash-flow tuff; minor andesitic lava	Mainly NW of Mt Hart homestead; near Pardaboora R	Low rounded ridges	Andesitic types near base have prominent epidote replacing pyroxene
				Ᵽwa		Massive crystal-poor rhyodacitic ash-flow tuff; minor crystal-rich tuff	Extreme W on Pardaboora R about 6 km NE of King Sound Tin Mine	Low ridges	Quartz and feldspar phenocrysts prominent; matrix 50% or more of the rock
				Ᵽwb		Dacitic and minor rhyodacitic biotite-rich ash-flow tuff	In SW, a few km E and NE of King Sound Tin Mine	Prominent bouldery ridges. Less rugged than adjacent Mondooma Granite	Phenocrysts and lenticles of biotite prominent; quartz phenocrysts less abundant than in other varieties
			LOWER	Woodward Dolerite Ᵽbd		Dark grey-green very coarsely porphyritic to non-porphyritic amphibolite	SW near Hawkstone and Alexander Crs	Upstanding bouldery ridges, heavily grassed	Glomerocrysts of plagioclase up to 20 cm across. Intrudes and is folded with Halls Creek Group
ARCHAEAN?		HALLS CREEK GROUP		Ah	Unknown about 1500 preserved	Phyllite, minor quartzite; andalusite, chloritoid, staurolite, kyanite, and garnet mica schist. Actinolite - clinozoisite - garnet quartzite present locally	Small inliers between Hawkstone Cr and headwaters of the Pardaboora R in SW	Hummocky hills with short discontinuous ridges and closely spaced drainage	Metamorphism appears polyphase low to moderate pressure regional type. Arsenic and tin mineralization at King Sound Tin Mine. Kyanite-corundum-topaz deposit at contact with Woodward Dolerite

Impure quartzites are almost everywhere fine-grained and pale fawn to grey, poorly cleaved, flaggy to fissile and thin-bedded, though in some areas massive to blocky parting is common. Mica aggregates along bedding planes, and porphyroblasts of actinolitic amphibole and rare andalusite occur sporadically throughout the sandstones. Phyllite interbeds are common; ripple marks, graded bedding, micro-crossbedding, convolute bedding, and rare flame and pull-apart structures (Fig. 3a) have been found.

Green-grey *hornfels,* at a contact with granite near the Pardaboora River, shows spots of andalusite and chloritoid. A massive biotite-andalusite-quartz granofels 3 km west of old Federal Downs homestead has been formed by relatively intense thermal metamorphism.

Less abundant rock types in the Halls Creek Group include graphitic phyllite, calcareous phyllite, and breccia containing angular quartzite fragments in a meta-greywacke matrix. An unusual large lenticular xenolith of net-veined quartz-amphibole-feldspar-garnet gneiss, measuring 45 m by 6 m, occurs in Lennard Granite about 4 km west-southwest of Federal Downs homestead. It is blue-grey and quartzitic, with abundant grains of amphibole and small (1-2 mm) scattered grains of pink garnet. The net-veining by quartz produces a pseudoxenolithic effect (Fig. 3b).

Structure

Pelites in the Halls Creek Group are generally highly cleaved, and at least two cleavages are present in most specimens. One is usually subparallel to the bedding; the other, a crenulation cleavage, intersects it, and has produced a lineation on bedding planes. Bedding is vertical or steep to the south or southwest, though northerly dips are common in the inliers near the Pardaboora River. Mineral lineations generally plunge southeast, southwest, and east.

Only small-scale folding is recognizable; the microfolds are tight to isoclinal, and plunge to both the northwest and southeast.

Petrography

Phyllite contains bands composed principally of either quartz, quartz and muscovite, or muscovite; biotite and chlorite are less common. The micas are generally well oriented, but rare mica porphyroblasts are transverse to the schistosity. Rutile and tourmaline are common accessories.

Pelitic schists: Staurolite-andalusite-muscovite-biotite-quartz assemblages are common in the Hawkstone Creek/Alexander Creek belt. Staurolite forms subhedral grains from 0.3 mm to 1 mm, some of which show cruciform interpenetration twinning. Quartz inclusions and vermiform intergrowths with quartz occur in the cores of some grains. Staurolite also forms concentrations in andalusite-muscovite porphyroblasts, in one case in association with kyanite. Garnet forms porphyroblasts 1 to 5 mm in diameter. Trains of quartz and rare biotite inclusions are present, oblique to the schistosity in the rock, which wraps around the garnet. In one specimen from an inlier near the Pardaboora River chloritoid crystal aggregates with some chlorite are pseudomorphous after andalusite (Fig. 4a). Elsewhere chloritoid is independent of andalusite, and is commonly altered to inclusion-rich biotite. In the kyanite deposit chloritoid occurs with quartz in small veinlets. Andalusite forms large porphyroblasts which may contain abundant inclusions of

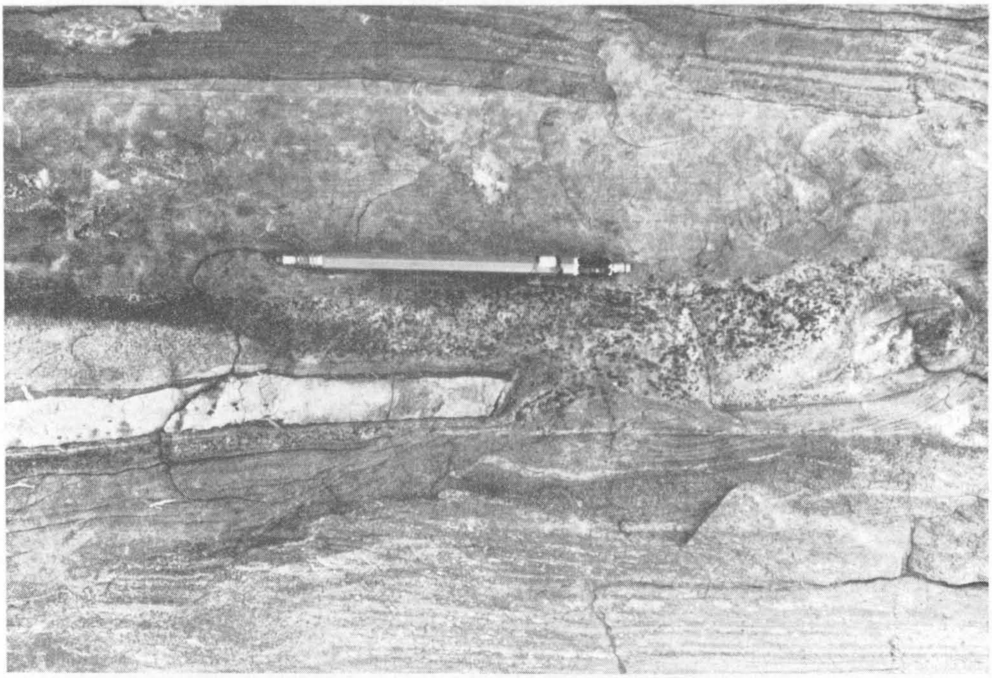

Fig. 3a. Bedded metasediments of Halls Creek Group, showing white bed of competent quartzite (centre) fractured during deformation and less competent pelite showing flow deformation. Note flame structures of psammite intruding upper pelite bed. M431.

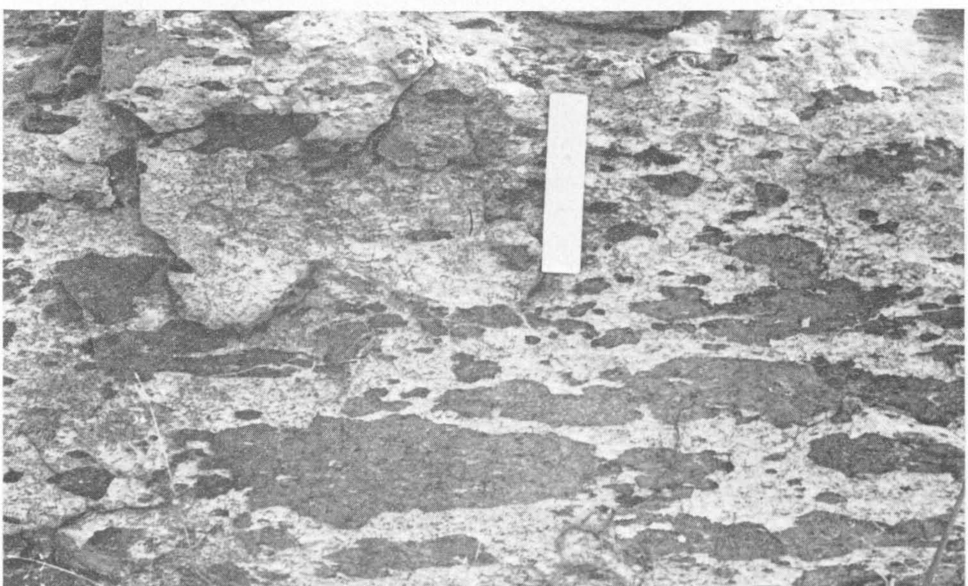

Fig. 3b. Dark patches of quartz-amphibole-feldspar-garnet rock intricately veined by quartz, producing a pseudo-xenolithic effect. Halls Creek Group gneiss 4 km west-southwest of Federal Downs. M431/3B.

quartz; chiastolite is also common. Muscovite is the most common alteration product, though some crystals are altered to a biotite-muscovite aggregate. Many specimens show at least two generations of andalusite, and pre and post-tectonic porphyroblasts.

Aluminous rocks in the kyanite deposit: Kyanite schist (Fig. 5a), tourmaline-dumortierite-kyanite rock, and corundum-sericite rock from the kyanite deposit have been described by Derrick & Morgan (1966). Corundum-mica-topaz and kyanite-topaz rocks are also present. The corundum forms granular aggregates arranged radially about a field of mica, and topaz forms narrow veinlets of anhedral medium-grained aggregates.

In the kyanite-topaz rocks, kyanite forms square-sectioned metacrysts 1-2 mm across in a fine-grained topaz matrix. Fine-grained opaque inclusions in the cores of the square-sectioned kyanite crystals suggest that kyanite is pseudomorphous after chiastolite (Fig. 5b). Some of the metacrysts are altered to an aggregate of muscovite and coarse-grained topaz.

Yellow-green tourmaline and rutile are accessory minerals, generally concentrated along microfractures. Sphene and actinolite are common in a calcareous bed within the kyanite-bearing sequence.

Hornfels: A massive biotite-andalusite-quartz-granofels has been examined. Andalusite poikiloblasts up to 1.5 cm long are fresh, and contain abundant quartz intergrowths. Biotite is red-brown and free from inclusions, in contrast to muscovite with which it is associated. Quartz is abundant, and in places contains needles of sillimanite which also forms fibrolitic aggregates closely associated with biotite. Locally it replaces andalusite, and this is similar to occurrences noted by Chinner (1961) and Gemuts (1965). Plagioclase (1%) is of composition An_{9-12}; accessories are coarse-grained olive-green tourmaline, zircon, and magnetite.

A xenolith of *net-veined gneiss* in Lennard Granite shows prominent amphibole poikiloblasts with Z = grey-blue, extinction angle 11°, and optic axial angle 85°. The amphibole, possibly actinolite, forms slender euhedral prisms 1 to 4 mm long, with abundant iron oxide and clinozoisite inclusions. The Z axial colour is more intense than in similar crystals in psammites in the Halls Creek Group, and probably reflects higher-temperature conditions. Pale pink euhedral garnet crystals up to 2 mm diameter are also present, in a matrix of quartz, clinozoisite, epidote, plagioclase, and iron oxide.

Psammites: These are well banded, siliceous, and slightly calcareous. Actinolite is the most abundant poikiloblast (Fig. 4b), and forms euhedral crystals up to 3 mm long, with Z = pale blue-green. It is associated with granoblastic quartz, muscovite, sphene, and plagioclase, in bands containing variable amounts of garnet and clinozoisite. Plagioclase ranges from An_{17} in one specimen to An_{31} in another.

LOWER PROTEROZOIC

Lower Lamboo Complex

Woodward Dolerite

Sills of metamorphosed, commonly porphyritic dolerite and gabbro, which intrude the Halls Creek Group in the southwestern corner of the Sheet area, are referred to as the Woodward Dolerite. The sills are members of a discontinuous series that extends from Mount Nellie (Yampi Sheet area) in the northwest to Ruby Plains (Gordon Downs Sheet area) in the southeast.

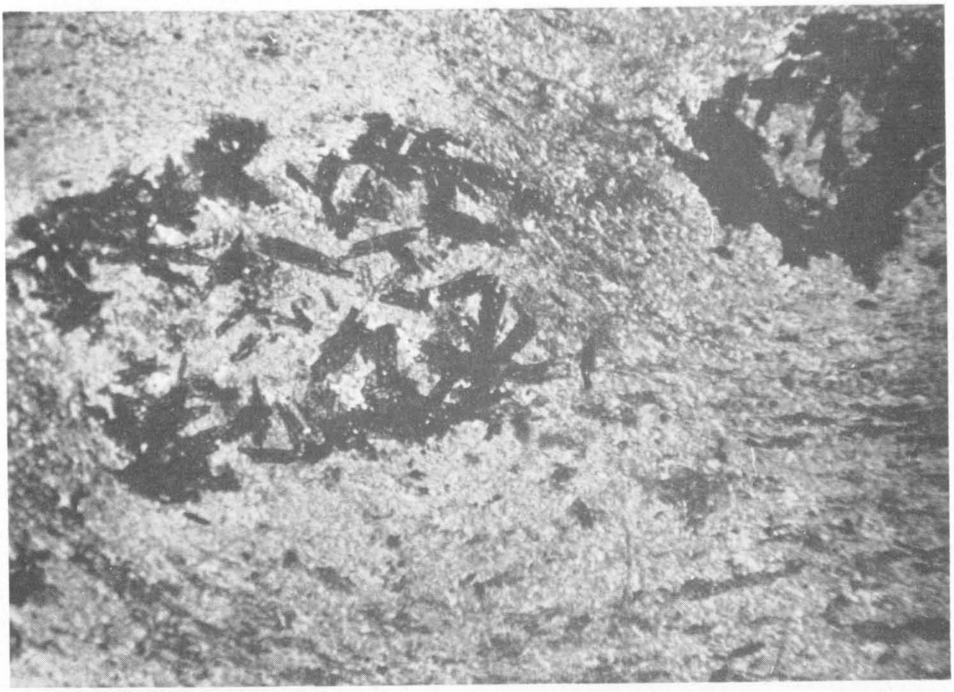

Fig. 4a. Chloritoid aggregates pseudomorphing andalusite porphyroblasts in phyllite. Plane polarized light. x 36. Halls Creek Group inlier 6 km north-northwest of King Sound Tin Mine. M759.

Fig. 4b. Actinolite poikiloblasts in quartzite. Crossed polarizers. x 36. Halls Creek Group, 3 km west of Hawkstone Creek kyanite deposit. M692.

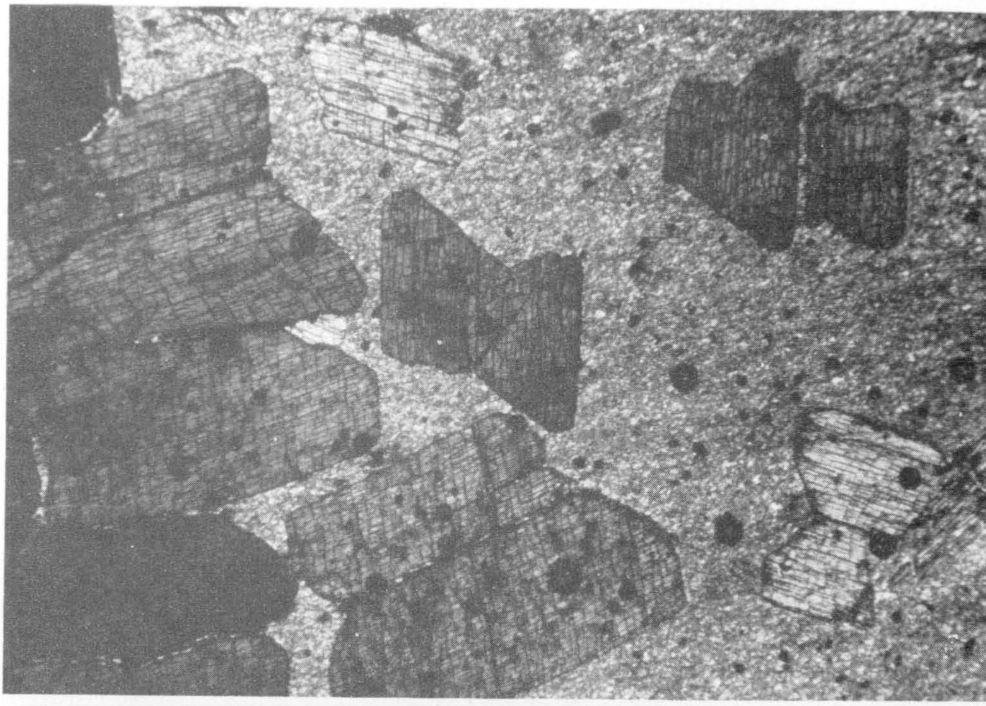

Fig. 5a. Twinned porphyroblasts of kyanite in mica schist. x 36. Crossed polarizers. From Hawkstone Creek kyanite deposit. M692.

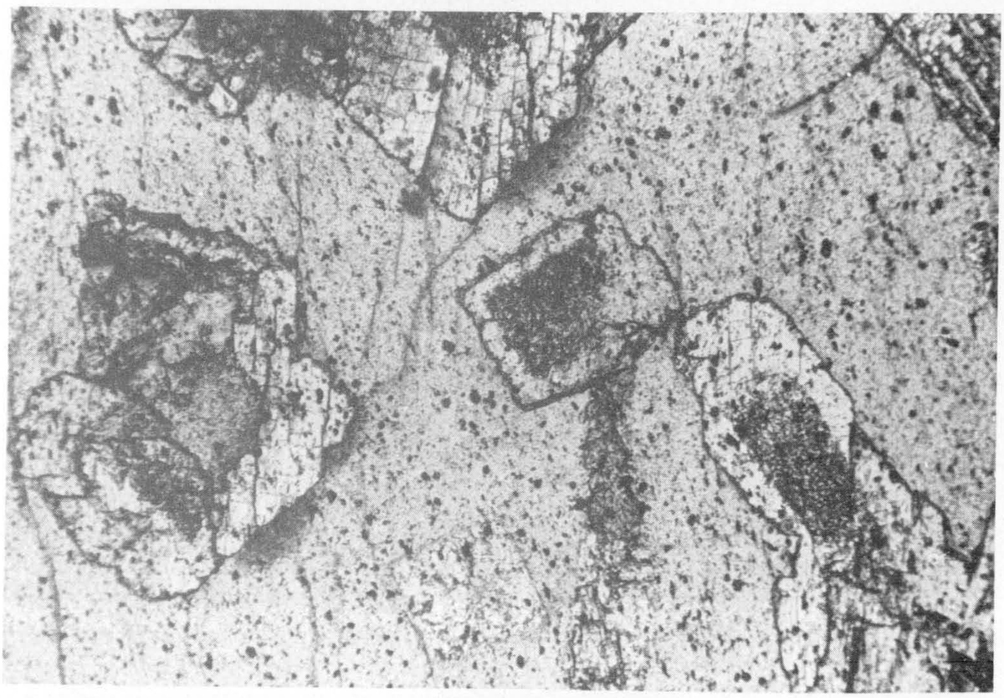

Fig. 5b. Pseudomorphs of kyanite after andalusite. Note relict chiastolitic cores in kyanite. Fine-grained matrix is topaz aggregate. x 36. Plane polarized light. From Hawkstone Creek kyanite deposit. M759.

Lithology

In hand specimen the dolerite is dark grey-green, massive or poorly foliated, and is mostly non-porphyritic. It is porphyritic locally near the upper part of the main sill, and also in the thin sill that underlies it. Most porphyritic types contain equant plagioclase phenocrysts and glomeroporphyritic aggregates 1 to 2 cm across and making 20 to 50 percent of the rock. Porphyritic types are found locally with abundant phenocrysts of hornblende 2 to 3 mm across, but lacking plagioclase phenocrysts, for example 2.5 km west of the kyanite deposit.

In one locality about 5 km south of the kyanite deposit large rosettes of plagioclase phenocrysts up to 20 cm across make up about 50 percent of the rock, but the size and abundance of phenocrysts decrease rapidly northwards (downwards in the sequence).

Phenocryst sizes and contents at sample areas of this outcrop have been studied in detail by grid point-counting of photographs. The variations in phenocryst size and content are shown in Figure 6.

The feldsparphyric types, for the most part, appear to be confined to one section in the upper part of the main sill. Locally, for example 2.5 km west of the kyanite deposit, and also in the northwestern part of the Lennard Sheet area about 3 km south of Hawkstone yard, the feldsparphyric types are regularly interlayered with the non-porphyritic.

Petrography

Specimens of the Woodward Dolerite are typically normal dolerites which have been metamorphosed to the amphibolite facies, producing rocks composed

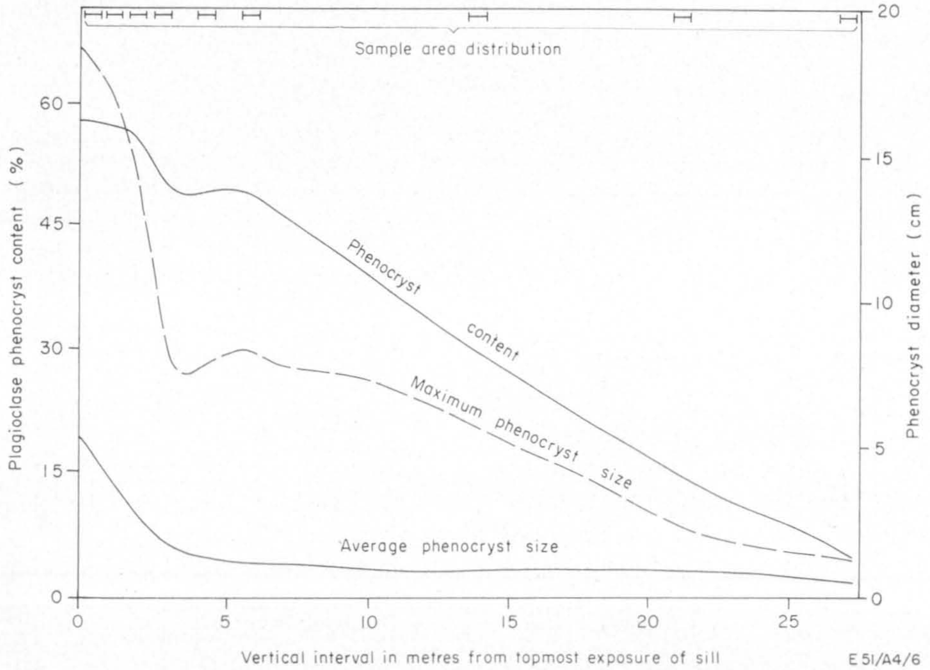

Fig. 6. Variation in plagioclase phenocryst size and content in outcrop of Woodward Dolerite 6 km south of Hawkstone kyanite deposit.

almost entirely of plagioclase and hornblende, and minor amounts of quartz, sphene, ilmenite, ?magnetite, goethite, and locally epidote, zoisite, and chlorite. In most rocks the hornblende content appears to exceed that of plagioclase. Only in the feldsparphyric rocks does plagioclase predominate, and in these hornblende generally makes up more than 50 percent of the groundmass.

Plagioclase phenocrysts consist of aggregates of subhedral equant and tabular grains and partly of anhedral sub-grains derived from larger grains by fracturing and recrystallization. The plagioclase is fresh, but invariably contains aligned acicular hornblende inclusions, and small hornblendes developed along fractures. Albite, carlsbad, and pericline twinning are common, pericline twinning conspicuously so. Composition of phenocrysts ranges from An_{45} to An_{65}. Most are apparently unzoned. Groundmass plagioclase occurs as subhedral tabular and anhedral equant grains up to 0.5 mm across. Twinning is similar to that in the phenocrysts, but pericline twinning is relatively less common. The grains are fresh and of composition An_{60} to An_{65}. The groundmass plagioclase appears to be more calcic than plagioclase phenocrysts in the same rock, but more work is required to establish this.

Hornblende phenocrysts, present in only one rock (R 66.16.1000), occur as anhedral 3 mm grains elongated slightly in the cleavage direction. They contain ophitic and subophitic tabular plagioclases locally, and patchily arranged minute inclusions of plagioclase and (?)magnetite. Hornblende phenocrysts commonly show twinning parallel to (100) and have $Z^1c = 15°$ and $Y = b$. Pleochroism is X very pale brown, Y pale olive green, Z pale blue-green. Groundmass hornblende commonly shows good preferred orientation. Crystals are similar to the phenocrysts except that ophitic texture is absent, Z^1c is generally in the range 18° to 24°, and blue-green is absent from the pleochroic scheme. They are mostly free from inclusions, but in one specimen (R 67.16.1023) hornblendes completely enclosed in plagioclase phenocrysts contain minute lenticular lamellae of (?)magnetite aligned along cleavages.

Quartz occurs only as rare 0.2 mm grains associated with matrix plagioclase. Sphene forms coronas of varying width around ilmenite. Epidote forms small inclusions in plagioclase only in one rock containing phenocrysts of hornblende (with blue-green absorption in the Z direction); the same rock contains scattered tabular grains of a colourless to very pale olive green chlorite. Scattered grains of zoisite are present in most of the other rocks both within and bordering plagioclase.

Middle Lamboo Complex

Whitewater Volcanics

A sequence of acid volcanics, mainly ash-flow tuffs, in the southwest corner of the Charnley Sheet area is referred to as the Whitewater Volcanics (Dow et al., 1964; Dow & Gemuts, 1969). They crop out extensively throughout the older Precambrian of the East and West Kimberley areas.

The Whitewater Volcanics crop out as low rounded bouldery ridges, generally less rugged than the adjacent Mondooma Granite. The ridges mostly have a thick covering of grass, which gives them a light tone on aerial photographs.

The outcrops northeast of King Sound Tin Mine and east of King Creek yard are conspicuously layered. In the former area the layering is subvertical: in the latter it dips northwards at about 30°. The other outcrops are less well mapped and their structure is unknown. The maximum thickness exposed in the Sheet area is estimated to be about 3400 m, but the full sequence is not exposed.

Lithology

In hand specimen the predominant rock type is a pale grey-green, coarsely porphyritic ash-flow tuff containing prominent phenocrysts (up to 6 mm) of bipyramidal quartz and feldspar, and small patches of mafic minerals. The ash-flow tuffs have been subdivided into crystal-poor and crystal-rich varieties and where possible these have been delineated on the map. In hand specimen it is difficult to distinguish crystal-rich tuff from Mondooma Granite.

A more mafic variant, generally found near the base of the sequence, has been mapped as biotite-rich ash-flow tuff. It is dark grey in hand specimen, contains only sparse quartz phenocrysts, has conspicuous spots and lenticles of biotite, and is dacitic, in contrast to the more common rhyolite and rhyodacitic types.

An unusual variant which forms a continuous flow near the base of the most northerly outcrop is a black aphanitic porphyritic andesite. This rock is apparently a lava rather than an ash-flow tuff. Boulders of fine-grained grey-green non-porphyritic andesite (probably lavas) have also been collected from stream beds draining the sequence containing the black andesite.

Contact relations

The Whitewater Volcanics overlie the Halls Creek Group, but the contact is obscured; in the Lennard River Sheet area (Gellatly et al., 1968) they are unconformable on the Halls Creek Group. The volcanics are overlain unconformably by the basal beds of the Speewah Group.

The Whitewater Volcanics are apparently intruded by the Mondooma Granite. The contact has not been observed, but the probable relation is well displayed on a large scale by the truncation of the layering of the volcanics by the Mondooma Granite about 11 km east-northeast of King Creek yard (see 1:250 000 map).

Petrography

Most specimens from the Whitewater Volcanics are densely welded ash-flow tuffs of rhyolitic, rhyodacitic, or dacitic composition, and there are rare andesitic lavas. Most of the volcanics are porphyritic and contain both whole phenocrysts and phenocryst fragments and splinters. Phenocryst content tends to be slightly lower in intermediate than in acid varieties. The average grainsize of the phenocrysts ranges from 1 mm to 2 mm.

Quartz occurs typically as equant pyramidal grains which commonly show prominent resorption embayments. In one of the more densely welded examples quartz has broad turbid overgrowths. Plagioclase is the dominant feldspar in most specimens. Composition is around An_{30} to An_{40} but can rarely be determined because of intense alteration to sericite and clinozoisite. Clinozoisite tends to be more abundant near crystal cores (suggesting zoning from intermediate cores to more sodic margins), but scattered plagioclase are altered to clinozoisite throughout. Potash feldspar is generally a microcline microperthite of the 'patch' variety and is unaltered. Probable sanidine has been noted in one sample. Grains of original pyrobole (probably pyroxene) are pseudomorphed variously by biotite + clinozoisite or by chlorite + specks of (?)magnetite, and are locally streaked out into lenticles. Minor amounts of apatite, granular magnetite, and zircon are associated with these mafic pseudomorphs. Ilmenite bordered by sphene, and pink zircon are accessories.

The matrix is generally a partly recrystallized aggregate of polygonal cloudy grains of quartz and feldspar. Flow lines curving round phenocrysts are generally evident. Rare glass shards are preserved as recrystallized quartz.

The porphyritic andesite differs texturally from the ash-flow tuffs in its lack of crystal fragments and shards. Phenocrysts are entirely of highly altered plagioclase, and euhedral aggregates of epidote and associated magnetite-ilmenite which apparently pseudomorph original pyroxene. The matrix is a streaky devitrified glass containing microlites of possible pyroxene.

A further example of a possible andesitic lava contains rare microphenocrysts of augite and scattered microlites of plagioclase in a chloritic matrix.

Discussion

In the Charnley Sheet area the Whitewater Volcanics are of interest since they contain the first lavas to be recognized with certainty in the formation. Lavas may also occur elsewhere, for example in the southwest part of the Lansdowne Sheet area (Gellatly et al., 1965), but there they are too altered to be recognized with certainty. In both areas all the probable lavas are of andesitic composition, and most are near the base of the formation.

Mount Disaster Porphyry

The Mount Disaster Porphyry, named from Mount Disaster in the Yampi Sheet area (Sofoulis et al., 1971), is found throughout the West Kimberley and is closely associated with the Whitewater Volcanics.

Lithology

The Mount Disaster Porphyry is a coarsely porphyritic quartz-feldspar porphyry of granitic composition. Pink to white phenocrysts of potash feldspar up to 1.5 cm predominate, and locally form ovoids up to 6 cm in diameter (Fig. 7a). Cream-green plagioclase and glassy to pale blue-grey quartz phenocrysts up to 1 cm across are also abundant. Biotite is the only obvious mafic mineral present. The groundmass is fine-grained. Dioritic xenoliths are common in the Barker River area. Small xenoliths of pale green to grey Whitewater Volcanics are present in the dyke in the Robinson River. The chilled margin of the dyke is grey and less coarsely porphyritic. Quartz and potash feldspar form phenocrysts up to 2 mm long (Fig. 7b).

Contact relations

The Mount Disaster Porphyry is in contact with the Halls Creek Group in the Hawkstone Creek area, about 11 km east of the King Sound Tin Mine. The contact is not exposed, but it is inferred that the porphyry intrudes the Halls Creek Group. In this area the porphyry contains moderately abundant metasedimentary xenoliths (probably Halls Creek Group), mostly about 15 cm across.

At most localities the Whitewater Volcanics are intruded by the Mount Disaster Porphyry. Along the Barker River, large xenolithic blocks of fine-grained

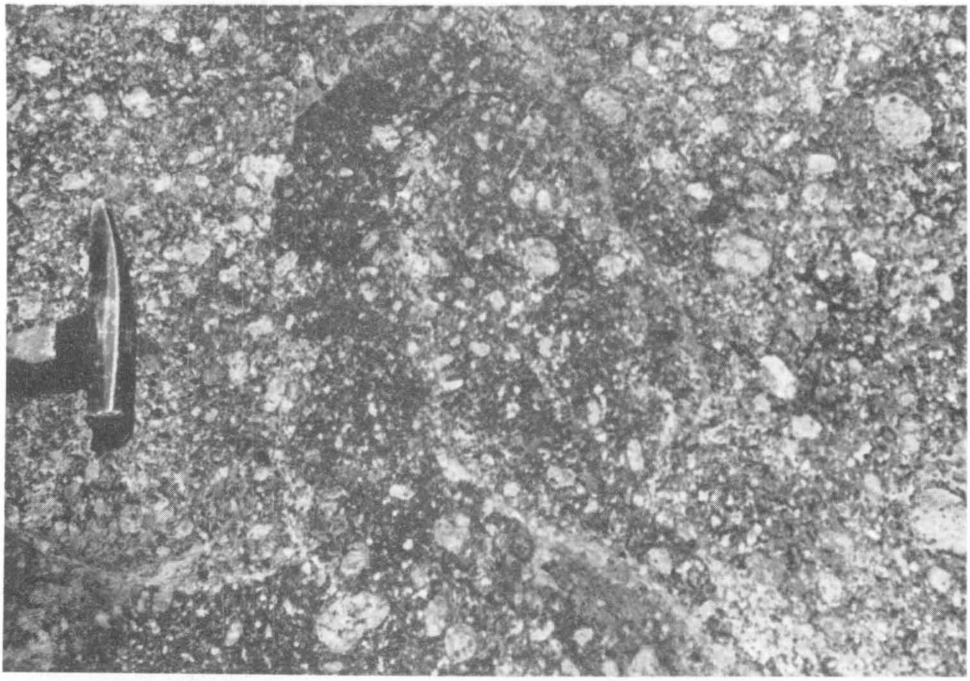

Fig. 7a. Highly porphyritic Mount Disaster Porphyry, with large ovoid phenocrysts of potash feldspar. Dark patches are due to weathering. 10 km east of King Sound Tin Mine. M/1101.

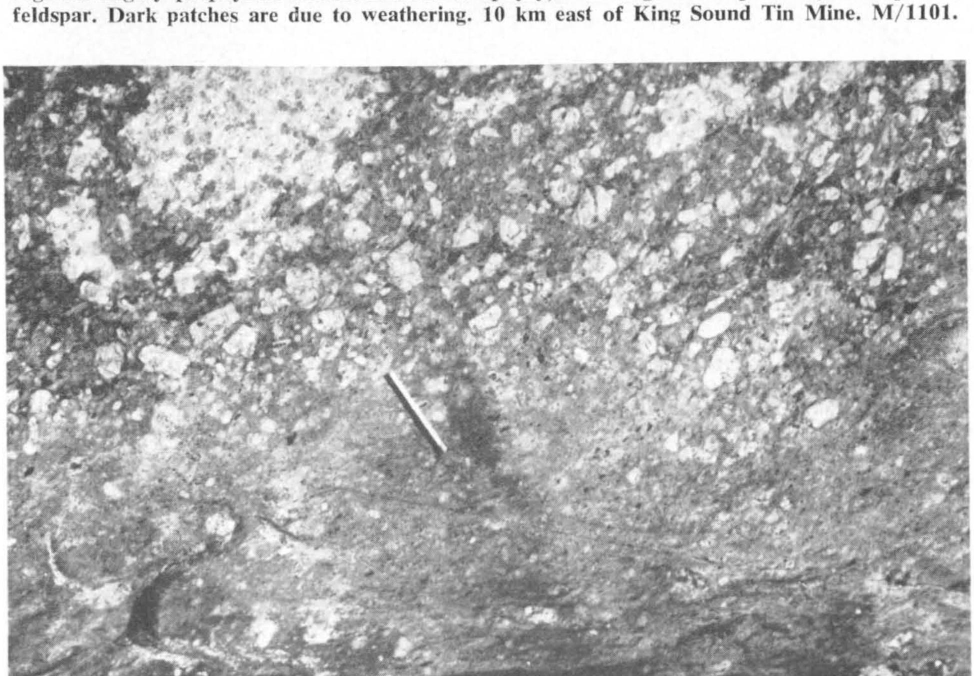

Fig. 7b. Dyke of Mount Disaster Porphyry showing phenocryst-rich centre and finer-grained chilled margin, with rare large phenocrysts. Note orientation of phenocrysts at right angles to match stick. In Robinson River near western boundary of Sheet area. M528.

crystal-poor ash-flow tuff show sharp contact with the enclosing Mount Disaster Porphyry. In the Robinson River the porphyry dyke (Fig. 7b) transgresses the flow-foliation in dark fine-grained crystal-poor tuff, and is chilled against the tuff sequence. The chilled margin shows contorted flow-banding.

Possible reverse relations are suggested in the Hawkstone Creek locality, where the Mount Disaster Porphyry and biotite-rich crystal tuff are intimately mixed. The tuff contains a xenolith of possible porphyry, and also xenocrysts of quartz and feldspar, probably derived from the porphyry.

The Mount Disaster Porphyry is probably older than the Mondooma Granite, though the two units appear coeval in many places. Near its margin the granite contains lenticular, coarsely porphyritic patches 8 cm to 30 cm across, resembling the Mount Disaster Porphyry. Contacts between the patches and the host rock are both sharp and gradational, and they probably represent xenoliths which differed little in composition and temperature from the Mondooma Granite at the time of incorporation. These features are more fully described in the section on the Mondooma Granite.

The Mount Disaster Porphyry is intruded by the Lennard Granite. The contact is well exposed about 10 km west of Mount Hepple. It is sharp and irregular, and the Lennard Granite shows a chilled margin 10 cm wide. Dykes and sheets of aplitic granite in the contact zone cut the porphyry.

Petrography

Three thin sections have been examined, two of which are from the dyke in the Robinson River. Modal analyses are given in Table 2. Specimen 67.16.1055 represents the porphyritic centre of the dyke, and 67.16.1058 is typical of the chilled margin. Specimen 67.16.1054 is typical of the larger masses of porphyry throughout the Sheet area.

TABLE 2. MODAL ANALYSES OF MOUNT DISASTER PORPHYRY

Number	R67.16.1055	R67.16.1058	R67.16.1054
Locality	1132 E 28835 N	2232 E 28835 N	2689 E 28741 N
Phenocrysts	25%	30%	45%
Quartz	16	12	13
Potash feldspar	4	7	4
Plagioclase	2	10	20
{ Biotite	3(bi)	1(mu)	7
{ Muscovite			
{ Hornblende	—	—	1
Groundmass	75%	70%	55%
Quartz	24	26	20
Potash feldspar	48	40	35
Mica (bi + mu)	1	1	—
Plagioclase	2	2	—
	100%	100%	100%

The phenocryst content of the rocks and the relative proportions of the phenocryst minerals vary widely. The granular, highly potassic groundmass is typical and optical methods and staining indicate an almost complete absence of plagioclase.

The porphyry is mostly of granitic composition. Quartz phenocrysts are clear with slightly undulatory extinction. Fine-grained polygonal aggregates are formed along microfractures in the larger quartz grains, which are embayed and marginally corroded. Potash feldspar forms subhedral to euhedral grains which are well aligned in the dyke rocks. The grains are microperthitic and show simple Carlsbad twinning; cross-hatching of the feldspar is rare and patchily developed. Plagioclase is highly altered to sericite and clinozoisite and the composition cannot be determined. In 67.16.1055 it forms very irregular, highly corroded grains. In 67.16.1054, the plagioclase contains granophyric intergrowths of quartz and potash feldspar.

Biotite, the dominant mafic mineral, generally occurs as elongate clots of fine-grained green-brown crystals. In 67.16.1054 it shows fawn to vivid red-brown pleochroism. Chlorite and clinozoisite are the main minerals associated with biotite. In one sample fluorite is developed along the biotite cleavage planes. Muscovite is common in the dyke rock, in which it poikilitically encloses part of the groundmass, and less commonly replaces potash feldspar phenocrysts. Green-brown hornblende in 67.16.1054 appears to postdate biotite and chlorite. Accessory minerals include zircon, apatite, iron oxide usually associated with biotite, and fluorite and calcite in narrow veinlets with quartz and rare plagioclase. Allanite, showing strong zoning, forms grains up to 1.5 mm long in 67.16.1054.

Phenocryst orientation in dyke rock

The dyke in the Robinson River has a fine to medium-grained chilled margin which contains rare large phenocrysts similar to those in the highly porphyritic centre of the dyke. The phenocrysts in the centre are aligned obliquely to the dyke walls. The orientation of the feldspar phenocrysts is possibly related to sinistral shear deformation along the dyke walls or may be due to irregular flow during intrusion.

Mondooma Granite

The Mondooma Granite, named after Mondooma yard in the Yampi Sheet area, is defined in Sofoulis et al. (1971). It consists essentially of porphyritic biotite microgranodiorite characterized by the presence of bipyramidal quartz phenocrysts. In places it closely resembles the crystal-rich phases of the Whitewater Volcanics, and is also similar to and probably related to Bickleys Porphyry of the Lansdowne and Lennard River Sheet areas.

Field occurrence

Distribution. The Mondooma Granite extends from the Barker River west and northwest to the margin of the Sheet area, and forms about two-thirds of the outcrop area of the pre-Carpentarian rocks. It is bounded in the northeast by the Speewah Group, and in the south by belts of Halls Creek Group and Whitewater Volcanics. This broad expanse of Mondooma Granite, totalling about 780 km^2, is interrupted only by a series of roof pendants of Halls Creek Group, minor areas of Whitewater Volcanics, and iregular intrusions of Lennard Granite. Scattered roof pendants of Mondooma Granite occur in the Lennard Granite east of the Barker River.

Topographic expression and photo-pattern. The Mondooma Granite forms a monotonous series of dark rounded bouldery hills, as seen from the Swift Creek area southeast towards Mount Matthew. Southwest of the Robinson River the hills are more widely spaced and slightly elongate in a northwest direction and tracts of soil and alluvium are more abundant.

Dissection along the intersecting joints of the Mondooma Granite has produced a trellised drainage pattern, and large-scale segmentation of the outcrop (Fig. 2a). The photo-pattern of the granite is dark grey and moderately smooth-toned, interspersed with black patches of vegetation-free boulders, especially near the Lennard Granite. The photo-pattern of the Mondooma Granite is difficult to distinguish from that of the Whitewater Volcanics, though the latter tend to form lower hills and to show bedding-foliation trends.

The average elevation decreases from nearly 360 m along the foot of the King Leopold Ranges to about 240 m in the far southwest. The tops of the hills are generally coincident, and are probably remnants of an erosion surface sloping gently to the west and southwest. Relief throughout the area is 30 to 150 m.

Lithology

The Mondooma Granite consists of coarse to medium-grained porphyritic microadamellite and minor porphyritic microgranite and microgranodiorite. A few specimens are non-porphyritic. It varies from light to dark grey, grey-blue, or pale fawn. Discrete quartz phenocrysts from 2 mm to 5 mm are characteristic, and show a euhedral pyramidal form; some specimens contain anhedral quartz splinters similar to those found in the Whitewater Volcanics. The quartz dominates the appearance of the granite in weathered outcrop, and generally forms up to 30 percent of the rock surface. Plagioclase and potash feldspar phenocrysts are less obvious, although both are widespread throughout the mass. They range from 2 mm to 1 cm, and occur singly or in thin discontinuous bands and patches. Mafic content varies widely, and appears to be lowest in the belt adjacent to the sandstone ranges south of Mount Humbert. Biotite, the principal mafic mineral, forms clots of fine-grained flakes or discrete plates. Laths of dark green amphibole up to 3 mm long are widespread, and show a highly altered yellow-brown core, possibly after pyroxene.

Common throughout the granite are patches, lenticles, and discontinuous bands of coarsely porphyritic granite which resembles Mount Disaster Porphyry. These xenolithic remnants are 10 cm to 1 m long, and contain anhedral to euhedral alkali feldspar phenocrysts 1 cm to 4 cm long, and locally ovoid phenocrysts up to 5 cm across. Contacts between these xenoliths and host rock are sharp to gradational, and some xenoliths are partly resorbed. Many of the large discrete potash feldspar phenocrysts in Mondooma Granite may in fact be xenocrysts derived by partial resorption of these xenoliths.

Form and structure

Detailed information regarding the form of the Mondooma Granite is lacking because of its massive nature and the paucity of exposed contacts with other rocks. Foliations with gentle but variable dips measured in the Alexander Creek area suggest that the granite there forms an undulating sheet. However, foliations elsewhere in the Mondooma Granite have steep dips. Observed contacts are steeply dipping; for example, near the junction of Swift and King Creeks a roof pendant of Mondooma Granite has steeply dipping contacts with Lennard Granite, and east of Federal Downs homestead the Mondooma Granite has steep contacts with roof pendants of Halls Creek Group.

Much of the granite outcrop is massive and structureless except for joints trending northwest, north, and northeast. Near contacts with Lennard Granite and Halls Creek Group a foliation is present, defined by alignment of phenocrysts or xenoliths, and by localized compositional banding.

Contact relations

The Mondooma Granite intrudes the Halls Creek Group, which forms three roof pendants up to 3.5 km across, east and southeast of Federal Downs homestead. Flow banding in the granite is ubiquitous near contacts and is defined mainly by orientation of potash feldspar phenocrysts. Compositional banding of at least two types is also widespread, for example, near the Pardaboora River, where bands up to 8 cm thick are defined by variations in mafic content. The bands show swirls and vague folds, and may be ghost relics of assimilated metasediment. Another type of banding, found along the eastern contact of the Pardaboora River inlier, consists of very thin laminae of non-porphyritic Mondooma Granite (metasomatized Halls Creek Group?) alternating with porphyritic granite rich in quartz phenocrysts (Fig. 10). Elsewhere there are bands with abundant large potash feldspars. Although such banding suggests assimilation of metasediment by Mondooma Granite, the Halls Creek Group is only slightly recrystallized at most other contacts. The granite at one locality in the Alexander Creek area has a chilled margin 0.5 m wide, and the Halls Creek Group is veined by quartz and some aplite. Xenoliths are common in the contact zones, and although slightly recrystallized, retain their original lamination. Most are 2.5 to 15 cm long, lenticular, fine-grained, and biotite-rich.

In the Robinson River area the transition from crystal tuff of the Whitewater Volcanics to Mondooma Granite is inconspicuous, and marked only by a coarsening of the groundmass in the former, and abrupt changes of foliation direction between the two rock types. Platy xenoliths of ash-flow tuff in the Mondooma Granite are evidence that the Whitewater Volcanics are intruded by the Mondooma Granite.

The numerous xenoliths resembling Mount Disaster Porphyry that are scattered throughout the Mondooma Granite indicate that the latter is younger, although the varying degrees of assimilation of xenoliths and their diffuse margins suggest that the porphyry may not have been completely crystallized at the time of intrusion of the Mondooma Granite, and thus any age difference is very small.

The Lennard Granite intrudes the Mondooma Granite, which is slightly hornfelsed and shows a coarsening of the groundmass. The higher resistance of this contact zone is probably responsible for concentration of the massive black boulder outcrops around areas of Lennard Granite. About 3.5 km west of King Creek yard the Mondooma Granite is cut by veins of a mafic-rich variety of Lennard Granite. In the same area massive Lennard Granite becomes finer-grained towards the Mondooma Granite and contains abundant flow-oriented tabular xenoliths parallel to the contact. These xenolith-rich contact zones are described in the chapter on the Lennard Granite.

About 7 km west of Federal Downs homestead, small roof pendants of Mondooma Granite are heavily veined by large masses of aplite and tourmaline-bearing pegmatite of the Mount Amy Granite. Similar large aplite masses truncate the Mondooma Granite 3.5 km north of Alexander Creek. The mafic minerals in the Mondooma Granite are slightly recrystallized, and the granite has a thin (5 cm) border which is more even-grained than usual.

TABLE 3. ESTIMATES OF MODAL COMPOSITION—MONDOOMA GRANITE

*Specimen No.**	66.16 1008	66.16 1009	67.16 1020	67.16 1033	67.16 1034	67.16 1076	67.16 1036	67.16 1037	67.16 1049	67.16 1051	67.16 1056	67.16 1061	67.16 1071	67.16 1073	67.16 1075	67.16 1076	67.16 1084	67.16 1085
Phenocrysts	65	90	100	50	100	50	60	60	55	75	65	60	65	60	70	65	55	75
Quartz	15	20	22	20	25	10	15	10	15	25	27	10	8	20	25	8	7	27
Plagioclase	25	45	40	15	30	17	30	35	30	12	5	25	28	10	25	35	35	15
K. feldspar	15	15	28	13	35	15	7	5	3	30	30	20	21	27	17	12	15	28
Biotite	10	2	4	1	5	8	8	10	4	8	3	5	4	3	3	10	—	5
Hornblende	—	3	6	1	5	—	—	—	3	—	—	—	4	—	—	—	—	—
Orthopyroxene	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Groundmass	35	10	—	50	—	50	40	40	45	25	35	40	35	40	30	35	45	25
Quartz	20	8	—	20	—	25	20	20	20	15	12	?15	?10	15	?12	15	15	10
K. feldspar	11	2	—	20	—	25	20	20	25	10	18	?15	?13	20	?12	20	25	15
Plagioclase	4	—	—	10	—	—	—	—	—	—	5	?10	?12	5	?6	—	?5	—
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Plagioclase phenocryst composition (average)	An_{41}	An_{37}	An_{40}	An_{37}†	An_{37}	An_{38}	An_{30}†	An_{32}	An_{30}†	An_{42}	—	An_{30}†	An_{38}	An_{43}	An_{30}†	—	—	An_{32}†

† Minimum value.
* BMR Sample numbers. Location of samples shown in Figure 8.

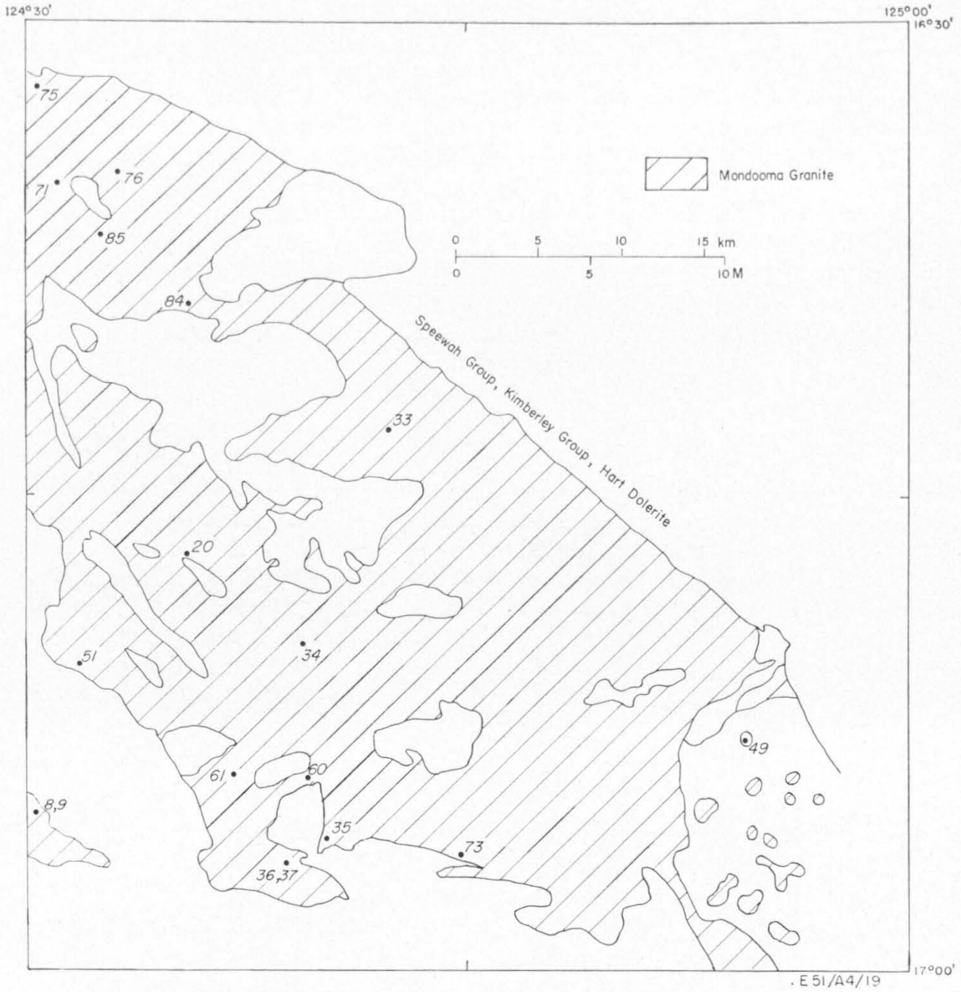

Fig. 8. Sample localities. Mondooma Granite.

Petrography

Both even-grained granite and porphyritic microgranite occur in the Mondooma Granite, and although differing texturally, are similar petrographically. Seventeen specimens have been examined in thin section, and the modal analyses and distribution are given in Table 3 and Figure 8 respectively. The modes were estimated from thin section and from rock slices stained for potash feldspar.

The phenocryst/groundmass ratio in the porphyritic rocks ranges from 3:1 to 2:1. Phenocrysts of quartz vary from 8 to 27 percent of the total rock, of plagioclase from 5 to 45 percent, and of potash feldspar from 3 to 27 percent. Mafic minerals form 3 to 10 percent of the suite.

Quartz forms discrete clear phenocrysts from 1 to 7 mm (average 3 mm), which are subhedral to euhedral and commonly embayed and corroded. Rarely the grains are elongate, angular, and completely anhedral, or are recrystallized to a fine-grained polygonal aggregate. Fine trails of dust-like inclusions are present. Most grains show a patchy undulose extinction.

Potash feldspar (microcline-microperthite) generally forms clear subhedral to anhedral grains from 1 to 4 mm. Generally the microperthite is best developed in the centres of the grains, and the cross-hatching towards the margins. Zones of quartz blebs are prominent near grain margins, and in some places limit the development of microperthite and cross-hatched twinning. The potash feldspar on both sides of the quartz-bleb zone is usually optically continuous, but in two specimens, feldspar forms distinct overgrowths with differing optical orientation from the phenocryst core, in the zone between the quartz blebs and the grain margins.

Much of the potash feldspar is clouded with fine dusty ferruginous inclusions in rocks along the northeast margin of the older Precambrian outcrop. Rocks with clouded potash feldspar form roof pendants in, or at contacts with, Lennard Granite.

Triclinicity values of 0.75 and 0.76, and compositions Or_{94} and Or_{84} have been calculated for two samples, 67.16.1033 and 66.16.1009, respectively.

Andesine ranging from An_{30} to An_{47} is the most abundant phenocryst mineral. It forms subhedral to euhedral grains from 0.6 to 5 mm (average 2 mm) which show varying degrees of saussuritization: the most intense alteration is seen in specimens which contain clouded potash feldspar. Values less than An_{37} in the table of modal analyses are all minima, since intense alteration precluded accurate measurement. Normal, reverse, and oscillatory zoning are all present, and typically the zones are gradational over most of the grain. However, in many grains there is a sharp transition from zoned andesine to a narrow clear untwinned rim of sodic plagioclase or, in rare cases, myrmekite. Table 4 shows the plagioclase variation within some zoned crystals.

TABLE 4. ZONING IN PLAGIOCLASE, MONDOOMA GRANITE
(Flat stage determinations using normal to *a* and combined Carlsbad/albite method)

Sample	*Type of Zoning*	*Composition* ($\pm An_5$)
67.16.1020	Normal	An_{43} to An_{36} to sodic rim
67.16.1037	Normal	An_{37} to An_{35} to sodic rim
67.16.1035a.	Oscillatory/reversed	An_{37} to An_{44} to An_{35}
b.	Normal	An_{47} to An_{33}
67.16.1034	Normal	An_{38} to An_{32} to sodic rim
66.16.1008	Oscillatory/reversed	An_{32} to An_{38} to sodic rim
66.16.1009	Normal	An_{47} to An_{36}

Zones of quartz inclusions are present in plagioclase as well as in potash feldspar, though not to the same extent. They are particularly well displayed in sample 66.16.1009, which also contains many disrupted and corroded andesine phenocrysts.

Biotite forms either discrete plates from 1 to 2 mm or aggregates of fine-grained flakes 2 mm across. It is present in nearly all samples, and is pleochroic from straw to red-brown or green-brown. Many plates are poikilitic, and enclose granular quartz, apatite, zircon, sphene, and iron ore. Clinozoisite is a common associate.

Amphibole occurs in seven samples. At least two types are present; a colourless to pale green actinolitic type which forms cores to most of the amphibole grains, and is intimately associated with an orange-brown alteration product; and hornblende, with X = fawn, Y = olive green, and Z = dull green to deep blue-green, which forms irregular rims to the actinolite. The hornblende, in particular, poikilitically encloses quartz, plagioclase, and many of the accessory minerals. It occurs near the biotite but does not seem to be associated with it.

Orthopyroxene occurs only in specimen 66.16.1009 from near the Sheet boundary in the southwest (see also Sofoulis et al., 1971). It is faintly pleochroic, with X = very pale fawn, Y = pale fawn and Z = very pale green, and has an estimated 2V of 60° to 70°. Most grains are rimmed by a narrow zone of colourless to pale green actinolite and a broader zone of green-brown poikilitic hornblende. Extremely fine lamellar structure is present in some pyroxene grains.

In Table 5 a chemical analysis of a concentrate of this orthopyroxene is compared with analyses 16, 18, and 19 from Deer et al. (1963). The chemical analysis is directly comparable with eulite (Fs_{70-90}) and to a lesser extent ferrohypersthene, but contains significantly higher titanium and slightly higher calcium. This is possibly due to slight contamination of the sample by hornblende, which, as noted earlier, rims most of the orthopyroxene grains. The composition of the orthopyroxene from the estimated 2V is Fs_{69} to Fs_{77} (Deer et al., 1963).

TABLE 5. CHEMICAL ANALYSES OF ORTHOPYROXENE, FROM MONDOOMA GRANITE AND ELSEWHERE

Sample	1.	2.	3.	4.
SiO_2	44.44	44.52	49.43	50.26
TiO_2	5.60	1.39	0.17	0.16
Al_2O_3	2.91	4.76	0.38	3.13
Fe_2O_3 + FeO	38.07	39.92	34.95	27.19
MnO	0.80	0.28	1.19	0.76
MgO	5.17	6.59	12.96	16.36
CaO	2.23	1.40	0.71	1.76
Na_2O	0.17	0.39	{ 0.02	0.24
K_2O	0.25	0.19	}	0.13
	100.03	99.85	99.81	99.99

1. Phenocrysts Mondooma Granite (R66.16.1009).
2. Eulite, granite.
3. Ferrohypersthene, ferrohypersthene-hornblende gabbro.
4. Hypersthene phenocrysts, augite-bearing hypersthene dacite.

Accessory minerals. Zircon is fresh, zoned, and euhedral. Short prismatic crystals are predominant, but one grain in sample 67.16.1061 shows a length/breadth ratio of 9:1. Apatite is abundant, particularly as inclusions in amphibole. Sphene is widespread, and forms rims around ilmenite, which commonly shows a 60° ?exsolution pattern and alteration to cloudy leucoxene. Calcite is present in some sample only.

In the groundmass, quartz, potash feldspar, and minor plagioclase form an allotriomorphic granular aggregate. Myrmekite is developed between the groundmass and potash feldspar phenocrysts, as well as between the phenocrysts themselves.

Discussion

Textures. The significance of textural variation in the Mondooma Granite is discussed in Sofoulis et al. (1971), who concluded that the Mondooma Granite is essentially a high-level mass, parts of which have undergone rapid variations in magma-phenocryst equilibrium and rapid disruptive intrusion. Similar conclusions can be drawn from specimens of Mondooma Granite in the Charnley Sheet area. The triclinicity value of 0.75 for potash feldspar indicates a relatively rapid rate of cooling in contrast to the slow cooling of deeper-seated batholithic granites. Variations in magma-phenocryst equilibrium are indicated by zones of quartz inclusions and overgrowths of alkali feldspar on alkali feldspar; the latter texture alternatively suggests that the cores of some feldspars may be xenocrystic. The presence of zoning in both plagioclase and potash feldspar is a further indication of rapid cooling of the rock at a high crustal level.

Coarsely porphyritic patches. All gradations are present between xenoliths of Mount Disaster Porphyry and porphyritic patches in the Mondooma Granite. These patches are of limited extent and large feldspar phenocrysts are generally absent near the xenoliths. It seems improbable that the porphyritic patches are a direct result of crystallization from the Mondooma Granite magma, since conditions of crystallization within a large body of acid magma are unlikely to vary over a distance as small as 10 cm. A more likely origin for the porphyritic patches is that Mondooma Granite magma was intruded into a body of Mount Disaster Porphyry in varying stages of consolidation. Completely consolidated porphyry now forms discrete xenoliths, whereas incompletely crystallized material forms diffuse xenoliths and dispersed xenoliths.

Absence of aplite and pegmatite. In contrast to the batholithic Lennard Granite, the Mondooma Granite is not accompanied by late-stage aplite and pegmatite. This can be accounted for by loss of volatiles in the Mondooma Granite,

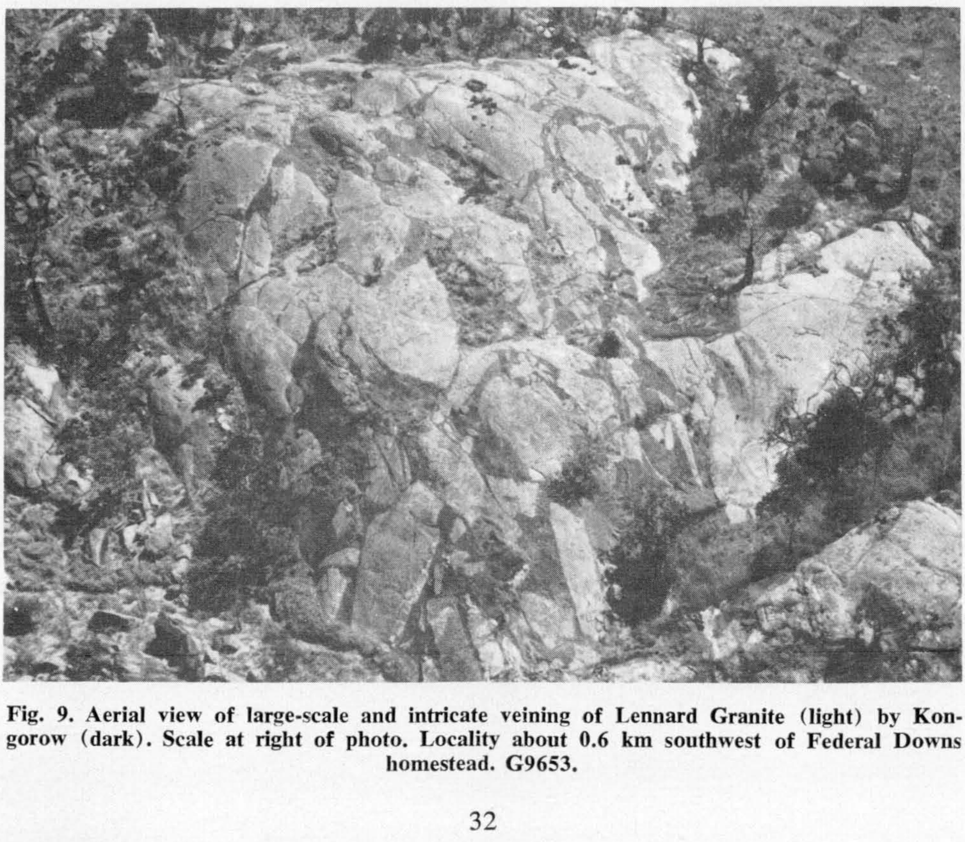

Fig. 9. Aerial view of large-scale and intricate veining of Lennard Granite (light) by Kongorow (dark). Scale at right of photo. Locality about 0.6 km southwest of Federal Downs homestead. G9653.

which has crystallized and been intruded at a higher level than the Lennard Granite. Much of the volatile loss is probably due to extrusion of the Whitewater Volcanics, as ash-flows, before intrusion and crystallization of the related Mondooma Granite.

Correlations

The Mondooma Granite is equivalent to Bickleys Porphyry, in the southeast Lennard River Sheet area (Gellatly et al., 1968). Orthopyroxene-bearing Mondooma Granite has no actual counterpart in the Bickleys Porphyry, but it resembles the Little Gold River Porphyry from the Lansdowne Sheet area, which is a high-level dacitic intrusion with 10 percent ferrohypersthene, similar to that in parts of the Mondooma Granite. The Little Gold River mass is also closely associated with, and intrusive into, the Whitewater Volcanics.

Upper Lamboo Complex

Lennard Granite

The Lennard Granite is a coarse-grained leucocratic even-grained to porphyritic biotite granite, containing abundant, usually equant 2 cm, phenocrysts of potash feldspar. It locally resembles the Kongorow Granite but the latter is generally more mafic, and carries fewer and more elongate phenocrysts. The reference area is in the Lennard River Sheet area (Gellatly et al., 1968).

Field occurrence

Extent and location of outcrop. The Lennard Granite is exposed in the Charnley Sheet area between the Barker River and King Leopold Ranges, southwest of the Pardaboora River, along Swift Creek, near the headwaters of the Robinson River, and southeast of the King Sound Tin Mine.

Topography and photo-pattern. In the Pardaboora River area and in the area south of the Barker River the Lennard Granite forms elongate northwest-trending whalebacks, separated by narrow strips of sand. Elsewhere the granite is relatively poorly exposed. Small domes and low whalebacks projecting through sand and soil cover are the usual forms, although monadnocks rising more than 90 m above the plain are common in the Swift Creek area. The photo-pattern is light-coloured because of soil cover, and contrasts sharply with the darker tonings and black boulder scree of the associated Mondooma Granite and Whitewater Volcanics.

Lithology

The Lennard Granite is generally a mottled grey-white leucocratic coarse to medium, even-grained to slightly porphyritic rock. It is usually massive, particularly in the Swift Creek area and southeast of Mount Hart homestead. Any foliation present is usually defined by alignment of phenocrysts and platy xenoliths. In general the intensity of foliation in the granite increases southwestwards from the King Leopold Ranges.

Contaminated, xenolithic, and banded varieties of Lennard Granite are described separately.

Contact relations

Lennard Granite intrudes Mondooma Granite with irregular but well defined contacts. At the contact zone the Lennard Granite is characterized locally by

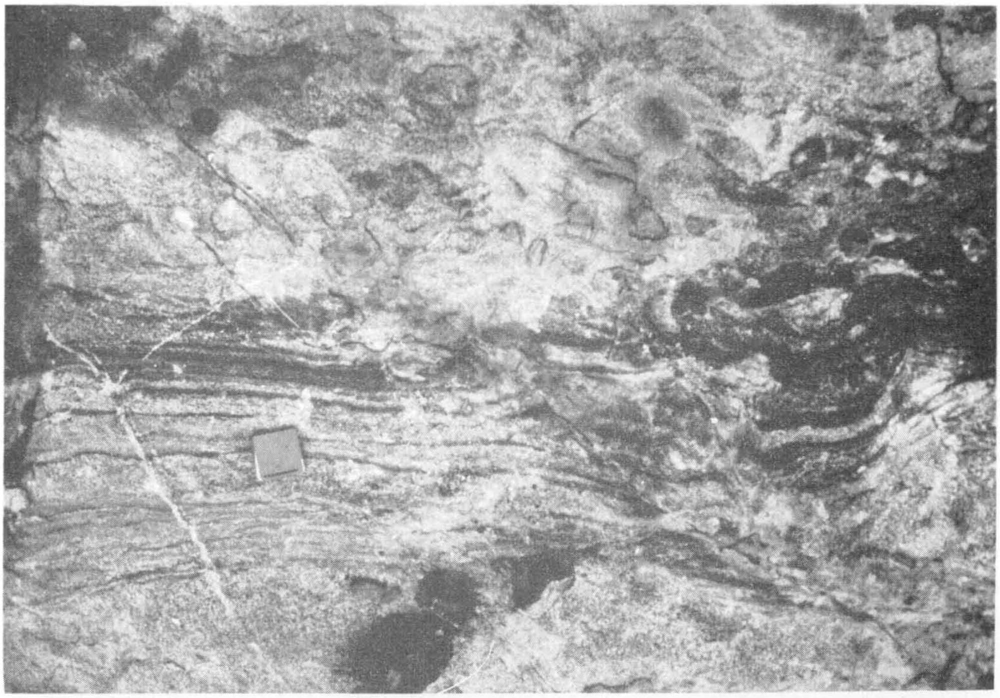

Fig. 10. Banding in Lennard Granite. Band covered by notebook shows good grading of biotite. Notebook 10 cm long. Locality about 5½ km west of Federal Downs homestead. G9619.

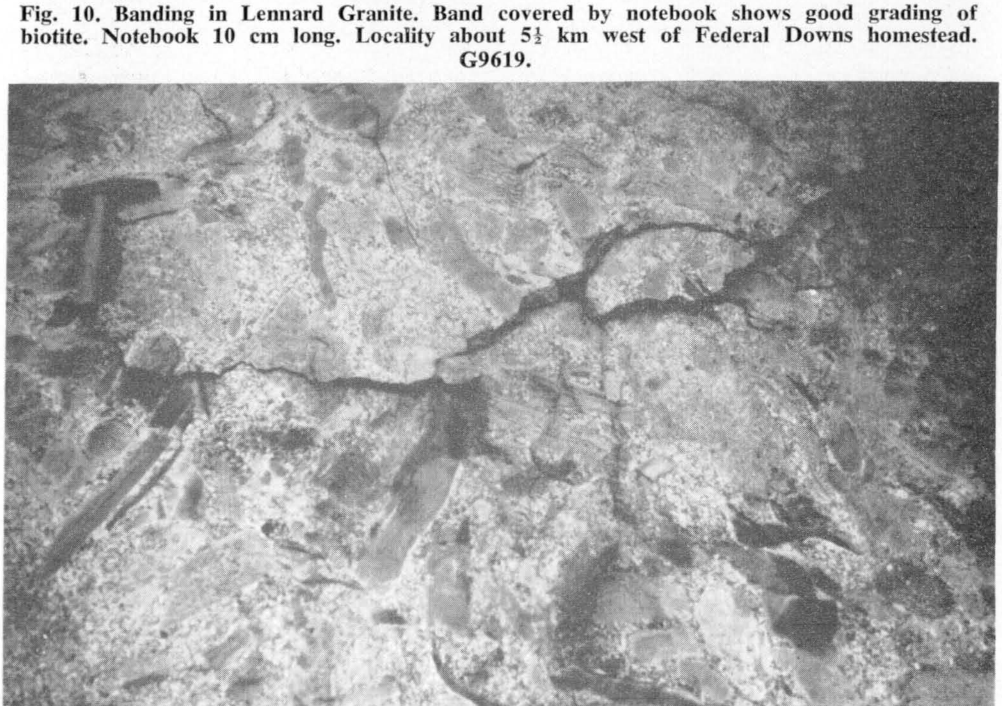

Fig. 11. Xenolith-rich Lennard Granite near contact with Mondooma Granite. Xenoliths are metasedimentary. Swift Creek, 2½ km southeast of King Creek yard. G9715.

swarms of Halls Creek Group inclusions, and less commonly by scattered xenoliths of Mondooma Granite, which are generally flow-oriented parallel to the contact. The Mondooma Granite xenoliths range from small pieces to large blocks and slabs up to several metres across. Near the junction of King and Swift Creeks, phenocrysts in the Lennard Granite become smaller and sparser close to the contact. Minor quartz veins and aplite and pegmatite veins are common in the marginal areas of the Lennard Granite. Locally rosettes of tourmaline are intergrown with feldspar and muscovite. At some contacts the Mondooma Granite displays a thin (1.5 cm) recrystallized biotite-rich selvedge.

Lennard Granite is intruded by the Mount Amy Granite 10 km west of Mount Hepple. The Mount Amy Granite contains xenoliths of Lennard Granite near the contact and south of Mount Hart it forms dykes and veins cutting Lennard Granite.

Dykes and veins of Lennard Granite cut Mount Disaster Porphyry near the Mount Hart Road, near the southern margin of the Sheet area. Chilled margins are up to 7 cm wide in the Lennard Granite.

At a contact between Lennard Granite and Halls Creek Group on the Pardaboora River about 3 km east-southeast of Federal Downs homestead, veins of granite up to 15 cm wide and sub-parallel to the contact cut the metasediments. Apart from minor recrystallization of muscovite, there appears to be no significant contact metamorphism.

Contacts with Kongorow Granite are described in the section on that unit.

Petrography

Detailed petrographic descriptions of specimens of Lennard Granite from the Charnley Sheet area are given in GSWA Petrological Report 152 (R. Peers). Specimens of Lennard Granite are mainly medium-grained porphyritic adamellite containing phenocrysts of potash feldspar. The ground mass is composed essentially of quartz, microcline, and plagioclase of average grainsize 0.1 to 0.2 mm. Grains are commonly anhedral with poorly defined boundaries. The texture of most specimens is xenomorphic granular. Estimated modal analyses of 12 specimens of Lennard Granite are given in Table 6.

TABLE 6. ESTIMATES OF MODAL COMPOSITION—LENNARD GRANITE

Charnley Sheet Area

Spec. No.	*K-Feldspar*	*Quartz*	*Plagioclase*	*Mafics*
R67161044 CH14-79-4	27	33	31	8
R67161045 CH13-99-13a	32	20	38	10
R67161046 Y14-29-2a	50	40	5	5
R67161047 CH14-74-5a	34	28	30	8
R67161059 Y14-31-28	40	38	15	7
Y10-02-1	30	25	35	10
Y11-02-2B	25	30	30	15
Y11-02-3	35	30	25	10
CH15-13-50	30	40	25	5
CH15-13-52	30	45	20	5

R prefix denotes BMR Registration Nos. Other numbers refer to GSWA specimens.

Microcline forms anhedral perthitic grains up to 10 mm, some with quartz-filled microfractures. Quartz forms irregular grains up to 6 mm, which are commonly strained; the strain pattern in the quartz is parallel to a very weak foliation. Irregular patches of quartz are included micrographically in potash feldspar, and as vermicular blebs in plagioclase. Plagioclase forms subhedral to anhedral crystals (1-6 mm), which are zoned from andesine in the centres to oligoclase at the margins. Most grains are patchily saussuritized, and some smaller grains are almost completely replaced. Biotite in subhedral flakes (1-3 mm) is strongly pleochroic with X = pale yellow, Y = straw yellow, and Z = reddish brown. In some specimens the original biotite has been partly or wholly altered to chlorite, muscovite, and secondary green biotite. It usually occurs in fine-grained aggregates or as discrete crystals with a slight preferred orientation.

Zircon, apatite, epidote, and magnetite and ilmenite form inclusions in the biotite. Minor calcite is scattered through two specimens; several euhedral patches of brown amorphous material in specimen Ch. 14.79.1 are probably altered allanites.

Banding

Prominent banding is present in the Lennard Granite about 4 km west of Federal Downs homestead. The banded zone is from 1 to 2 m thick and 10 m long, and forms part of a gently domed exfoliation pavement of granite.

The banding (Fig. 10) consists of alternate biotite-poor and biotite-rich layers in fine to medium-grained granite. The layers dip at 35° to the south, and generally show a sharply defined mesocratic base and an upward gradation into biotite-poor granite. The distance between the mafic-rich layers is 2 to 15 cm, and becomes less towards the south of the outcrop (Fig. 10).

Overall, the zone grades into normal leucocratic Lennard Granite. On a smaller scale, contacts between Lennard Granite and the biotite-rich bands are relatively sharp, but are gradational between Lennard Granite and the fine to medium-grained granite of the bands.

Petrography

Thin sections of the bands are not available Staining for potash feldspar on cut surfaces, and good exposures of quartz on weathered surfaces, have allowed estimation of modal analyses across two typical bands. The subdivisions of the bands are about equal.

Two types of quartz are present; one forms grains with an average diameter of 2.5 mm, and the other generally forms interstitial grains from 0.5 to 1 mm diameter. The distribution of the coarser quartz defines a layering, while the finer type is more widely and evenly distributed through the rock.

TABLE 7. ESTIMATES OF MODAL COMPOSITION OF BANDED ROCKS IN LENNARD GRANITE

		Biotite	*Quartz*	*Potash feldspar*	*Plag.*
Band 1	Upper	12	50	25	13
	Middle	8	35	28	29
	Lower	45	25	10	20
Band 2	Upper	10	50	30	10
	Middle	5	35	35	25
	Lower	25	30	20	25

Discussion

The banding in the Lennard Granite probably originated in one of two ways, either by xenolith recrystallization or by primary magmatic layering.

If of xenolithic origin, spacing and grading of the bands may reflect original bedding and grading in the recrystallized sediment, although such grading is possibly inverted through metamorphism. Partly resorbed xenoliths in the Yampi Sheet area show an irregular streaky banding and a much lower granitic fraction than the banding here. Recrystallized xenoliths, forming swarms in the Charnley Sheet area, contain amphibole as well as biotite and are associated with tonalite, neither of which has been found in this banding.

Regularly repeated mafic and granitic bands may have developed by crystal settling, magmatic currents, and differentiation *in situ*. Banded granitic rocks from Greenland, similar to those from the Charnley area, have been described by Emeleus (1963) and Harry & Emeleus (1960). They display trough banding, impersistent banding resembling sedimentary current bedding, and contorted structures attributed to slumping, typically at high levels. Granitic magma with a high concentration of volatiles is postulated, in order to increase the time available for crystallization and to lower the viscosity of the magma.

Abundant pegmatite, aplite, and quartz layering near the layering in the Charnley Sheet area indicates a higher concentration of volatiles than is usual in the Lennard Granite. This fact, together with the marked physical resemblance between this granite and known examples of layering, suggest that primary magmatic layering is a more likely explanation of the banding than xenolith recrystallization; however, there is little direct evidence to favour either origin.

Xenolith swarms

Field occurrence. Xenolith swarms are common in the Lennard Granite close to its contact with the Mondooma Granite. They are particularly abundant at contacts near King Creek Yard, where they probably form continuous zones along the margin of the Lennard Granite. However, owing to lack of outcrop and because of the reconnaissance nature of the mapping, it has been possible to delineate only isolated patches of xenolithic granite on the accompanying map.

The xenolith swarms are well developed in the middle of King Creek about 2½ km and 5 km south of King Creek yard. The xenoliths are angular to subrounded. Many are tabular in shape, suggesting derivation from bedded sediments. The size of xenoliths ranges from about 5 cm to 0.6 m (average about 20 cm).

In many outcrops xenoliths make up 30 percent to 40 percent of the rock. In others, particularly farther from the contact, xenoliths are sparse and diminish to about 1 percent or less. A poorly defined near-vertical flow foliation is present in some outcrops.

Most xenoliths are dark grey and fine-grained. Many show small-scale lamination. Most are biotite-bearing hornfelses of probable sedimentary origin. Rare examples are probably altered porphyritic ash-flow tuff (Whitewater Volcanics?) and non-porphyritic amphibolite (Woodward Dolerite?); they have been identified only in hand specimen, but one rock examined in thin section may be an altered tuff.

The host rock for these xenoliths is a coarse-grained pale grey massive biotite tonalite which forms a marginal zone to plutons composed mainly of granite and adamellite. It is generally non-porphyritic, especially in the xenolith-rich outcrops, but becomes sparsely porphyritic in the more poorly xenolithic outcrops.

Petrography. Eight examples of the xenoliths have been sectioned. Four of the thin sections also contain patches of the enclosing granite. There is little difference between the xenoliths in macroscopic appearance, but two distinct petrographic suites are present. One is characterized by predominant quartz and plagioclase, and the other by abundant potash feldspar, generally with subordinate plagioclase, but with little or no quartz.

Specimens in the first group (R67.16.1064-1067) contain abundant sericite-rich saussuritized tabular plagioclase crystals ophitically or subophitically enclosed in quartz. Strongly pleochroic red-brown (locally with green-brown margins) to pale grey-brown biotite and a colourless fibrous (?)amphibole are the predominant mafic minerals. The (?)amphibole, which is at present unidentified, has low Z^1c up to 24° and is neutral to very pale brown. It is associated with, and is commonly peripheral to, lamellar twinned (locally untwinned) cummingtonite with $Z^1c = 15°$ and $2Vz = 70\text{-}80°$. Small granules of opaque oxide (?magnetite) are common.

The second group (R67.16.1068-1070; 1018) is texturally variable. Most specimens are xenomorphic microgranites in which small equant grains of microcline-microperthite predominate over sericitized plagioclase. Quartz is rare or absent. Biotite is the dominant mafic mineral and is accompanied locally by a very pale brown (?)sericitic mica. Small amounts of pale olive-green chlorite and opaque oxides are present. Large areas of sericitic matrix contain irregular, locally cuspate patches of potash feldspar and pale brown microcrystalline micaceous material. The shapes of these patches are reminiscent of shards, suggesting that the rock may have been an ash-flow tuff. If so, the absence of identifiable quartz is unusual.

The host rocks are mostly tonalites. However, one specimen is a granodiorite in which highly altered plagioclase, quartz, and biotite are the principal constituents. Potash feldspar, where present, is a slightly turbid microcline-microperthite. Minor constituents, mostly associated with biotite, include orthopyroxene, clinozoisite, chlorite, magnetite, apatite, and pale pink-brown zircon.

The presence of abundant xenoliths in the Lennard Granite is unusual, but is paralleled by similar occurrences in the Lennard River Sheet area (Gellatly et al., 1968). The curious feature about the xenolith swarms in the Charnley Sheet area is that although the rock intruded is Mondooma Granite, the xenoliths consist entirely of metamorphosed equivalents, principally of Halls Creek Group and rare examples of Woodward Dolerite and Whitewater Volcanics. The xenolith assemblage is even more surprising when it is considered that the nearest outcrop of Whitewater Volcanics is 7 km from the xenoliths, and the nearest outcrop of Halls Creek Group 17 km.

Any explanation is necessarily speculative. A suggestion that there has been flotation of country rock xenoliths towards the top of a dome-shaped intrusion of Lennard Granite is included in the discussion of ocellar hybrids below. This is doubtful, since the xenoliths would be considerably denser than the enclosing granitic magma. The greater density of the xenoliths would depend partly on their composition (they contain more biotite and plagioclase than the granite) and partly on the density difference between magma and solid rock of the same composition.

Two alternatives are suggested. Firstly, that the xenoliths may have been carried upwards by flowage of a granitic crystal mush. Those near the contacts would have been trapped by rapid chilling, whereas those in the main body of the intrusion would have tended to sink and would probably have been completely assimilated. Secondly (and perhaps less likely), that the Mondooma Granite, which must have been emplaced into a pre-existing complex of Halls Creek Group, Woodward Dolerite, and Whitewater Volcanics, was no more extensive before intrusion of the Lennard Granite than after it, and that the Lennard Granite advanced by stoping out of pre-existing, denser country rocks. This presupposes that the present contacts between Mondooma Granite and Lennard Granite are close to the original contacts between Mondooma Granite and older country rocks. If this is true, it means that the xenoliths have not been moved far from their original (pre-granite intrusion) location, and that they have been trapped almost in place, whereas material farther from the contact was stoped out and sank in the magma.

Other xenolith occurrences

Xenoliths other than those described above are sparse in the Lennard Granite. They range from patches 2 cm or so across to roof pendants 90 m across. Most of these xenoliths consist of porphyritic microgranite or acid porphyry. Most are tabular, and the average diameter is 15 to 30 cm. They are only slightly concentrated at the margins of the granite.

South of Mount Hart homestead large xenoliths of porphyritic microgranite form resistant tops to many low granite rises. The xenoliths appear slightly hornfelsed, and biotite is locally redistributed and recrystallized to form mafic-rich margins. Thin sections of the xenoliths show that they contain quartz, plagioclase, and potash feldspar phenocrysts in a micrograinitic groundmass. Biotite and muscovite are the mafic minerals and clinozoisite, zircon, and sphene the chief accessories. Quartz in the groundmass is intergrown granophyrically with potash feldspar. The quartz phenocrysts are generally fractured and show undulatory extinction. These micrograinites resemble, and are probably related to, the Mondooma Granite, Mount Disaster Porphyry, and Whitewater Volcanics.

Contaminated granite with quartz ocelli

A contaminated variant of the Lennard Granite is closely associated with the Mondooma Granite in the Robinson River/Swift Creek area 5 to 14 km north of old Federal Downs homestead. The granite forms massive rounded bouldery hills rising to 130 m above the plain, and resembles the Mondooma Granite in photopattern and topography.

Field occurrence. The contaminated granite has been noted at four localities. It is a grey massive coarse-grained porphyritic rock, adamellite to granodiorite, characterized by marked textural inhomogeneity. Euhedral to anhedral white plagioclase grains from 3 mm to 2 cm are the most common phenocrysts. Some contain biotite inclusions arranged zonally. Abundant quartz ocelli are rimmed by a dark green mafic corona up to 1 mm thick. These ocelli, 2 mm to 1 cm in diameter, are usually subrounded or slightly elongate. In some places the margins of the ocelli are gently curved and indented. Biotite grains up to 1.5 cm diameter, and amphibole grains up to 3 mm, are also present. The groundmass consists of quartz, grey feldspar, and spots of hornblende.

Relations with adjacent rock types are not known, although at one locality the contaminated granite encloses a patch of Mondooma Granite. No contacts have been seen.

Petrography. Two thin sections from each of the two specimens were examined. Estimated modal analyses of these two specimens are listed in Table 8.

TABLE 8. ESTIMATES OF MODAL COMPOSITION—CONTAMINATED LENNARD GRANITE

	66.16.1021	*67.16.1038*
Quartz (ground mass)	29	27
Quartz ocelli	3	3
Plagioclase	20	25
K feldspar	35	30
Amphibole	2	3
Pyroxene	—	1
Biotite	10	10
Accessories	1	1
	100%	100%

The most striking feature of these rocks is the presence of quartz ocelli, see Figure 12. In specimen 67.16.1038 they are rounded to elongate and slightly embayed grains up to 1 cm across, surrounded by a rim of amphibole, pyroxene, and minor biotite. In specimen 66.16.1021 the rims are entirely amphibole and biotite. Large single grains of quartz, or groups of 2 to 3 smaller grains, contain abundant very fine-grained inclusions and have slight undulatory extinction. Rare large grains of potash feldspar, amphibole, and biotite are developed in marginal areas of the large quartz ocelli, and euhedral zircon and a single grain of tourmaline form inclusions.

The mafic rims are about 1 mm wide, and contain clinopyroxene, red-brown biotite, and two varieties of amphibole. The following optical properties apply also to the same minerals in the host rock away from the rims. Clinopyroxene is very pale green but is non-pleochroic. The optic axial angle is about 60°, and Z'c about 37°. This diopsidic augite occurs adjacent to the quartz ocelli, inside the hornblende rim. Two types of amphibole are present: the older variety is pale green, with pleochroism X = colourless to pale green, Y = pale green-brown, and Z = apple green. It has replaced some of the pyroxene rims, and also forms rims around pyroxene grains in the remainder of the rock. This variety is in turn being replaced by a common hornblende, with pleochroism X = fawn, Y = green-brown, and Z = olive green to dull blue-green. It also has partly replaced pyroxene. Extinction angles are from 14° to 20° for the pale green variety, and 23° to 26° for the green-brown hornblende.

In the remainder of the rock anhedral plagioclase phenocrysts up to 1 cm long are highly saussuritized in sample specimen 66.16.1021, but are fresh in 67.16.1038.

Two varieties of biotite are present; an older dull brown fine-grained type associated with pale green amphibole and partly replaced by green-brown hornblende; and fresh poikilitic red-brown plates, which enclose quartz, plagioclase, and potash feldspar. This type contains abundant acicular rods of (?)rutile arranged at 60° intervals in the basal plane of the mica. Radioactive zircon and apatite inclusions, and ilmenite rimmed with sphene, are also abundant.

The two types of amphibole in the mafic rims are widespread throughout the remainder of the rock. Rare clinopyroxene grains with amphibole rims are also present. Most of the groundmass is a quartz-potash-feldspar-plagioclase aggregate with average grainsize 0.8 mm.

Xenoliths and mafic patches. Small xenoliths range from amphibolite to xenomorphic mesocratic granodiorite. The amphibolite contains anhedral to subhedral laths of green amphibole, deeper in colour than the pale green amphibole described above. It shows pleochroism X = pale fawn, Y = pale green-brown, and Z = apple green, and forms up to 70 percent of the xenolith. It is associated with abundant clinozoisite, plagioclase, biotite, and quartz. Other xenoliths contain anhedral grains of twinned microcline, and altered plagioclase. Small amounts of quartz and also pale fawn to pale orange-brown biotite are present. Patches of sphene are common.

The suite of mafic minerals in these rocks shows the following reaction series:

$$\text{Clinopyroxene}— \begin{cases}\text{biotite 1}\\ \text{amphibole 1}\end{cases} — \begin{cases}\text{amphibole 2}\\ \text{biotite 2}\end{cases}$$

Amphibole 2 and biotite 2 both form large poikilitic plates, and although in contact in many places no reaction is evident between them.

Origin of quartz ocelli and the contaminated granite. Quartz ocelli have been recorded from many localities. Theories concerning the origin of these structures vary widely. Most authors agree that they are associated with hybrid rocks in which basic magma has assimilated acid material or vice-versa. The quartz ocelli were called 'birds-eye' quartz by Wells & Wooldridge (1931), and were found in a considerably modified gabbroic xenolith in granite. Although the quartz ocelli appeared xenocrystic, they were considered to have been liberated from a hybrid magma at a late stage of crystallization. An inner rim of augite and an outer rim of hornblende characterized the ocelli described by Thomas & Smith (1932), who thought that they were a direct result of hybridization of norite by a granite fraction; the hornblende throughout the rock was a late stage alteration of the original pyroxene. They also considered that the quartz was a result of concentration of a residual silica-enriched liquid derived from alteration of hypersthene to augite and biotite; that is development of quartz preceded that of the mafic rims. Muir (1953) showed that augite crystallized around quartzite xenoliths to form large-scale ocellar structures, and was subsequently altered to hornblende. The ocelli described by Angus (1962) have hornblende rims with minor relict pyroxene, and have been produced from basalt inclusions by acid fluid metasomatism. The quartz is porphyroblastic, and grew from plagioclase-quartz-hornblende intergrowths by addition of silica. Expulsion of iron and magnesium during the growth of the quartz created a minor basic front and contributed to the development of the mafic rims. Phillips (1968) recorded the presence of quartz ocelli, but remarked only that they were a product of hybridization.

The quartz ocelli in the Charnley region show no evidence of a porphyroblastic origin from basaltic inclusions (Angus, op. cit.), nor do they appear to be metasomatic silica infillings of voids after the development of mafic rims (Thomas & Smith, op. cit.). It is most likely that they are xenocrysts, and that the clinopyroxene rims are a product of early crystallization from a contaminated granite-granodiorite magma, as was also postulated by Muir (op. cit.). Clinopyroxene appears to have crystallized in the groundmass of the hybrid as well as around the quartz xenocrysts, and in both cases has later been completely or partly altered to pale green amphibole and common hornblende. The xenocrysts have acted as bases or nuclei for crystallization of the early clinopyroxene phase.

The source of this postulated hybrid magma is unlikely to have been either the Mondooma Granite or the Mount Disaster Porphyry, because of the lack of quartz phenocrysts in the groundmass of the contaminated granite, but assimilation of either rock type could have provided the quartz xenocrysts. The most likely parent magma is probably a non-porphyritic phase of the Lennard Granite which previously was slightly contaminated by assimilation of basic and pelitic xenoliths. The postulated sequence of events is shown in Figure 12.

Kongorow Granite

The Kongorow Granite comprises a suite of various biotite-rich porphyritic granites which are widespread throughout the older Precambrian of the West Kimberley. It is named from Kongorow Pool in the Lennard River Sheet area and is defined by Gellatly et al. (1968).

Field occurrence

The Kongorow Granite crops out in a restricted belt within the Lennard Granite, 3 km southwest of the abandoned Federal Downs homestead. It forms a large-scale net-veined complex with Lennard Granite and nowhere forms large homogeneous exposures. The granite is dark grey and mesocratic, coarse-grained,

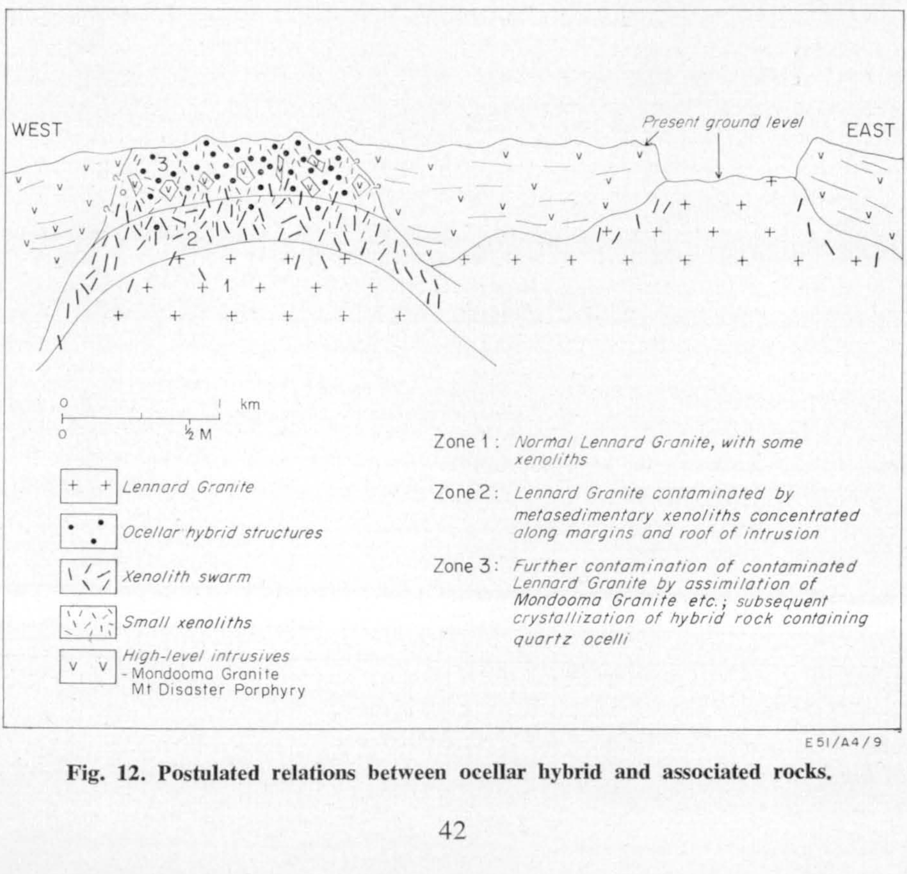

Fig. 12. Postulated relations between ocellar hybrid and associated rocks.

and porphyritic. Phenocrysts of potash feldspar up to 3 cm long are more abundant than quartz and plagioclase phenocrysts. The quartz phenocrysts in many places consist of a sugary aggregate of finer grains. Muscovite is a common accessory.

Together with the associated Lennard Granite, the Kongorow Granite forms low whalebacks and smooth exfoliated rock pavements.

Contact relations

Whereas Kongorow Granite both older and younger than Lennard Granite has been tentatively recognized in the Lennard River Sheet area, only the younger variant is present in the Charnley Sheet area. Contacts with the Lennard Granite are most striking. The Kongorow Granite intrudes the Lennard Granite, forming localized net-veined complexes (Fig. 9), in which blocks of Lennard Granite up to 12 m across are common. The foliation in the separate blocks is essentially parallel to that in other blocks, which suggest that rotation of the blocks in the veining or brecciation process has been minimal. Contacts are generally sharp, and flow foliation in the Kongorow Granite parallels the contacts. Along contacts an aplitic selvage is usually present. Aplite and pegmatite veins and dykes, with abundant black tourmaline, are ubiquitous in the net-veined complexes.

Petrography

No thin sections are available from the Charnley Sheet area, where the Kongorow Granite is similar to the type Kongorow Granite described from the Yampi Sheet area (Sofoulis et al., 1971), which is a quartz-rich biotite granite.

Mount Amy Granite

The Mount Amy Granite is named after Mount Amy in the Lennard River Sheet area. In the Charnley Sheet area it forms small scattered outcrops near the Mount Hart track, east of the Barker River, and in the southwest about 10 km west of Federal Downs homestead. The granite is highly weathered, and forms low rises, pavements, and small bouldery hills associated with abundant sand and soil. The principal rock type is a medium to fine-grained muscovite adamellite. In the southwest it forms a small plug-like intrusion about 90 m across, associated with veins of tourmaline pegmatite and aplite.

Contact relations

Veins of Mount Amy Granite intrude the Lennard Granite and Mondooma Granite, and show narrow chilled margins. In the southwest the muscovite granite contains roof pendants, up to 30 m across, of Mondooma Granite, which is highly veined by tourmaline-bearing pegmatite and aplite. Nearby sediments of the Halls Creek Group are feldspathized, tourmaline-enriched, and veined by quartz. A local outcrop of andalusite-sillimanite-biotite-muscovite-quartz granofels is possibly related to the thermal effects of this small intrusion of Mount Amy Granite.

Petrography

The only specimen examined is muscovite adamellite with a hypidiomorphic granular texture. Quartz (45%) is clear and unstrained, and forms polygonal aggregates. Plagioclase (30%) is fresh and well twinned, of composition An_{8-10}. Rims of myrmekite are abundant, and grow into microcline microperthite (20%)

showing some Carlsbad twinning. Muscovite (4%) forms flakes 1 to 2 mm in diameter which enclose quartz and some plagioclase sub-poikilitically. Biotite (1%) is pale fawn to deep brown and forms stringers through the rock. Accessories are iron oxide and orange-green chlorite.

Discussion

As in the Lennard River and Yampi Sheet areas, the Mount Amy Granite is one of the youngest stages of igneous activity in the Lamboo Complex, and is probably genetically related to the Lennard Granite. The contact metamorphic andalusite-sillimanite granofels represents the highest grade of contact metamorphism yet found in the West Kimberley. Although a small plug of Mount Amy Granite is tentatively thought to be responsible for this degree of metamorphism, the 'aureoles' of both the Mount Amy and Lennard Granites elsewhere in the West Kimberley characteristically contain metasediments of only low metamorphic grade.

Dykes

Dolerite

Dolerite dykes are rarer in the Charnley Sheet area than in other parts of the West Kimberley, especially parts of the Lennard River Sheet area (Gellatly et al., 1968). The most notable dykes intrude the Kimberley Group and belong to the Hart Dolerite (q.v.). Others intrude the older Precambrian. The dykes are from 0.8 to 14 km long and from 1.5 to 9 m wide. They intrude mainly the Lennard and Mondooma Granites, and trend northwest and northeast. Most are dark green to grey, fine to medium-grained and show a relict subophitic texture; some are variously amphibolitized or chloritized. These dykes may be earlier than, and distinct from, the Hart Dolerite.

Quartz syenite

A quartz syenite dyke intrudes Lennard Granite about 14 km south of Mount Hart homestead, beside the Mount Hart track. It is about 1 m wide, and trends north-northwest for about 0.5 km. Quartz is notably deficient in the rock, which is grey-green and coarse-grained. Between the syenite and granite a narrow zone 2 to 5 cm thick contains abundant quartz grains which appear to be a result of local diffusion and reaction between the two rock types. In thin section, perthitic potash feldspar (45%) is anhedral, clouded, intensely fractured, and partly chloritized. Anhedral albite of An_5 (35%) contains fine inclusions of chlorite and mica, and has microfractures. Quartz (8%) is interstitial to feldspar, and forms anhedral and fractured grains. The mafic minerals (8%) are fine-grained biotite and chlorite, forming aggregates and stringers, associated with abundant zircon and apatite, and iron ore. Calcite (4%) is widespread throughout.

The dyke is slightly folded and microscopically deformed, and has probably been intruded at about the same time as dolerite in the area.

Aplite and pegmatite

Where exposures are sufficiently extensive aplite and pegmatite are mapped as part of the Mount Amy Granite. They also form comparatively isolated dykes up to 1 km long and 0.5 to 10 m wide. Most are homogeneous pink to grey aplite, fine-grained, and porphyritic in places. Some are composite and have a central core of tourmaline pegmatite. Contacts with the enclosing rocks are sharp, and contact metamorphism slight.

Quartz veins and plugs

Quartz veins are widespread in the older Precambrian rocks and range from gashes a few centimetres thick to massive reefs at least 7 km long. Small quartz veins in the Halls Creek Group, usually subparallel to bedding and cleavage, are lenticular and usually contain large patches of green chlorite. Large quartz veins 15 to 800 m long and 0.6 to 3 m wide are also present in the Halls Creek Group. Some are intimately associated with the Hawkstone Creek kyanite deposit and the King Sound Tin mine (see Economic Minerals).

Within the granites quartz veins occupy curvilinear joints which trend north to northwest. A major shear zone trending east-west near the Robinson River contains abundant en echelon quartz gashes which diminish in abundance eastwards.

A group of at least six quartz plugs intrudes the Mondooma Granite near the Robinson River headwaters. They are roughly circular and 15 to 40 m in diameter. All project 5 and 10 m above the plain level and one or two form ring structures. The quartz is massive, white, and unmineralized, and has prominent horizontal jointing.

CARPENTARIAN

Speewah Group

The older Precambrian rocks described in the preceding chapters are overlain unconformably by Lower Proterozoic sediments of the (structural) Kimberley Basin. The Kimberley Basin succession, which consists mainly of quartz sandstone, comprises the Speewah, Kimberley, and Bastion Groups.

The Speewah Group (Gellatly et al., 1965) overlies the Lamboo Complex with a major unconformity, and is conformably overlain by the Kimberley Group. The Speewah Group comprises the O'Donnell Formation, Tunganary Formation, Valentine Siltstone, Lansdowne Arkose, and Luman Siltstone, which are defined by Gellatly et al. (1965).

As a result of facies changes taking place northwestwards along strike from the Lansdowne Sheet area (from which the Speewah Group was redefined), the constituent formations can be recognized only with difficulty, and none can be traced as far west as the boundary with the Yampi Sheet area. Why the Speewah Group disappears westwards remains uncertain, but it seems likely that it is due more to a combination of lithological variations (particularly the disappearance of siltstone) and thinning of the sequence, than to removal by erosion as in the southeast corner of the Lansdowne Sheet area and parts of the Mount Ramsay Sheet area (Roberts et al., 1973).

O'Donnell Formation

Stratigraphic relations

In the Charnley Sheet area the O'Donnell Formation lies unconformably on the Whitewater Volcanics and non-conformably on the Mondooma and Lennard

Granites. It is overlain conformably by the Tunganary Formation, and is intruded by the Hart Dolerite. To the west it passes laterally into sandstones that have been mapped as King Leopold Sandstone in the Yampi Sheet area.

Distribution and topographic expression

The formation forms a narrow northwest-trending outcrop in the southwest, from near Mount Hepple to Humbert Creek. The lower part mostly forms a single escarpment and narrow dip-slope, whereas the upper part forms the lower part of a poorly developed scarp slope capped by the lower beds of the Tunganary Formation.

Lithology

In the Lansdowne and Lennard River Sheet areas the O'Donnell Formation consists essentially of coarse quartz sandstone (lower part) and siltstone (upper part). In the Charnley Sheet area these divisions have been recognized near the southern border, but to the northwest, near Humbert Creek, the upper part consists almost entirely of coarse quartz sandstone and granule conglomerate.

The lower part of the formation consists mainly of white, pale fawn, pale grey, and very pale rust brown, medium to coarse, well sorted quartz sandstone, and minor granule and pebble conglomerate. In the south near Mount Hart homestead, the basal beds consist of pebble and cobble conglomerate. At higher levels the pebbles become smaller, and conglomerate gives way to sandstone. Pebbles range from subangular to rounded and are mainly of vein quartz, phyllite, and quartzite, and rare altered diorite. Bedding ranges from thin to thick; parting is blocky to massive. Individual conglomerate beds are 20 to 30 cm thick. Sandstones interbedded with the conglomerates are coarse-grained, locally granule-bearing, and have a friable ferruginous matrix. Conglomerates diminish in abundance and become finer-grained westward. Near Humbert Creek the basal beds consist of pale fawn coarse-grained thin-bedded quartz sandstone, and granule conglomerate.

In the Charnley Sheet area the upper part of the O'Donnell Formation rarely directly overlies the lower part, but it is present, at least locally, overlying Hart Dolerite and underlying the Tunganary Formation but obscured by detritus. In the south the upper part consists essentially of laminated grey-green siltstone, and minor white and fawn, fine to coarse quartz sandstone, locally containing magnetite lenticles. A measured section is given in Table 9. To the west the upper part becomes more arenaceous and consists of white to pale rust brown, coarse-grained, thin to thick-bedded, blocky, well sorted quartz sandstone and granule conglomerate, which locally contain thin tourmaline-rich beds. Thin partings of grey-green siltstone on bedding planes are all that remain of the characteristic silt component that predominates to the southeast.

Thickness

The thickness of the O'Donnell Formation in this area is uncertain because of extensive intrusion by the Hart Dolerite and consequent uncertainty as to the completeness of most sections. Over much of its length the preserved thickness underlying the Hart Dolerite is 30 m or less. The total thickness of the formation probably ranges from about 90 to 165 m. No complete section has been measured.

TABLE 9. O'DONNELL FORMATION—SECTION D1

Section about 8 km west-southwest of Mount Hepple.
Overlain conformably by *Tunganary Formation*

Thickness (m)	
56	*Siltstone:* dark green, crudely laminated, weathering to red-brown
4	*Sandstone and siltstone:* white, coarse-grained, strongly cross bedded quartz sandstone with magnetite stringers up to 1 cm thick; cross-bedding comprises many short, steep units: interbedded with flaggy, very fine-grained, greenish, locally cross bedded, laminated siltstone weathering to pale brown
4	*No exposure*
2	*Quartz sandstone:* fawn and green, weathering to greenish brown, fine grained, very poorly sorted massive siliceous quartz sandstone; contains highly contorted beds near the base
	Hart Dolerite
ca. 100	*Quartz sandstone and pebble conglomerate:* forms prominent ridge; not examined in detail; thickness estimated from aerial photographs.
ca. 166	NONCONFORMITY

The only complete sequence, about 10 km northwest of Mount Humbert, is estimated from aerial photographs to be about 100 m. A section of probable upper O'Donnell Formation amounting to 60 m has been measured a short distance southeast of Mount Hart, and the lower O'Donnell Formation a few kilometres southeast at Inglis Gap (Lennard River Sheet area) is estimated from aerial photographs to be about 105 m thick, giving a total thickness of about 165 m about the southern boundary of the Charnley Sheet area. Considered in conjunction with a thickness of 520 m near Sandy Creek Gorge (Lennard River Sheet area) these figures indicate a general northwest thinning of the O'Donnell Formation in this area.

Tunganary Formation

Stratigraphic relations

The Tunganary Formation conformably overlies the O'Donnell Formation and is conformably overlain by the Valentine Siltstone in the south near Mount Hepple. In the west near Humbert Creek there is more or less a continuous sandstone sequence indicated on the map as 'Speewah Group undifferentiated' comprising the Tunganary Formation, possible Valentine Siltstone (not exposed), and Lansdowne Arkose. It is intruded by, and largely overlies, the Hart Dolerite.

Distribution and topographic expression

The Tunganary Formation forms a narrow discontinuous outcrop near Mount Hepple in the south. It has been recognized in the field 55 km to the northwest near Humbert Creek, but has not been traced for much of the intervening distance because of the similarity of its topographic expression and photo-pattern to those of the Lansdowne Arkose and King Leopold Sandstone.

In the south the formation forms the lower part of the prominent southwestern escarpment of Mount Hepple, and a narrow steeply dipping strike ridge. To the northwest, between Mount Matthew and Mount Humbert, it probably forms the lower parts of the steep southwestern slopes of the King Leopold Ranges.

Lithology

Near the southern border of the Sheet area coarse and medium-grained silica-cemented quartz sandstone predominates; quartz granule conglomerate, feldspathic sandstone, and green-grey and blue-grey siltstone and shale are subordinate. To the northwest, near Humbert Creek, medium-grained quartz sandstone predominates and siltstone and shale are absent.

Cross-bedding is well developed in some of the sandstones, and a prominent lamination is a feature of others.

Thickness

No thickness has been measured near the southern margin of the Sheet area. The thickness near Humbert Creek is probably about 80 m, a considerable reduction from the 160 m measured in the Lennard River Sheet area and 230 m in the Lansdowne Sheet area, but it indicates a continuation of the northwestward thinning already established.

Valentine Siltstone

The Valentine Siltstone is rarely exposed in the Charnley Sheet area and little is known about it. The formation has been mapped mainly on the basis of its topographic expression and on isolated siltstone detritus. Volcanic material characteristic of the formation farther southeast has not been recognized with certainty in the Charnley Sheet area.

The only exposure noted is on the southern slopes of Mount Hart and consists of a dark red powdery ochreous rock (altered (?)volcanic) overlain by poorly exposed pink-maroon siltstone. To the southeast near Mount Hepple, and to the northwest near Humbert Creek, float of similar dark red-brown weathered ferruginous siltstone has been noted.

No definite information is available on thickness.

Lansdowne Arkose

Stratigraphic relations

The Lansdowne Arkose is conformable between the Valentine Siltstone and the Luman Siltstone.

Distribution and topographic expression

The Lansdowne Arkose forms a narrow northwest-trending outcrop from near Mount Hepple to Humbert Creek. It may extend westwards from Humbert Creek to the western boundary of the Sheet area, but cannot be distinguished there from the King Leopold Sandstone.

Near Mount Hepple it forms bold strike ridges bounded above and below by narrow soil-covered valleys of Valentine and Luman Siltstones, both generally intruded by valley-forming Hart Dolerite. Northwest of Mount Hart it forms the southwestern escarpment of the King Leopold Ranges; there is no distinct topographic upper boundary to the Lansdowne Arkose in this area, but a prominent short dip-slope probably marks the top of the formation. In this area the base of the Lansdowne Arkose cannot be recognized and the Speewah Group has not been divided into its constituent formations.

Lithology

In the Charnley Sheet area the Lansdowne Arkose (which was named from the Lansdowne Sheet area, where feldspathic sandstone and arkose predominate) consists of quartz sandstone and minor feldspathic sandstone.

Near Mount Hepple, where the formation is well exposed, it consists of medium to coarse, white, well sorted, silica-cemented quartz sandstone. Feldspar is rare, and some interstitial sericite is present. In outcrop the formation is mostly thick-bedded and blocky to massive: laminated sandstones are present locally.

About 10 km northwest of Mount Humber feldspathic sandstone is absent; quartz sandstone predominates and is associated with poorly sorted quartz granule conglomerate containing quartz granules up to 5 mm.

Cross-bedding is common in the formation. The upper part locally contains well developed festoon cross-beds which are characteristic of the Lansdowne Arkose in parts of the Lennard River Sheet area. Palaeocurrent directions were from the northwest.

Thickness

A thickness of about 350 m has been estimated 5 km northwest of Mount Hepple, and about 150 m northwest of Mount Humbert. This represents a progressive thinning northwestwards from Mount Ord in the Lennard River Sheet area, where a thickness of 850 m has been measured.

Luman Siltstone

Stratigraphic relations

The Luman Siltstone is conformable between the Lansdowne Arkose and the King Leopold Sandstone. There is no direct evidence in the Charnley Sheet area or elsewhere for the suggested unconformity at the base of the King Leopold Sandstone (Dow & Gemuts, 1969). The formation thins westwards.

Distribution and topographic expression

The Luman Siltstone forms a narrow discontinuous northwest-trending outcrop in the southwestern part of the Sheet area from near Mount Hepple to Humbert Creek. It may extend farther westwards on the southern side of the King Leopold Ranges, but cannot be recognized there on aerial photographs. It is poorly exposed and has been mapped largely on its photo-pattern and stratigraphic position. Between Mount Hart and Humbert Creek its presence is indicated only by a very thin, gently dipping soft bed overlying a short dip-slope of Lansdowne Arkose.

Lithology

Because of poor exposure few lithological observations are available. About 8 km southeast of Mount Hepple (about 3.5 km south of the southern boundary of the Charnley Sheet area) good exposures have been examined. The dominant rock type is purple-grey siltstone, with sporadic thin interbeds and nodules of cream siltstone. The rock is massive in outcrop, but because it is well bedded it is flaggy in hand specimen. Elsewhere in the Mount Hepple/Mount Matthew area red-brown and khaki siltstone predominates. This grades into greenish fine-grained sandstone near the contact with the overlying King Leopold Sandstone. Towards the northwest the Luman Siltstone becomes more arenaceous and near Mount Humbert is represented by only a thin (ca. 3 m) bed of dark red-brown to purple-brown quartz sandstone and laminated white and dark purple-brown quartz sandstone with varying amounts of hematite.

Thickness

The formation thins from about 35 m near the southern boundary of the Sheet area to about 3 m near Mount Humbert.

TABLE 10. SPEEWAH GROUP—SECTION S1

Estimated section of part of Speewah Group 9 km northwest of Mount Humbert. Distances paced.

Overlain by probable King Leopold Sandstone (pale buff, coarse-grained, very thick-bedded, blocky to massive, poorly sorted silica-cemented quartz sandstone).

Thickness (m)	
	Luman Siltstone(?)
ca 3	*Quartz sandstone:* dark purple-brown, interlaminated pale buff and purple, fine-grained, flaggy, well sorted, friable; poorly exposed
	Lansdowne Arkose(?)
74	*Quartz sandstone:* white to pale pink-brown, coarse-grained, thin to thick-bedded, blocky to massive; some slightly sericitic—after feldspars?; well developed festoon cross-beds locally
10	No outcrop—alluvium in valley bottom
16	*Quartz granule conglomerate:* white to pale buff, thick-bedded, blocky to massive, granule conglomerate and coarse-grained, poorly sorted, quartz sandstone; gives way upwards to coarse-grained, well sorted quartz sandstone; cross-beds indicate currents from west and northwest
3	*Quartz sandstone:* white, medium-grained, thick-bedded, well sorted
50	*Quartz granule conglomerate:* white to pale buff, thick-bedded, blocky to massive, poorly sorted; contains granules up to 5 mm; cross-beds indicate current from northwest
17	*Quartz sandstone:* pale pink-brown, medium-grained, well sorted
	Valentine Siltstone?
5	No outcrop. Detritus of dark red-brown siltstone and shale
	Tunganary Formation
42	*Quartz sandstone:* pale pink-brown and pale grey, medium to coarse, thick-bedded, blocky, well sorted; contains scattered grains of feldspar and prominent tourmaline grains
30	*Feldspathic quartz sandstone:* white to pale pink, medium-grained, thick-bedded, blocky, feldspar is highly altered, and makes up 5 to 10% of the rock
5	*Quartz sandstone:* white to pale pink and pale red-brown, thick-bedded, blocky, well sorted
3	*Quartz sandstone and granule conglomerate:* pale buff, very coarse-grained, thick-bedded, blocky, clean-washed granule-bearing
	O'Donnell Formation
105	*Quartz sandstone:* coarse-grained quartz sandstone and granule conglomerate with partings of grey-green siltstone
Total about 363	

KIMBERLEY GROUP

The Kimberley Group overlies the Speewah Group conformably and is unconformably overlain by the Mount House Group.

The Kimberley Group comprises the (1) King Leopold Sandstone, (2) Carson Volcanics, (3) Warton Sandstone, (4) Elgee Siltstone, and (5) Pentecost Sandstone. The first three crop out extensively; the Elgee Siltstone and Pentecost Sandstone are represented only by small outcrops. As far as is known, relationships between the constituent formations of the group are conformable everywhere in the Sheet area.

King Leopold Sandstone

Distribution and topographic expression

The King Leopold Sandstone is widely distributed throughout the Sheet area except in the southwestern corner. The total area of outcrop is about 4800 km^2, about half of the Sheet area.

The King Leopold Sandstone forms bold cliffs and escarpments along its southwestern margin. Cliffs are also well developed where fault or joint fractures are deeply eroded, and where the formation is intruded by sills of more easily weathered Hart Dolerite. This is particularly marked in the northwest, around Mount Jamieson and Mount Shadforth. Elsewhere the King Leopold Sandstone forms rugged, rocky butte topography and gently undulating sandy plains with scattered low rocky outcrops. Outcrops are mostly massive with good partings.

Lithology

The formation consists of a uniform sequence of white to pale buff coarse-grained quartz sandstone. Near the base it contains scattered pebbles 1 cm to 5 cm in diameter, appears poorly sorted, and commonly has a small amount of clayey matrix. Most of the sequence consists of well sorted, coarse to medium, thick-bedded, silica-cemented quartz sandstone with well rounded grains, and commonly shows well developed cross-bedding. Most of the sandstone weathers to a very pale rust brown. Leaching of the silica cement has taken place to varying degrees in surface outcrop, but silica-cemented sandstone is ubiquitous at the bottom river gorges. Localized surface resilicification is generally confined to the outer 2 cm or so of outcrops which consist internally of friable poorly cemented sandstone.

Thickness

Too few dips have been measured in the area to allow computation of the thickness. A thickness of 800 m has been estimated 15 km east-southeast of Mount Ord in the Lennard River Sheet area, and a section 1100 m thick has been measured near Mount Nellie in the Yampi Sheet area. The thickness in the Charnley Sheet area probably lies between these two values.

Carson Volcanics

Distribution and topographic expression

The Carson Volcanics form broad elliptical outcrops surrounding the Harding, Synnot, and Barnett Ranges, and a broad belt on the southwestern flank of the Phillips Range extending northwestwards to near Beverley Springs homestead.

The Carson Volcanics form broad lowlands with low rounded hills interspersed with a veneer of red-brown soils and by scattered areas of black soil plain. Hills become steep and conical near the Harding and Synnot Ranges, and west of Beverley Springs are locally capped by laterite.

Lithology

The Carson Volcanics consist predominantly of tholeiitic basalt and spilite, and minor agglomerate. Siltstone forms the topmost part of the sequence in the east.

A probable thin sandstone bed is present about 90 m above the base of the formation in the Calder River valley near the southern margin of the Sheet area, but has been noted only from aerial photographs.

At the head of the Charnley gorge, excellent cliff exposures in the base of the formation (Fig. 13a) contain seven flows, each about 8 m thick, which are constant in thickness over 60 m of continuous outcrop. In other exposures flows thin out over 0.5 km.

Fig. 13a Basal flows of Carson Volcanics in Charnley River Gorge about 18 km west-southwest of Mount Blythe. Seven flows are present within sequence in cliff face. GA1888.

Fig. 13b. Sandstone breccia of Beverley Springs Member showing cavities produced through weathering out of angular siltstone fragments. Locality about 21 km south of Beverly Springs homestead. G1881.

The lower 3.5 m of each flow consists of tough dark grey-green basalt with sporadic large amygdales with chalcedony infillings. These are about 5 cm long, and have domed tops. The next 1.5 m carries many small quartz veins and amygdales. The top 100 cm is highly amygdaloidal, with small amygdales of 0.5 to 1.5 cm diameter infilled with quartz and chalcedony. In other areas, infillings include quartz, chalcedony, chlorite, epidote, pyrite, chalcopyrite, and galena. No flow banding was seen in any of the faces exposed.

The upper part of the formation is lithologically variable. In the Synnot Range, about 25 to 30 m of agglomerate is present immediately underlying the Warton Sandstone. The agglomerate is a dark greenish rock, crumbly on the surface, and forms steep, rough slopes. A crude stratification gives a stepped appearance to the outcrop. The agglomerate is cut by dykes up to 15 cm thick and irregular sill-like bodies of an aphanitic pale grey rock. Also basaltic agglomerate containing large angular xenoliths of fine-grained pink siliceous rock, possibly granophyre or meta-arkose, 25 cm across, is seen close to the main Derby/Gibb River road near the southern boundary of the Sheet area. A further outcrop of agglomerate alongside the Mount House road, 3 to 5 km to the southeast, contains ellipsoidal basic pyroclastic bombs in a matrix of quartz-rich tuffaceous agglomerate. The agglomerates are probably lower in the sequence than that in the Synnot Range.

Near Mount House homestead, about 7 km south of the Sheet area, grey-green and purple-grey siltstone with minor dolomite and algal chert form the topmost beds of the Carson Volcanics. These beds (which are found throughout the eastern part of the Kimberley Basin) are probably present below the escarpment of the Barnett Range, where the topmost beds of the Carson Volcanics are obscured by detritus from the Warton Sandstone. These siltstone beds have not been found in the central or western parts of the Charnley Sheet area and are apparently absent from the western part of the Kimberley Basin.

In the Mount House/Mount Barnett area the siltstones at the top of the Carson Volcanics are overlain by feldspathic sandstone assigned to the Warton Sandstone.

Thickness

A thickness of 450 m has been estimated from aerial photographs near Mount Barnett homestead. In the eastern part of the Yampi Sheet area a thickness of over 1000 m has been measured and the formation probably thickens westwards in the Charnley Sheet area.

Warton Sandstone

Distribution and topographic expression

The Warton Sandstone crops out in the centre of three broad synclines forming the Mount Barnett Plateau, and the Synnot and Harding Ranges; the Harding syncline in the west is the largest, and contains more than half of the total area of outcrop, which is estimated to be about 1700 km^2.

The Warton Sandstone is flat-lying and forms large flat-topped plateaux except in the western part of the Harding Range, where gently dipping cuestas are the predominant landform. It can be distinguished from the King Leopold Sandstone on aerial photographs by its more pronounced bedding and less well defined jointing.

Lithology

The Warton Sandstone consists principally of medium-grained (and rare coarse-grained) white to very pale rust-brown, clean washed, well sorted quartz sandstone, and subordinate feldspathic sandstone and possible siltstone. In outcrop the quartz sandstones are mostly thick-bedded and blocky, and are generally silica-cemented. Cross-bedding is common, with current directions mainly from west and northwest. Foresets are mainly about 0.3 m thick, but locally, especially in the lower beds, are up to 1 m thick. Large-scale ripples with a wavelength of around 1 m have been noted in the extreme west in quartz sandstone near the top of the sequence. One overturned cross-bed was noted in the west.

Feldspathic sandstone makes up the basal part of the sequence, especially in the east where about 180 m of feldspathic sandstone forms a steep rubble-covered slope at the base of the main Warton Sandstone escarpment, south of Mount Barnett homestead. The feldspathic sandstone is flaggy to blocky, locally micaceous, mostly medium-grained, and contains angular grains of pink feldspar and minor arkose. Feldspathic sandstone is common in other Sheet areas in the middle and upper parts of the Warton Sandstone, and may also be present at equivalent stratigraphic levels in the Charnley Sheet area. Similarly, from photogeological evidence, it appears that a siltstone member which is present in much of the Yampi Sheet area may be present about 13 km west-southwest of Mount Lochee in the Harding Range.

Thickness

The total sequence of Warton Sandstone is preserved only in the extreme west, between Doubtful Bay and Walcott Inlet. Because of faulting and lack of measured dips the thickness is uncertain. Some 40 km to the southwest, in the Yampi Sheet area, 550 m of Warton Sandstone has been measured, and to the north in the Prince Regent/Camden Sound Sheet area the thickness has been estimated to be about 900 m (Williams & Sofoulis, 1967, 1971). A thickness of about 600 m is thus likely in the west of the Charnley Sheet area. In the east the full sequence is not preserved, but extrapolation of data from the Lansdowne Sheet area suggests that the formation is thinner in the east of the Charnley Sheet area than in the west.

Elgee Siltstone

Distribution and topographic expression

The Elgee Siltstone crops out only in the extreme west of the Sheet area between Doubtful Bay and Walcott Inlet, in escarpments capped by more resistant Pentecost Sandstone; it is generally obscured by detritus. Most outcrops are in rugged inaccessible country where even helicopter landing spots are rare.

Lithology

Little is known of the lithology of the Elgee Siltstone in this area. A few fragments of red-brown siltstone and laminated sandstone have been found near the southern end of the most southerly outcrop of Elgee Siltstone, and to the north of this, red-brown to maroon flaggy beds (probably flaggy micaceous sandstone and possible siltstone) have been observed from the air.

At a locality 6 km southeast of Eagle Point, 5 km west of the Charnley Sheet area, a basal bed of pebble conglomerate and granule sandstone is overlain by fine-grained red-brown quartz sandstone. Fragments of dark red-brown shale and siltstone have been found at the same locality.

Thickness

Because of lack of exposure, and lack of access where exposures occur, no section of Elgee Siltstone has been measured either in the Charnley Sheet area or in the immediately adjacent part of the Yampi Sheet area. From flight observations of exposed Elgee Siltstone around 2242E; 29470N it appears that only about 30 to 60 m of section are present.

Pentecost Sandstone

Distribution and topographic expression

The Pentecost Sandstone is present only in the extreme west, immediately south of Doubtful Bay.

The lower beds form resistant cuestas overlying the more easily eroded Elgee Siltstone. They are light-coloured on aerial photographs and show well developed bedding and jointing. The uppermost beds form rounded hills with a dark grey even-toned photo-pattern, but bedding and jointing in these beds cannot be detected on aerial photographs.

Lithology

The lower beds have not been examined in the Charnley Sheet area but their lithology is known from exposures about 5 km southeast of Eagle Point in the Yampi area. There they consist of white to pink and pale buff mostly medium-grained well sorted quartz sandstone commonly containing 1 to 2 percent weathered feldspar. It is thin to thick-bedded, blocky, and has well developed cross-beds.

The upper beds consist mainly of white and red-brown fine-grained highly feldspathic sandstone. The sequence contains thin interbeds of grey-green siltstone up to 0.6 m thick, which themselves contain thin interbeds of ripple-marked fine-grained sandstone.

Thickness

Since only part of the Pentecost Sandstone succession is present in this area no section has been measured. It is estimated that there are probably about 120 to 150 m of the lower beds present and about 100 m of the upper beds.

Correlation

The relation of the upper beds to the lower beds is uncertain, as is also their place in the Pentecost Sandstone succession. If the upper beds are conformable on the lower then they must be the products of a localized facies change, since lateral equivalents 7 km to the northwest are less feldspathic and contain no known siltstone interbeds.

An alternative explanation is that these beds are correlatives of the feldspathic facies of the Yampi Member (of the Pentecost Sandstone), which is present a few kilometres to the west, overlying beds some 200 m higher in the Pentecost Sandstone sequence than those they overlie in the Charnley area.

Both explanations would imply that movement had taken place during the deposition of the Pentecost Sandstone in this area. One would imply tectonic control of facies changes, and the other temporary uplift and erosion of rocks now depressed in a graben (see 'Structural Geology').

PALAEOCURRENT DIRECTIONS

Palaeocurrent directions from cross-bed orientations have been recorded from most other Sheet areas in the Kimberley region. Too few observations have been made in the Charnley Sheet area to come to any independent conclusions. However, the data agree well with those from other Sheet areas and help to complete the regional picture of palaeocurrents in the Kimberley Basin sediments (Gellatly, Derrick, & Plumb, 1970).

Cross-bed orientations have been measured mostly in sets of 25 readings from each locality. Fewer measurements have been made from other localities. The data are presented in Figure 14.

Current directions near the base of the sequence (two sets of readings south of Walcott Inlet) are from the east and northeast, as in the Speewah Group and lower part of the King Leopold Sandstone elsewhere in the Kimberley area.

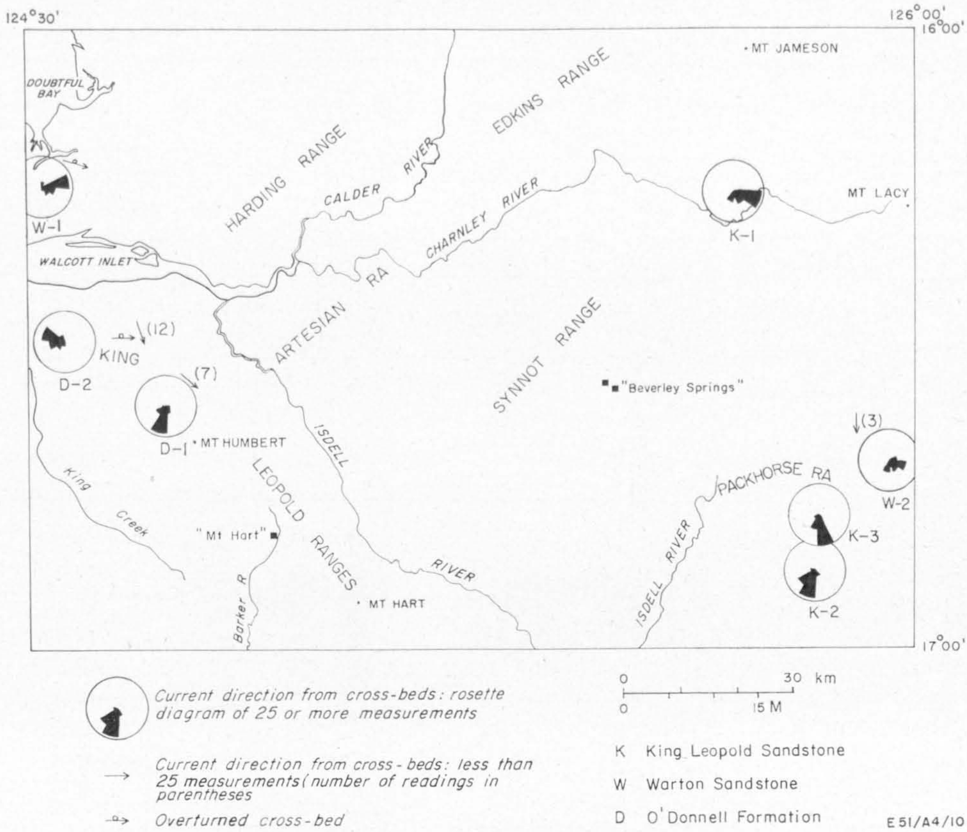

Fig. 14. Sedimentary structures.

Measurements from the upper part of the King Leopold Sandstone and from the Warton Sandstone indicate currents mostly from north and northwest and conform with other measurements from these formations. A southwesterly direction noted from the Warton Sandstone in the extreme west is unusual, but has a parallel in one set of recordings from the eastern part of the Yampi Sheet area.

Hart Dolerite

The name Hart Dolerite is given to extensive sills of tholeiitic dolerite and associated granophyre which intrude the sediments of the Kimberley Basin. The use of the name follows that of Harms (1959), who renamed the 'Hart Basalt' of Guppy et al. (1958).

Field occurrence

Distribution, thickness and topographic expression. Sills of Hart Dolerite are extensive throughout the Kimberley Basin. In the Charnley Sheet area they are best developed along the southern flank of the King Leopold Ranges, where concordant sills extend for over 80 km. The dolerite is also extensive within the surrounding Synnot Range syncline, and in the northeastern part of the Sheet area where long sinuous outcrops are exposed at the bottom of narrow valleys and gorges developed in the King Leopold Sandstone. The total area of outcrop is about 1200 km^2.

The main sill intruding the lower formations of the Speewah Group is up to 3000 m thick, but is mostly about 1300 m. Sills intruding higher formations have thicknesses mostly in the range 30 to 300 m but a few exceed this.

The Hart Dolerite forms rounded, boulder-strewn hills and ridges which on aerial photographs have an even grey tone broken by scattered black patches, indicative of dark-weathering rocky residual boulders free of vegetation. Broad valleys underlain by dolerite are characterized by treeless, generally stony, black-soil plains. The upper part of the granophyre is mostly resistant to erosion and forms a prominent strike ridge (e.g. Mount Humbert), but the basal part is commonly easily weathered and forms a narrow valley floored by red-brown soil.

Stratigraphic relations

The Hart Dolerite intrudes all the formations of the Speewah and Kimberley Groups up to and including the Pentecost Sandstone, but is most extensive where it intrudes the Speewah Group. Locally it intrudes the Whitewater Volcanics and the Mondooma Granite. The thickest and most extensive sills intrude the O'Donnell and Tunganary Formations and the Valentine Siltstone. Except for a thick sill intruding the Carson Volcanics east of the Isdell Gorge, intrusions in formations higher than the Valentine Siltstone are thin and laterally impersistent. Stratigraphic horizons higher than the Valentine Siltstone that have commonly been intruded by the Hart Dolerite include the Luman Siltstone, a horizon near the top of the King Leopold Sandstone, the contact of the King Leopold Sandstone and the Carson Volcanics, and a horizon near the base of the Warton Sandstone.

The only contact that has been observed in the Charnley Sheet area is in the Synnot Range. Here, Warton Sandstone overlying the Hart Dolerite has been contact metamorphosed and has developed a strong columnar jointing with 8 cm diameter columns.

Form of the intrusions. Most sills are concordant and appear to have been intruded by splitting of the sediments (especially siltstone) along favourable horizons. The granophyre forms a concordant layer near the top of the main sill and grades downwards into the dolerite.

Transgressive parts of sills, which are rare in comparison to the concordant parts, mostly follow north or northeast-trending joint or fault fractures. Good examples of transgressive sills are present in the Charnley Gorge, on the southern side of the Harding Range, and near Hann Pass. A notable feature of the Hart Dolerite is the way in which large areas of sediment have been rafted out of place by dolerite over considerable distances, e.g. north of Mount Humbert and near Mount Hepple.

Two northwest-trending major dyke systems, one of them 110 km long, and each consisting of several discontinuous sections (some en echelon) of what at depth is probably a single dyke, are also regarded as representatives of the Hart Dolerite. In the Lennard River Sheet area the southeastern continuation of one dyke system cuts the basal sill of Hart Dolerite but apparently does not cut the immediately overlying sill, and may have been a feeder for it. The northwestern end of this same dyke system terminates a few kilometres east of Doubtful Bay, against a major east-northeast fault.

A few northeast and northwest-trending dolerite dykes cut the older Precambrian rocks in the southwestern corner of the Sheet area, but their relation to known Hart Dolerite is uncertain.

Lithology

The Hart Dolerite is a dark grey medium to coarse ophitic dolerite in which in the lower parts are small scattered pits on the weathered surface owing to preferential weathering out of altered olivine. Locally, in the southwest, the dolerite is saussuritized and is green-grey in hand specimen.

The granophyre is a coarse-grained pale pink to pale grey rock with pale pink and pale green feldspar phenocrysts and thin elongate pyroxenes (up to 1 cm) set in a granophyric quartz-feldspar matrix.

Age

The age of the Hart Dolerite is early Carpentarian. Bofinger (1967), using specimens from the Lansdowne Sheet area, has determined the age to be about 1800 m.y.

ADELAIDEAN

Mount House Group

In the Charnley Sheet area the Mount House Group comprises the Walsh Tillite, Traine Formation, Throssell Shale, and the Beverley Springs Member which is a lateral equivalent of the Walsh Tillite. Apart from the Beverley Springs Member, the Group is confined to a small area in the southeast corner of the Sheet area.

Except for the Beverley Springs Member, little is known about these Adelaidean rock units in the Sheet area. Some information has been supplied by Plumb (in prep.), who has examined exposures in the Lennard River Sheet area a few kilometres south of the southeast corner of the Charnley Sheet area. Roberts & Perry (1966, 1969) have described the Adelaidean rocks from the adjoining Mount Elizabeth Sheet area.

Stratigraphic relations

The basal formation of the group, the Walsh Tillite, lies unconformably, but with very little discordance, on the Carson Volcanics. It is conformably overlain by the Traine Formation, which in turn is overlain conformably by the Throssell Shale. The group is overlain only by superficial Cainozoic deposits.

The relation between the Walsh Tillite and the Beverley Springs Member has not been observed in the Charnley Sheet area. However, the Beverley Springs Member may be traced intermittently to near Mount House in the Lennard River Sheet area, and is probably represented there by a coarse pebbly sandstone at the base of the Mount House Group. Thus the Beverley Springs Member is regarded as a facies equivalent of basal beds of the Walsh Tillite.

Correlations and age

The Mount House Group is correlated with the Moonlight Valley Tillite of the Duerdin Group of the East Kimberley (Dow & Gemuts, 1969). The Duerdin

Group has been dated at 740 m.y. by Bofinger (1967). This places the Duerdin Group, and thus also the Mount House Group, near the top of the Adelaidean.

Beverley Springs Member

Distribution and topographic expression

The Beverley Springs Member ocurs as scattered exposures around Beverley Springs homestead, where it unconformably overlies Carson Volcanics and King Leopold Sandstone.

The formation crops out as a series of low conical hills which are generally lower than the surrounding hills, and appears to have been laid down in a pre-existing valley or depression in the Carson Volcanics. The hills have a dark, even tone on aerial photographs.

Lithology

The Beverley Springs Member consists mainly of sedimentary breccia composed of a matrix of tough, pale-coloured quartz sandstone containing large numbers of angular pebbles of siltstone and flaggy siltstone (or their impressions) which are randomly distributed throughout the rock (Fig. 13b). It is not normally stratified, but on Clemens Hill and Sams Knob a crude impersistent stratification is visible. The matrix, which is much more abundant than the pebbles, consists of medium to fine-grained angular quartz and rare feldspar grains set in a fine ferruginous or siliceous cement. Sorting is poor, and the grains are angular to subangular.

Walsh Tillite

Distribution and topographic expression

The Walsh Tillite proper (excluding the Beverley Springs Member) is restricted to the extreme southeast of the Sheet area, where it forms a narrow outcrop some 5 km long.

The tillite, which is easily weathered, forms a small escarpment capped by resistant dip-slope-forming dolomite.

Lithology

The basal beds consist of coarse-grained pebbly sandstone but these are rarely exposed, being obscured by detritus from the overlying beds. The tillite consists of striated cobbles and boulders—mainly of sandstone—in a grey-green clayey matrix. The tillite grades up into siltstone through a decreasing megaclast content. Dolomite, which forms the topmost beds of the formation, is pink to brown and contains well preserved dome-shaped algal structures.

The thickness has not been measured, but a rough estimate from aerial photographs, based mainly on the height of the escarpment, suggests that it is about 50 m.

Traine Formation

Distribution and topographic expression

The Traine Formation is confined to a small outcrop in the southeastern corner of the Sheet area. It crops out as low hills and knolls at the foot of the dolomite dip-slope of the Walsh Tillite and has a dark photo-pattern.

Lithology

The Traine Formation has not been examined in the Charnley Sheet area. In the adjacent Lansdowne and Lennard River Sheet areas the formation consists of massive dark green to brown medium to coarse chloritic feldspathic sandstone, lithic sandstone with scattered glacial erratics, and minor sandy dolomite and dolomitic sandstone. The chloritic sandstone locally contains about 2 to 3 percent apatite.

The thickness is uncertain but is estimated from aerial photographs to be about 60 m.

Throssell Shale

Minor outcrops of the Throssell Shale occur in the extreme southeast. Only a few metres of section are preserved out of a total 235 m known in the region. It forms shale-strewn pediments and gentle debris slopes.

The lithology is predominantly of grey-green shale (commonly red-brown where weathered), and with thin interbeds of fine-grained buff and grey-green sandstone.

PALAEOZOIC

DEVONIAN

A small part of the Devonian limestone reef complex that forms the northern margin of the upper Palaeozoic sequence of the Fitzroy-Canning Basin crops out in the extreme southwest. The reef complex has been described by Guppy et al. (1958) and Playford & Lowry (1966), who have subdivided it into three main facies—reef, back-reef, and fore-reef. The reef complex overlies and interfingers with conglomerate. Only the back-reef facies and conglomerate are present in the Charnley Sheet area.

Van Emmerick Conglomerate

The Van Emmerick Conglomerate forms a very low rounded hill covered by cobble and boulder scree. Granite clasts predominate, and the matrix is arkosic. The conglomerate is probably part of a large alluvial fan which intertongues with the reef complex at its southwestern margin.

Pillara Limestone

The Pillara Limestone is the back-reef facies and consists predominantly of bedded flat-lying or gently-dipping stromatoporoid and algal limestone with interbedded oolite, calcarenite, and calcilutite. The reef complex dies out a short distance to the northwest and the Pillara Limestone here forms a narrow northwest-trending, well exposed ridge flanked by soil cover on both sides.

Napier Formation

The Napier Formation is the fore-reef facies. It consists largely of well bedded, rather steeply dipping (20°-30°), sparry calcarenite containing scattered small masses of reef limestone interpreted by Guppy et al. (1958) as bioherms and by Playford & Lowry (1966) as fallen blocks of reef limestone. The dips are essentially depositional rather than tectonic. The most obvious difference between the back-reef and fore-reef facies is that of dip, and this has been used for distinguishing these units by photo-interpretation.

CAINOZOIC

Tertiary laterite and eluvium, residual soils and lateritic soils (partly transported) of Tertiary to Quaternary age are found in the Sheet area. Alluvium in and around river courses, and coastal muds and sands in Walcott Inlet and Doubtful Bay are Quaternary.

TERTIARY

Laterite (Tp)

Scattered areas of laterite are preserved over the Carson Volcanics on the eastern side of the Synnot Range, and the western side of the Packhorse Range south of Beverley Springs homestead. A few areas of laterite overlie the King Leopold Sandstone and the Beverley Springs Member.

The laterite mainly forms as a capping on small mesas. Its thickness ranges from 10 m in the Synnot Range and 6 m near Eyles Field (6 km northeast of Beverley Springs homestead) to zero. The mesas are generally 35 m or more above the surrounding lowlands, and are believed to represent remnants of a more extensive sheet.

UNDIVIDED CAINOZOIC

Ferruginous pisolitic soil (Czl)

Ferruginous pisolitic soils are developed over laterite, and near the junction of laterite with sandy soils in the Synnot and Packhorse Ranges. Areas of pisolitic soils derived from erosion of laterite form alluvial fans, but these are too small and too localized to show on the accompanying map.

The soils are dark red-brown, friable, and contain small nodules and pellets of limonite up to 1 cm across.

Black soil (Czb)

Residual black and dark grey-brown soils and cracking clays are developed in low-lying areas overlying the Carson Volcanics and the Hart Dolerite. Small areas of these soils are also developed over the Halls Creek Group and Woodward Dolerite. They are usually hummocky, and during the dry season have deep polygonal cracks and sinkholes ('gilgai').

Other soils (Czs)

In this category are grouped various residual soils and eluvium. The principal types are (1) light-textured pale grey-brown shallow sandy soil developed over sandstone; (2) dark red-brown fine-textured clayey loams and podzols, and gravelly soils, developed over basic volcanics, over the granophyric phases of the Hart Dolerite, and over pediments underlain by the Woodward Dolerite; (3) coarse-grained grey and red-brown sandy clays overlying granites in the southeast; (4) red-brown and grey-brown clayey soils (locally skeletal) overlying the Halls Creek Group in the southwest; (5) localized areas of alluvial soils developed on flood plains adjacent to some of the larger rivers. Some of the soils bordering the Isdell River near Plover Hill are probably of this type.

Quaternary

Coastal muds and sands (Qc)

The shores of Walcott Inlet and Doubtful Bay are lined by mud-flats composed of dark grey clay, silt, and mud. They are colonized by mangroves along their seaward margins and generally have a salt crust above normal high-water mark. Palynology of the muds has been discussed by Ingram (1965).

Shoals of sand with well developed megaripples are found in Walcott Inlet. Their presence is probably influenced by the strong tidal currents characteristic of the region.

The coastal regions of this Sheet area and of most of the western part of the Kimberley region are of interest in that mud, silt, and fine-grained sand are being extensively deposited in the intertidal zone. Coarse-grained sands occur only away from the shoreline, especially in the bottoms of tidal channels.

Alluvium (Qa)

Alluvial sand, gravel, and silt are extensive within and close to most of the watercourses. Sand predominates in the river beds. River-bank and flood-plain alluvial sediments are confined mostly to within about 1 km of the watercourses, many of which are braided.

METAMORPHISM

Metamorphism in the Charnley Sheet area is confined mainly to the Halls Creek Group and Woodward Dolerite. The Halls Creek Group has undergone at least two episodes of metamorphism producing assemblages containing sericite, andalusite, staurolite, kyanite, or garnet as the highest-grade mineral. The Woodward Dolerite has been metamorphosed to amphibolites that are of uniform macroscopic appearance, but differ locally in the colour of the contained amphibole, the presence or absence of epidote, and the composition of their plagioclase (see chapter on Woodward Dolerite).

In addition, evidence of minor metamorphism has been noted in the Whitewater Volcanics, in dolerite dykes cutting the granites, in the Hart Dolerite, and in the Carson Volcanics.

The Whitewater Volcanics are less metamorphosed in the north, where pyroxene in andesites is replaced by epidote but original textures are still preserved, than in the south, where mafic minerals are mostly altered to biotite and a superimposed foliation has largely destroyed original eutaxitic textures. Dolerite dykes cutting the granites have locally been chloritized (as in an east-northeast-trending dyke 5 km north of King Creek yard) or amphibolitized (north-northwest-trending dyke in King Creek 2½ km north of King Creek yard). In places the Hart Dolerite is greenish in hand specimen owing to chloritization but has not been examined in thin section. Simpson (1951) reported glaucophane in the Carson Volcanics near Synnot Creek, but in most places the Carson Volcanics are fresh and unaltered.

Rocks of the Halls Creek Group show evidence of at least two phases of metamorphism, an early high-temperature low-pressure type (Miyashiro, 1961) in which andalusite was developed extensively, and a later high-pressure type in which staurolite, kyanite, and garnet were formed, at least partly at the expense of andalusite. A possible intermediate phase is evidenced locally by the presence of chloritoid.

Not all parts of the southwest corner have been affected by the same episodes of metamorphism, and where the same episodes have operated, they have done so with different intensities. Six main metamorphic zones can be recognized. Their distribution is shown in Figure 15. The zones are

1. *Andalusite-chloritoid zone,* lying mainly in the catchment area of the Pardaboora River.
2. *Sericite phyllite zone,* east and west of King Sound Tin Mine.
3. *Andalusite zone,* south and southeast of King Sound Tin Mine.
4. *Garnet zone,* immediately southwest of Hawkstone Creek kyanite deposit.
5. *Andalusite-staurolite kyanite zone,* southwest of and parallel to the garnet zone.
6. *Kyanite zone,* of the Hawkstone Creek kyanite deposit.

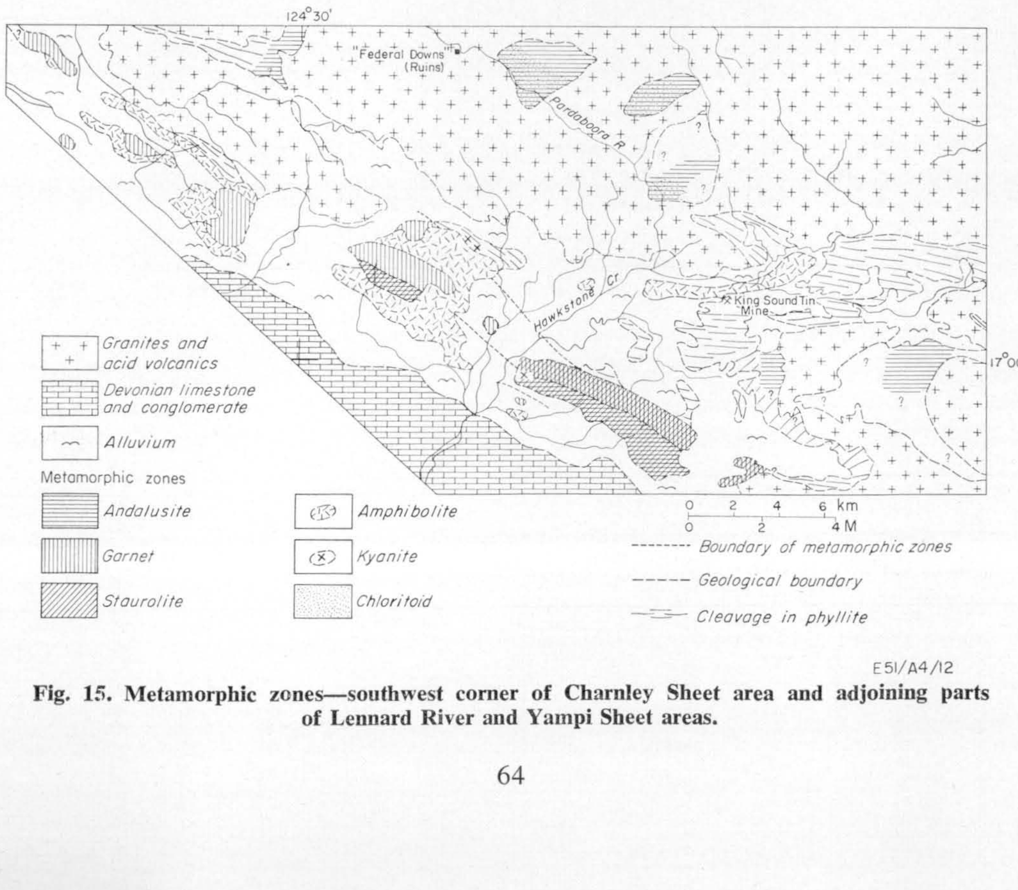

Fig. 15. Metamorphic zones—southwest corner of Charnley Sheet area and adjoining parts of Lennard River and Yampi Sheet areas.

The metamorphic mineral assemblages of four of these zones are given in Table 11. Those from the other two have not been examined microscopically, Minor accessory minerals, namely tourmaline, zircon, sphene, and opaque oxides, which are unrelated to the metamorphic conditions, are omitted from the assemblages in this table.

Andalusite-chloritoid zone. Rocks of this zone are mostly andalusite-bearing phyllite, schist, and hornfels, with well preserved bedding. Cleavage, developed locally, is of variable trend; lineations plunge east and southeast. In many parts of these inliers andalusite is recognizably pseudomorphed by a mica. In thin section it is commonly seen to be completely pseudomorphed by sericite and chloritoid, or by biotite, chlorite, and muscovite, but patches of these minerals retain the original form of the replaced (chiastolitic) andalusite. In some specimens a second generation of clear, fresh andalusite is present in addition to the pseudomorphed chiastolite.

TABLE 11. METAMORPHIC ASSEMBLAGES

Specimen No.	*Assemblage*
ANDALUSITE-CHLORITOID ZONE (NORTHERN INLIERS)	
66.16.1001	(Andalusite)[1] - chloritoid - ?cordierite - biotite - sericite - muscovite - chlorite-quartz
67.16.1026	(Andalusite)[2]-chloritoid-muscovite-biotite-sericite-chlorite-quartz
67.16.1027	Andalusite[2]-muscovite-sericite-biotite-quartz
67.16.1028	Muscovite-biotite-quartz
67.16.1029	(Andalusite)[1]-andalusite[2]-chloritoid-muscovite-biotite-quartz
67.16.1030	(Andalusite)[1]-andalusite[2]-chloritoid-muscovite-chlorite-biotite-quartz
67.16.1062	(Andalusite)[1]-chloritoid-sericite-biotite-plagioclase-quartz
67.16.1063	Chloritoid-biotite-sericite-quartz-andalusite
GARNET ZONE (a) Pelites	
66.16.1016	Garnet-muscovite-sericite-biotite-chlorite-?plagioclase-quartz
67.16.0339	Garnet-muscovite-biotite-oligoclase-quartz
(b) Calcareous Psammites	
66.16.1003	Hornblende-plagioclase-quartz
66.16.1005(a)	Garnet-plagioclase (An_{32})-hornblende-clinozoisite-quartz
(b)	Hornblende-clinozoisite-plagioclase-quartz
ANDALUSITE-STAUROLITE-KYANITE ZONE	
67.16.0340	(Andalusite)[1]-staurolite-kyanite-muscovite-biotite-quartz
67.16.0341	(Andalusite)[1]-staurolite-kyanite-muscovite-sericite-quartz
67.16.0342	(Andalusite)[1]-kyanite-staurolite-muscovite-biotite-quartz
66.16.1013	Staurolite-(andalusite)[1]-muscovite-biotite-quartz
KYANITE ZONE	
66.16.1010	Kyanite-dumortierite
66.16.1011	Kyanite-?paragonite
66.16.0301	Corundum-sericite
67.16.1042	Kyanite-corundum-topaz
67.16.1040	Muscovite-kyanite-topaz
67.16.1043	Kyanite-muscovite-quartz
67.16.1041	Muscovite-quartz
67.16.1032	Muscovite-biotite-quartz

Notes: Parentheses around a mineral name indicate that it has been either partly or wholly pseudomorphed by other minerals.

[1] indicates first-generation andalusite;

[2] indicates second-generation andalusite.

Since these rocks form inliers (probably roof pendants), completely surrounded by granite, the possibility of contact metamorphism must be considered. If contact metamorphism has been responsible for the development of andalusite, some variation in the assemblage might be expected with increasing distance from the contacts. No such variation has been noted in first-generation andalusite, although rocks 1500 m from granite contacts have been examined in these inliers. However, most specimens with fresh (second-generation) andalusite come from localities within about 500 m of granite contacts, and thus andalusite could possibly have formed as a result of contact metamorphism. Evidence from other specimens is conflicting: of two specimens collected about 1500 m from the contact of the most easterly inlier, one contains fresh andalusite, and one specimen from within a few metres of the margin of the middle inlier contains no fresh andalusite, but abundant chloritoid.

On the other hand, all specimens containing chloritoid are found within 500 m of contacts. In addition, there appears to be a consistent inverse relation between chloritoid content and distance from the nearest contact. Further evidence for possible effects of contact metamorphism in these inliers is the co-existence in some rocks of chloritoid and biotite, which are generally considered to be mutually exclusive in regional metamorphism. The co-existence of these two minerals may be explained by the fact that specimens containing them come from within 500 m of granite contacts and that chloritoid and biotite have previously been reported from contact metamorphics (Albee, 1965).

Sericite-Phyllite Zone. These rocks are only slightly metamorphosed and are characterized by sericite which defines a strong east-trending cleavage. Well developed bedding/cleavage lineations plunge steeply to east-southeast and are thus similar in trend to those in the inliers. No thin sections of rocks from this zone have been examined. The zone grades locally into rocks with altered andalusite.

Andalusite Zone. The extent of this zone is only partly known. Structurally it is characterized by a cleavage and lineation that parallel almost exactly those in the sericite phyllite zone to the north. Andalusite within the zone is invariably altered to a mica. Traces of staurolite have been noted in one locality.

Garnet Zone. Rocks of this zone are well cleaved muscovite schists containing garnet and generally also slender elongate staurolite crystals. The zone is more extensive in the Lennard River Sheet area (where staurolite is almost invariably present) and also extends into the Yampi Sheet area (staurolite absent). The garnet zone has a west-northwest-trending cleavage and two strong lineations, one plunging to the southeast and the other to the southwest. Both lineations, at least in part, must postdate the formation of garnet since pressure shadows on garnets are locally elongated in both directions. Inclusion trains in garnets are straight, but are oblique to the cleavage of the rock, suggesting that the garnets have been rotated after, but not during, growth.

A short distance west of the Hawkstone Creek kyanite deposit, calcareous psammites within the garnet zone do not necesarily belong to the same metamorphic subfacies. The rocks are characterized by both garnet and an amphibole, and have equivalents (but of slightly lower metamorphic grade) in the Lennard River Sheet area. These rocks probably belong to the amphibolite facies, but this is uncertain as the amphibole is pale in colour and may have actinolitic affinities.

Andalusite-Staurolite-Kyanite Zone. This zone, which parallels the garnet zone and lies on its southwest flank, is notable for the evidence it provides of two-phase metamorphism. Exposures of rocks of this zone have not been found in the Charnley Sheet area, but abundant detrital andalusite and staurolite indicate that it is well developed 3.5 km southwest of the kyanite deposit. Most of the information on this zone comes from its extension in the Lennard River Sheet area. A small outcrop of garnet-bearing schist south of the zone (about 3 km south of Hawkstone Creek yard) suggests that the andalusite-staurolite-kyanite zone is a narrow belt within a more extensive area of garnet-bearing rocks.

The principal characteristics of the zone are the presence of large crystals of altered chiastolite up to 10 cm long and 3 cm across, of thick short prismatic staurolite crystals, and of well preserved bedding. Lineations plunge mainly to the south and are similar in trend to those in the adjacent garnet zone. Alignment of andalusite parallel to this lineation has been noted in one outcrop. Kyanite is present only as microscopic crystals in pseudomorphs after andalusite, and its extent in the zone is unknown.

In thin section the chiastolites are seen to be completely pseudomorphed by an assemblage of muscovite, kyanite, and staurolite. In addition, discrete porphyroblasts and minute elongate grains of staurolite are closely associated with small flakes of biotite which define the cleavage. Many rocks contain discrete porphyroblasts of biotite up to 2 mm which commonly cut across the cleavage. These porphyroblasts have poikilitic margins containing abundant small quartz inclusions and are generally bordered by small scattered staurolites. Like similar transgressive biotite porphyroblasts in Halls Creek Group, those of the Lennard River Sheet area may have been derived from pre-existing chloritoid: since chloritoid is generally considered to be replaced by staurolite with increasing metamorphism, the presence of small staurolites bordering the biotite porphyroblasts tends to support the suggestion. In some specimens (e.g. 67160340) the porphyroblasts have been sheared out to form thin tabular grains but are still closely associated with small staurolites.

Kyanite Zone. The unusual mass of kyanite-rich rocks forming the Hawkstone Creek kyanite deposit apparently lies within the zone of low-grade sericite phyllites, but is very close to the garnet isograd. Even if the deposit lies within the greenschist facies, as seems likely (sericite phyllite is the host rock for the kyanite bands), it is probable that the assemblages within it conform with those formed elsewhere during the second metamorphic episode, since kyanite may form in the upper greenschist facies in place of pyrophyllite. The abundant evidence for replacement of andalusite by kyanite and by micaceous minerals suggests that the initial metamorphism affecting the deposit was essentially the same as elsewhere in the area.

This leaves unexplained two main features, namely the abundance of topaz locally within the deposit, and the unusual concentration of aluminous minerals. The presence of topaz is curious and the only explanation that can be offered is that it is the result of metasomatism, either through concentration of F and OH already present in the schists, or through introduction of these constituents from nearby granites. The unusually high concentration of topaz in the deposit is probably a direct result of the large amount of alumina present before the metasomatism. The role of alumina in the formation of topaz was merely to fix the volatile F ion in an insoluble form.

The great concentration of aluminous minerals of the kyanite deposit has its parallel in the Richenda River corundum deposit in the Lennard River Sheet area. It is probably significant that both deposits occur at the contacts of Halls Creek Group pelites with the Woodward Dolerite at the lower contacts of the respective sills. Similar corundum-rich rocks (whose origin has not been masked by the effects of subsequent metamorphism) have been described from Argyllshire by Smith (1965), who interprets the high concentration of alumina as the residue after selective removal from the pelites of a granitic melt as a result of contact metamorphism by the dolerite.

Thus one may envisage here a three-stage process: first, formation of an aluminous residuum (possibly corundum) through selective fusion and removal from the pelites of a granitic fraction; secondly, the first of the two episodes of regional metamorphism causing andalusite to develop in the deposit and then, thirdly, the alteration of andalusite to kyanite, to corundum + sericite etc. The incoming of fluorine probably postdated both episodes since topaz has replaced kyanite which previously had replaced andalusite.

Effects attributable to retrograde metamorphism include the breakdown of kyanite to diaspore, and of andalusite to a mica (muscovite or pyrophyllite). These reactions require minor movement of material either within the rock or into the rock. Similarly, late-stage small-scale movement of material is evidenced by veins of kyanite and chloritoid within the kyanite deposit and of concentrations of tourmaline and dumortierite along microfractures in kyanite-bearing rocks.

STRUCTURE

The Charnley Sheet area lies mainly within the structurally stable Kimberley Block. The southwestern corner, including the King Leopold Ranges, is part of the highly deformed King Leopold Mobile Zone. There is no definite boundary between the two units; the boundary is gradational and is determined by a decrease in intensity of deformation in the Kimberley Basin sediments to the northwest. Structures in the thick arenaceous sequence in the King Leopold Ranges resemble more closely those in the Kimberley Block than those in the mobile zone and are therefore described together with those of the Kimberley Block. The southern margin of the King Leopold Mobile Zone is obscured by Devonian and later sediments of the Canning Basin and probably lies some distance to the southwest of the Sheet area.

The Kimberley Block is characterized by folding along two main trends—northeast and west-northwest. The west-northwest folds truncate the northeast folds and are later than them. Folds within the mobile zone are more varied in their trend but southeast-plunging folds predominate.

Faults in the area trend mainly north, northwest, or northeast and are probably related to the main transcurrent fault system of the Kimberley, although only minor transcurrent movement has been recorded in the Charnley Sheet area.

Folds

King Leopold Mobile Zone

The only major folds discernible in the King Leopold Mobile Zone are an east-southeast-plunging syncline and anticline outlined by the main outcrop of Woodward Dolerite in the extreme southwest corner of the Sheet area.

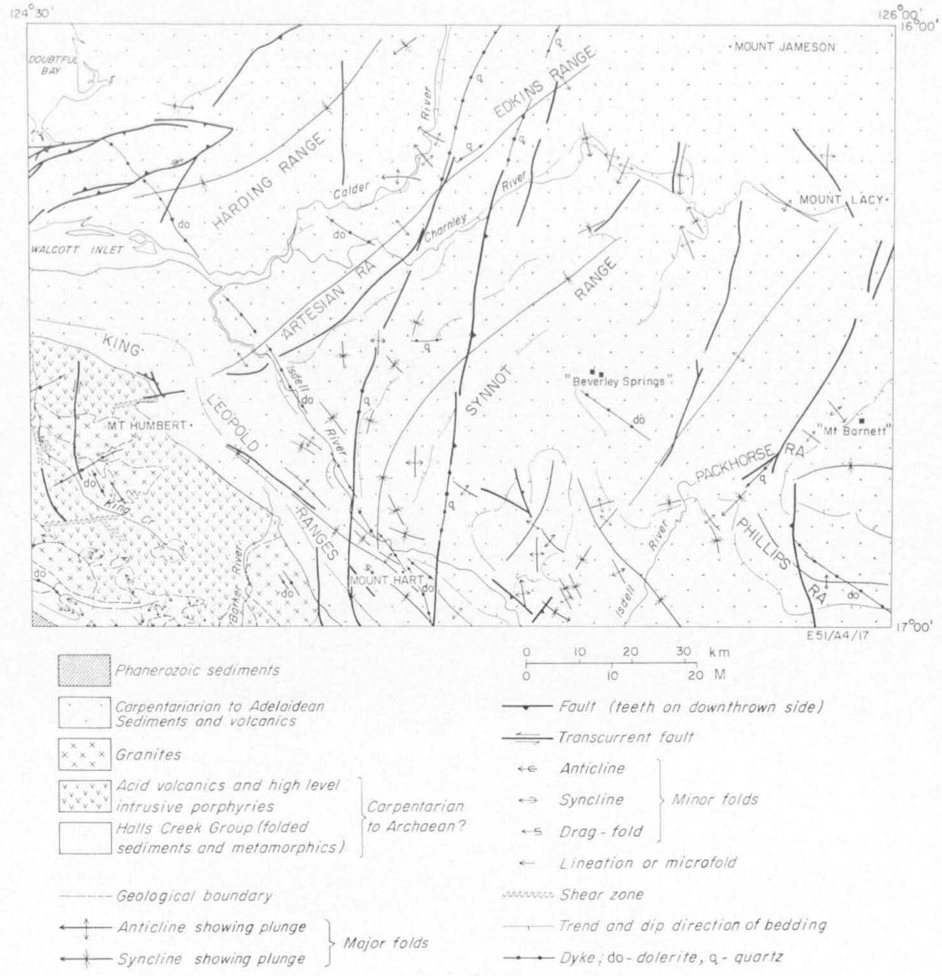

Fig. 16. Structural map.

Minor folds and associated lineations are abundant in the Halls Creek Group, and lineations trending in a similar direction as some of those in the Halls Creek Group (but not associated with discernible folds) are found in the granites. Lineations in the older Precambrian rocks of the Sheet area may be classified into bedding-cleavage intersections, cleavage-cleavage intersections (including crenulation microfolds), elongate pressure shadows on garnets, preferred linear orientation of metamorphic minerals, mineral grain lineations in sheared granite and in flow foliated granite, and fault-plane striations. The predominant types are cleavage-bedding intersections and cleavage-cleavage intersections. The latter predominate in garnet, staurolite, and kyanite schists that have been affected by the second metamorphic episode, whereas cleavage-bedding intersections predominate in rocks that have largely escaped the second metamorphism. The trends of minor structures in the older Precambrian are shown in Figure 17.

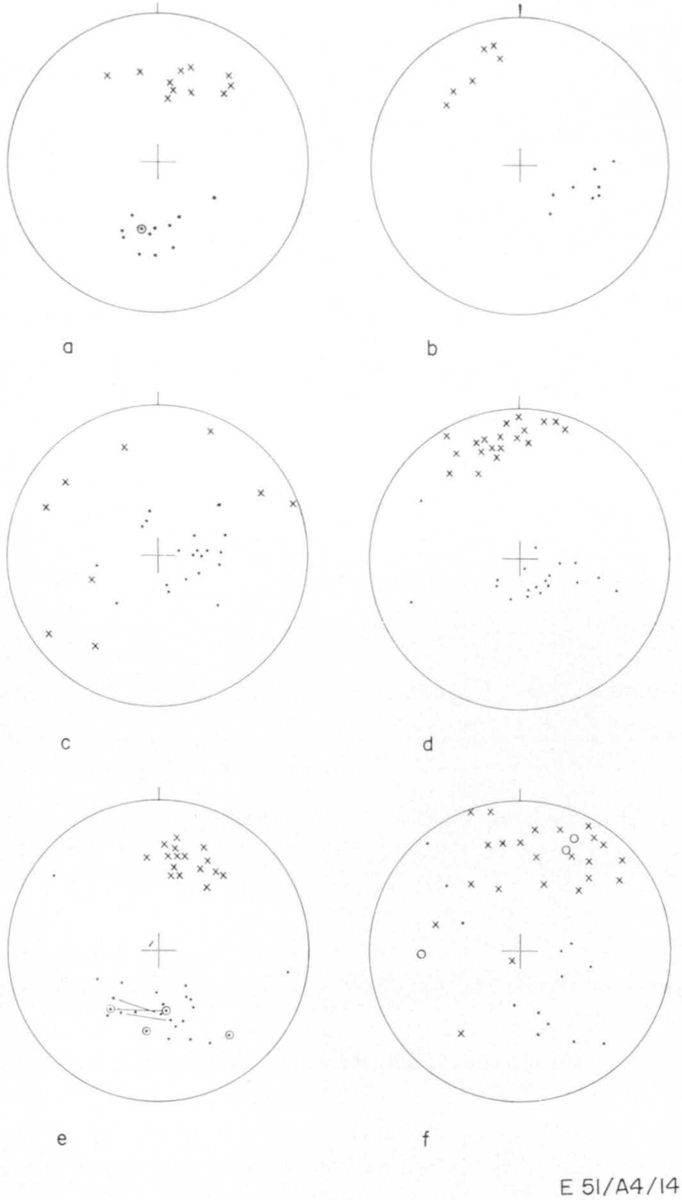

Fig. 17. Minor structures in the older Precambrian rocks.

All diagrams are lower-hemisphere equal-area projections. In all diagrams dots represent lineations and minor fold axes, crosses represent poles to cleavage.

(a) Lineations and poles to cleavage in andalusite-staurolite zone. The circled point indicates preferred linear orientation of andalusite porphyroblasts.
(b) Lineations and poles to cleavage in andalusite zone to south and southeast of King Sound Tin Mine.
(c) Lineations, minor fold axes, and poles to cleavage in Halls Creek Group inliers to the north of Hawkstone Creek and the Pardaboora River.
(d) Lineations, minor fold axes, and poles to cleavage in low grade phyllites around and to the east of King Sound Tin Mine.
(e) Lineations and poles to cleavage in garnet zone. Circled points indicate linear development of pressure shadows on garnets. Tie lines connect lineations on the same cleavage plane.
(f) Lineations and poles to cleavage in intrusive and extrusive acid igneous rocks. Circles indicate poles to flow foliation.

In rocks which have been affected by the first metamorphism, but which escaped the principal effects of the second metamorphism, lineations and minor folds have steep plunges to the east and southeast (Fig. 17, b, c, d) whereas rocks that have been strongly deformed during the second metamorphism (Fig. 17 a, e) have lineations that plunge mainly to the south-southeast and south-southwest. This is similar to the structural pattern in the central part of the Lennard River Sheet area, where the initial structures plunge northeast and those associated with the second metamorphism plunge southeast (Gellatly et al., 1968). Thus it appears that the pattern of development of minor structures in the older Precambrian of the Charnley Sheet area can be related to that in the Lennard River Sheet area. The only difference is that the two sets of Charnley structures differ in azimuth from their Lennard River counterparts. The variations in stress systems responsible for this difference must have antedated the development of structures in the Carpentarian rocks of the mobile zone since structural trends in these rocks are uniform in both areas.

The Kimberley Block and margin of the mobile zone

Following the usage suggested by Gellatly & Sofoulis (1966), major folds in this structural province may be divided conveniently into two broad classes—*first order folds,* which are readily apparent stratigraphically from the distribution of the various formations, and whose fold axes can be traced for up to 80 km; and *second order folds,* which can be detected mainly by observation of dips and bedding trends, either in the field or on aerial photographs, and whose fold axes can rarely be traced for more than about 8 km.

The first order folds comprise the northwest-trending geanticline of the King Leopold Mobile Zone (of which only the northeastern limb is preserved); two prominent broad northeast-trending synclines forming the Harding and Synnot Ranges respectively, and intervening anticlines forming the Artesian and Packhorse Ranges; part of the east-trending Mount Barnett syncline; and a broad west-northwest-trending upwarp in the northeast corner of the Sheet area. All are broad structures with dips seldom exceeding 10° (except in the King Leopold Ranges) and commonly less than 5°. The northeast folds tend to plunge very gently southwestwards in the northeast and very gently to northeast in the southwest, close to the King Leopold Ranges. In the King Leopold Ranges dips of about 30° are common in the south, but decrease northwestward to about 10° south of Walcott Inlet.

The second order folds in the Kimberley block are more varied in their trend than the first order folds. Most trend either northeast or northwest, but north and east-trending folds are also common. Northwest-trending folds increase in abundance and dips within them steepen as the mobile zone is approached. Some of the north-trending folds are close to the north-trending faults. Since bedding is not well displayed in the King Leopold Sandstone and Carson Volcanics, many of the second order folds are apparent only at the contact of the two formations. Amounts of dip and plunge are similar to those of the first order folds. The folds commonly have a wavelength of 3 to 8 km, except in the King Leopold Ranges, where axes of some of the northwest-trending folds are less than 1.5 km apart.

Interference fold patterns due to interaction of the northeast and northwest trends are conspicuous in the southeast corner of the Sheet area, and are also notable in other areas, e.g. the Calder River, where northwest-trending second order folds have deformed a northeast-trending first order fold.

Faults

The principal faults in the area fall into three broad classes—those that trend north or slightly east of north, those that trend northwest or west-northwest, and those that trend northeast or east-northeast.

North-trending faults

North-trending faults are of considerable lateral extent. Two extend right across the Sheet area, a distance of 110 km, and extend into the Lennard River and Prince Regent Sheet areas to the south and north respectively. The principal faults of this trend are infilled with quartz for much of their length and form prominent narrow ridges (Fig. 2b). Apparent vertical displacements to the west and east have been noted, but the amount of such displacement in relation to their length is very small (maximum probably about 60-90 m). A small sinistral transcurrent displacement has been noted on one fault cutting granite in the southwest, and strong shearing has been noted on others.

It is probable that the faults of this trend which have caused vertical displacement of the late Lower Proterozoic rocks are related to those with transcurrent displacement found in the older Precambrian. If so, it implies that the principal transcurrent movement took place after emplacement of the granites but before deposition of the Kimberley Basin sediments, and that the movement on the north-trending faults in the sediments has not been related to the stress system producing the transcurrent movement but has been related to slight crustal warping with movement being located preferentially along pre-existing fractures.

Northwest-trending faults

The principal faults with a northwest trend are found in the southwestern corner of the Sheet area. In the Isdell Range near Mount Hart, one west-northwest-trending fault has caused sinistral transcurrent displacement of a pair of dolerite dykes. Similarly, a north-trending fault near Junction Hill is sinistrally offset, possibly by northwest transcurrent faults. However, another fault of this trend has an associated dextral drag fold which plunges steeply to the southeast. In the granites, faults of this trend are expressed as shear zones which probably reflect transcurrent movement, but the sense of movement is unknown. It is probable that the sense of transcurrent movement on these faults cutting the Precambrian is sinistral—the sense of the only actual displacement noted (in Kimberley Basin rocks). Such a displacement would agree with the observed direction of transcurrent movements in faults of this trend in the Lennard River Sheet area.

Northeast-trending faults

Faults which belong to the northeast-trending group have trends that vary from a few degrees east of north to a few degrees north of east. The principal faults with these trends are found northwest of Mount Barnett, and south of Doubtful Bay where a prominent graben is present. Movement appears to have been mainly vertical. Displacements are small except on the northern margin of the graben where one fault has a throw of about 900 m and where the maximum total displacement of the deepest part of the rift is 1800 m. Together with faults in the eastern part of the Yampi Sheet area, the northern boundary fault of this graben forms part of arcuate fault system with a radius of about 40 km and with its centre about 16 km north-northwest of Mount Humbert.

Near Mount Humbert an east-trending fault has caused a small vertical displacement of Speewah Group rocks, but it is expressed as a shear zone in the older Precambrian; one other shear zone of this trend is present a few kilometres to the southwest. These features suggest that faults of this system may be partly related to transcurrent faults which have been subsequently reactivated.

Faults of this group in the eastern part of the Sheet area trend north-northeast parallel to the major transcurrent faults of the East Kimberley.

JOINTS

Most rocks of the area are very strongly joined. Major joints (visible on aerial photographs) are particularly abundant, and well displayed as a result of preferential erosion, in the King Leopold Sandstone and in the granites.

Three main trends are present (1) northwest to north-northwest, (2) northeast to east-northeast, and (3) north-south. In general these trends parallel those of the faults. The principal exception is that joints of the northwest-trending group do not coincide exactly in trend with the northwest faults, and as was noted above one west-northwest transcurrent fault displaces joints infilled by dolerite dykes.

An unusual feature is the presence in the granite west of Mount Matthew of arcuate joints with trends that swing from a few degrees east of north round to northwest. An explanation of this is not apparent.

Dyke trends

Basic dykes in the area are sparse and follow two main trends, northwest and east-northeast. The latter trend is found only in the granites and the former is more common in the Kimberley Basin rocks. A notable feature is the extent of the northwest dykes. Two individual dyke systems can each be traced intermittently for about 110 km. One dyke terminated against the northern boundary fault of the graben south of Doubtful Bay and is thus considered to be later than the fault.

TECTONIC HISTORY

The tectonic history of the Sheet area is summarized in Table 12. The information on the age relations of events on which this table is based are given in various sections of the text dealing with the rock units concerned. Evidence for the relative ages of events, if not available from the Charnley Sheet area, has been taken from other areas, particularly from the Lennard River Sheet area.

Some of the more important points of the tectonic history of the Charnley area are that the relations between principal early periods of folding and the two main metamorphic events, which were a little uncertain from evidence in the Lennard River area, have now been confirmed. Also, the relative age of the Woodward Dolerite before both events has now been established.

Evidence from the adjoining Sheet areas that the main transcurrent fault movements took place before deposition of the Kimberley Basin rocks, and that much of the faulting in these rocks is due to reactivation of old fractures has been further substantiated, although a second (post-Kimberley Group) period of transcurrent movement is also represented.

TABLE 12. SUMMARY OF TECTONIC HISTORY—CHARNLEY SHEET AREA

Era	*Deposition*	*Igneous Events*	*Tectonic Events*	*Metamorphism*	*Remarks*
CAINOZOIC	Alluvium; coastal mud and sands		MAJOR PERIOD OF EROSION UPLIFT		Formation of soils and laterite
PALAEOZOIC	Deposit of Devonian-Permian sediments				Only in extreme south-west
			Transcurrent west-north-west faulting		
			Folding along shallow-plunging northwest and southeast axes	Low grade, largely dynamic metamorphism	Glaucophane locally in Carson Volcanics; amphibolite and andalusite granofels in Yampi Sheet area
PROTEROZOIC: ADELAIDEAN	Deposition of Mt House Group including glacial rocks				
			Gentle folding along shallow-plunging north-east axes		e.g. Synnot Range syncline
PROTEROZOIC: CARPENTARIAN		Intrusion of late dolerite dykes			Related at least in part to Hart Dolerite
		Intrusion of Hart Dolerite			Rafting of sediment along north-trending fractures in Lansdowne Sheet area
			Faulting: northeast and north faults and joints formed		
	Deposition of Speewah and Kimberley Groups	(Extrusion of Carson Volcanics)			
	UNCONFORMITY		MAJOR PERIOD OF EROSION		Complete removal of Whitewater Volcanics locally

TABLE 12—*Continued*

Era	*Deposition*	*Igneous Events*	*Tectonic Events*	*Metamorphism*	*Remarks*
LOWER PROTEROZOIC		Intrusion of early dolerite dykes?	Transcurrent faulting		Shear zones in granites
		Intrusion of Lennard, Mt Amy, and Kongorow Granites	Folding along steep-plunging southeast axes	Mild metamorphism of some dolerite dykes	Foliation and lineation developed in granites
		Intrusion of Mt Disaster Porphyry and Mondooma Granite			
		Extrusion of Whitewater Volcanics			
	UNCONFORMITY		PERIOD OF EROSION		Cobbles of Woodward Dolerite in conglomerate near base of Whitewater Volcanics in Lennard River Sheet area
			Folding along steep east and southeast axes	Garnet and kyanite grade metamorphism	Strong cleavage developed
			Folding along steep southwest axes	Andalusite and staurolite low-stress metamorphism	
		Intrusion of Woodward Dolerite			
ARCHAEAN	Deposition of Halls Creek Group sediments				

ECONOMIC GEOLOGY

There are no mines operating in the area at present. The King Sound tin-tungsten deposits were worked briefly during 1911-13. During the course of the recent survey a small kyanite deposit was located. Other minerals of possible economic interest in the area include scorodite (ferric arsenate), andalusite, fluorite, and possible bauxitic laterite. Development of small deposits in the area is hampered by the absence of water except during the wet season. Groundwater is exploited at present by only seven operating bores and wells, but considerable potential exists for development.

Metals

Tin and Tungsten

King Sound Tin Mine. A deposit of cassiterite, wolframite, and scorodite in thin quartz veins in the catchment area of Hawkstone Creek has been known since 1907 (Woodward, 1909). The deposit was worked during 1911-1913, but development consisted only of shallow pits and trenches. There is no record of the amount of concentrates produced. The occurrence was mentioned briefly by Campbell (1909), and it has been described in detail by Blatchford (1914) and summarized by Simpson (1948), and by Finucane (1939), who made a detailed map of the deposit.

The ore-bearing veins crop out on the top of a 60 m narrow ridge of phyllite at 2457E, 28613N, about 10 km east-northeast of Hawkstone Creek yard.

Two main subparallel veins strike 285° and dip 85°S, and follow the cleavage of the Halls Creek Group phyllites. They extend for 100 m and 170 m respectively, with an average thickness of 20 cm, and carry most of the tin and tungsten mineralization. Thin anastomosing branches of both principal veins, and thin westerly extensions of the main south vein contain some scorodite but have no appreciable cassiterite or wolframite. Assays of vein material listed by Blatchford (1914) and Finucane (1939) indicate average contents of 1.54% SnO_2 and 0.55% WO_3. In addition, arsenopyrite and scheelite have been discovered by a local prospector, in one vein at the eastern end of the ridge (Harms, 1959). Examination under ultraviolet light of specimens of mineralized rock from the other veins during the recent survey revealed no further scheelite, and it thus appears that scheelite in the King Sound tin deposits is both rare and localized.

The mineral paragenesis has been studied both in the veins *in situ* and in excavated lumps taken from the veins. A remarkably consistent sequence is present, with scorodite invariably forming the wall zone of the veins and quartz the core; cassiterite tends to be concentrated preferentially in or close to the scorodite wall zone and wolframite is mostly disseminated in the quartz core.

The occurrence of scorodite as an early mineral in the paragenetic sequence implies that it is primary and is, at first sight, at variance with the prediction by Blatchford (1914) that the scorodite would give way to arsenopyrite at depth, a prediction based apparently on the assumption that scorodite is not a primary mineral in the veins but is a product of post-depositional surface oxidation. Its presence as a primary mineral at the present level of erosion suggests that either excess oxygen was present in the mineralizing solutions or that the veins were emplaced into an oxidizing (near-surface?) environment. Interpretation of the surface zoning of individual veins suggests that scorodite would persist in depth,

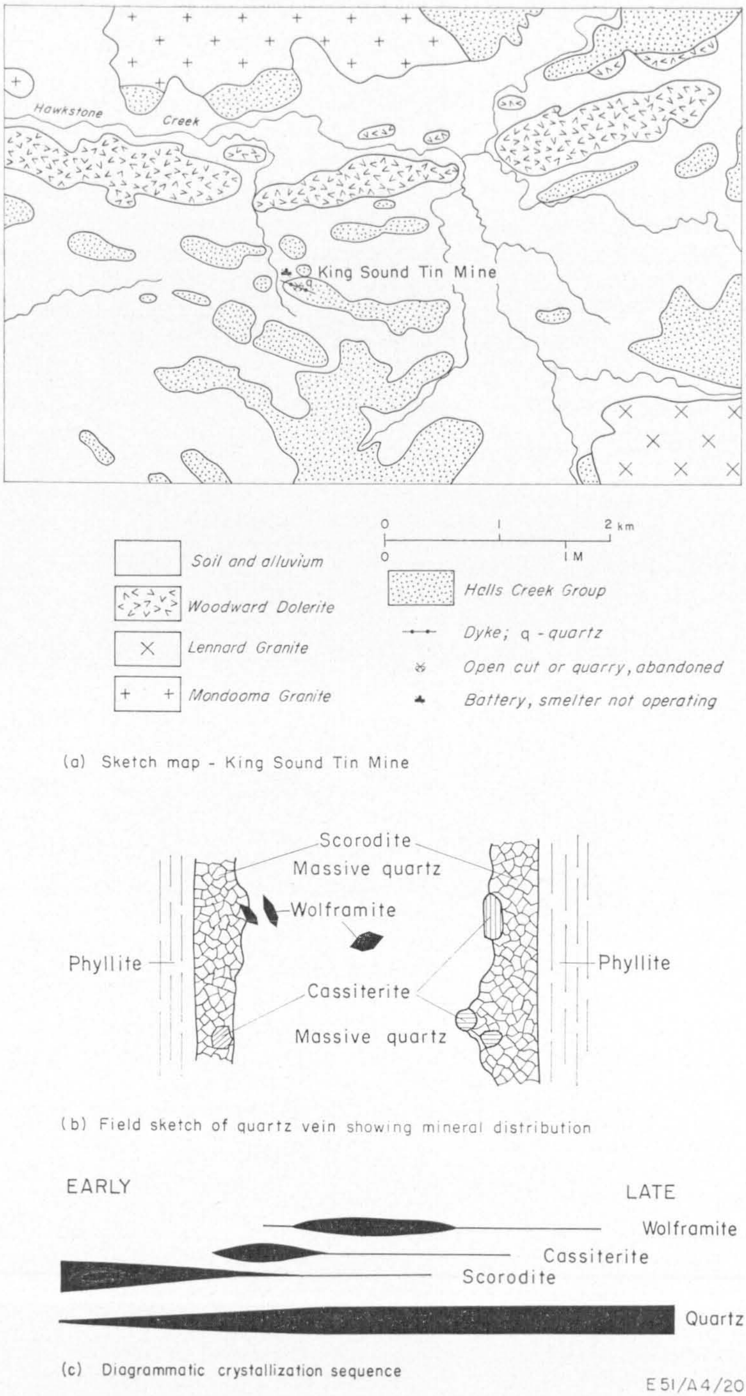

Fig. 18. King Sound Tin Deposit. Geology and mineral paragenesis.

rather than give way to arsenopyrite, but would tend to decrease in abundance, that cassiterite would initially increase slightly in abundance and then decrease, and that wolframite would increase slightly.

Silent Valley Tin Prospect. The exact location of this prospect has not been recorded previously and it was not located during the recent survey. Subsequent description of the locality by the discoverer, J. Stewart, suggests that it is located at 2465E, 28648N—about 3 km north-northeast of the King Sound Tin Mine. Harms (1959) gave the locality as 8 km northeast of King Sound Tin Mine.

In Silent Valley, Harms (1959) reported small pockets of cassiterite-bearing wash containing up to 1360 g of cassiterite to the dish, and larger quantities of wash under about 1 m of alluvium carrying about 28 g of cassiterite to the dish. The wash has been traced to thin quartz leaders containing cassiterite on their walls and to thin seams of cassiterite in greisen. The veins are apparently within Mondooma Granite close to the contact with Halls Creek Group phyllite. The deposit has been worked intermittently by Mr Stewart Harms (1959) reported other small alluvial deposits of cassiterite in a stream to the northwest of Silent Valley.

Copper etc.

In most parts of the Kimberley region specks of chalcopyrite are common in the basal 80 m of the Carson Volcanics, and also locally in the topmost (tuffaceous) beds. As yet economic concentrations have not been found. However, in view of the recent discovery of silver-lead-gold-copper mineralization in a fault zone in Hart Dolerite near Kununurra (Sofoulis, 1968), faults traversing both the Carson Volcanics and the Hart Dolerite in the Charnley Sheet area (and other areas in the Kimberley region where these formations crop out) warrant detailed prospecting for these metals. Silicified faults are probably the best prospecting targets.

Fluorescent Acid Intrusives. All rock specimens collected were examined under short wave ultraviolet light as a possible guide to mineralization. Several granitic rocks exhibiting fluorescence were analysed spectrographically. Only one specimen came from the Charnley Sheet area. It was one of Mount Disaster Porphyry from 2560E, 28606N: it contains Sn 4 ppm; W 20 ppm; Mo 5 ppm; Cu 12 ppm; Pb 100 ppm; Zn 25 ppm. As in most of the other fluorescent rocks the only anomalous metal content is that of lead, although three specimens from the Yampi Sheet area also contain anomalous tin values (20 to 80 ppm).

Non-metallic Minerals

Kyanite

Hawkstone Creek Kyanite Prospect. This has been described in detail by Derrick & Morgan (1966). It consists of a number of poorly exposed lenses and boulder trains of kyanite rock, kyanite schist, kyanite-topaz rock, vein kyanite, and some corundum-rock, enclosed by phyllite of the Halls Creek Group, and by the Woodward Dolerite. Topaz was not noted in the report by Derrick & Morgan; it forms dense chert-like masses in the northwest part of the deposit, and contains abundant small metacrysts of kyanite. The kyanite crystals are replaced in some instances by fine-grained massive topaz.

Chemical analyses of kyanite and corundum rock are contained in Appendix 2. They show silica values (for all but the corundum rock) from 35 to 37 percent and alumina values from 53.8 to 60.4 percent. For comparison topaz contains about 32 percent silica and 56 percent alumina. These values for kyanite compare favourably with the U.S. National Stockpile Specification listed in Appendix 2, although there is probably an excess of alkali in the Kimberley material. However, Report 13/67 of the Government Chemical Laboratories of Western Australia states that neither locally produced kyanite in America nor imported Indian sillimanite conforms fully to the stockpile specifications, which apparently are too stringent for general application.

Samples of pale blue fibrous kyanite and grey kyanite aggregates were submitted for specific gravity determination. Results are as follows: blue kyanite—3.48, 3.39, 3.57, 3.56, 3.59, 3.59 (average 3.53): grey kyanite—3.64, 3.61, 3.62, 3.62, 3.50, 3.73 (average (3.62): corundum rock—3.58, 3.54, 3.63 (average 3.58): topaz—3.51, 3.51, 3.52 (average 3.51).

The higher density of the grey kyanite is probably due to abundant microscopic inclusion of (?)magnetite and rutile, which also account for the colour difference. The relatively low specific gravity of the corundum rock is due to a substantial pyrophyllite-sericite content.

A full-scale refractory test has not been carried out on the Hawkstone Creek kyanite material. The pyrometric cone equivalent of massive kyanite rock from this prospect is 1820°-1835°C (Orton Cone No. 37-38). After testing, the sample was off-white in colour, vitrified, with a matte lustre (AMDL Report CE1852/67).

Reserves have been estimated to be 18 000 tonnes of kyanite rock per vertical foot (0.3 m) over an area of 60 960 m^2 (Derrick & Morgan, 1966). Although this area is possibly an overestimate, the tonnage available would be quite high-grade (60% Al_2O_3 or greater) because of the corundum present. Probably between 1000 and 2000 tonnes of kyanite rock are present as loose boulders scattered over the hill. Reserves at depth are unknown.

The kyanite deposit is of little economic significance at present, mainly because of its relatively small size and isolation. Trade requirements in Appendix 1 indicate that the Hawkstone Creek kyanite would be generally acceptable for refractory material and that the topaz, corundum, and even pyrophyllite present in the deposit would enhance both alumina content and refractoriness.

Andalusite

Schists of the Halls Creek Group about 5 km northwest of Hawkstone Creek yard contain up to 10 percent andalusite (chiastolite) as large individual crystals averaging 3 to 4 cm by 1.5 cm, and associated with short prismatic staurolites. The andalusite (and staurolite) weather out readily from the schist and are concentrated locally in detrital gravels. At least some of the chiastolite crystals are pseudomorphed by kyanite. If the demand and price for aluminium silicates were adequate for the nearby kyanite deposit to be worked it is possible that the andalusite-bearing schists and the lateral extensions of the same andalusite-staurolite belt to the southeast could provide a substantial additional tonnage of aluminium silicate, but crushing and separating facilities would be required to recover the andalusite, whereas they would probably be unnecessary for the kyanite rock.

Fluorite

Traces of fluorite have been noted at 2560E, 28649N, about 10 km east-northeast of King Sound Tin Mine, in Mondooma Granite, close to the contact with Halls Creek Group phyllite, and at 2280E, 28834N about 17 km north-northwest of Hawkstone Creek yard in a dyke of Mount Disaster Porphyry. These showings are not of direct economic significance, but are of interest in that they indicate the presence of a volatile phase in the sub-volcanic acid intrusives which enhances their mineralizing potential.

Bauxite

Scattered areas of laterite are present within a radius of 35 km of Beverley Springs homestead. Some may be bauxitic, but they have not been sampled in detail. Laterite and lateritic soils overlying the Carson Volcanics, which covers an area of about 16 km^2, by analogy with that from other Sheet areas to the north and northeast probably contain areas of bauxitic laterite interspersed with areas of highly ferruginous laterite.

Because of their small size, scattered distribution, and greater distance from the coast than many laterite outcrops farther north, the laterites of the Charnley area, even if they prove to be highly aluminous, are unlikely to be an economic source of bauxite in the immediate future.

Areas of lateritic soils (Czl) overlying the Warton Sandstone in the Synnot Range probably include true laterite locally. In other parts of the Kimberley region, however (e.g. Drysdale-Londonderry: Gellatly & Sofoulis, 1966), it has been shown that laterites overlying sandstone are more ferruginous and more siliceous than those overlying basic rocks and are unlikely to be a potential source of bauxite.

Construction materials

Sand and Gravel. Supplies of medium-grained clean quartz sand suitable for use in cement mortar and in concrete are available in most creeks draining the King Leopold Sandstone and the Warton Sandstone, which together underlie about 80 percent of the Sheet area. Sands derived from the granites in the southwest and from the Carson Volcanics would probably be unsuitable on account of their feldspar content and those from the Carson Volcanics because of their iron content.

Deposits of cobble and boulder gravels are present in many places along the main rivers and their principal tributaries, but most deposits are of limited extent.

Rock-fill

Beneath the zone of surface leaching, most of the sandstones in the area (as seen in rocky gorges) are compact and silicified and would probably make suitable rock-fill material ('dimension stone'), as would the igneous rocks of the area, with the possible exception of the Lennard Granite, which in places is highly altered.

Road metal

'Blue metal' for use in the preparation of bitumen-sealed roads could be obtained from the Hart Dolerite, Woodward Dolerite, Carson Volcanics, or Mondooma Granite. However, there is unlikely to be any demand for this in the

Charnley Sheet area in the immediate future. Material for forming and surfacing earth roads is more important at present. Residual soils derived from the Carson Volcanics and from the intermediate granophyric varieties of the Hart Dolerite are suitable for this purpose as also are laterite and residual material derived from it. Shale and siltstone from the Speewah Group and from the Carson Volcanics could be used locally but they are not extensive.

Dam Sites

The possible development of hydro-electricity using dams on the Isdell, Charnley, and Calder Rivers has been mentioned briefly by Maitland (1921). Good dam sites are present on the Isdell River at 2746E, 29110N (12 km north-northwest of trig point T033) and on the Charnley River at 3000E, 29328N (about 3.5 km downstream from its confluence with Synnot Creek). In both cases the excellence of the dam site is at least partly outweighed by isolation and by the lack of areas that could be irrigated with the water after its use for power generation.

Generation of electricity by tidal power using the ebb flow of the tide from Walcott Inlet has been mooted in recent years, but little preliminary work has been done apart from investigations by Gordon (1964) and Lewis (1962). The principal engineering works in connexion with such a scheme would probably be situated entirely in the Yampi Sheet area to the west.

Water Supply

Surface water

Permanent pools are abundant in most watercourses that drain areas of King Leopold Sandstone in the north and northwest and in areas of granite close to the King Leopold Range, but are scarce in areas of Carson Volcanics, which form the best grazing land, and are lacking in the extreme southwest.

Groundwater

Groundwater has been tapped only by 5 operating bores and two wells in the Sheet area (Allen, 1966). Details of these and of three unsuccessful bores and wells are given in Table 13. Most of the operating bores are situated in areas underlain by Carson Volcanics. This is a reflection of three factors: (1) that areas underlain by the volcanics are the best grazing areas, (2) that surface water supplies in these areas are inadequate for optimum distribution of stock in relation to grazing potential, (3) that satisfactory supplies of groundwater are available in the Carson Volcanics. Flow rates (0.75 to 2.25 l/s) are adequate for stock watering, and salinities are low.

TABLE 13. WATER-BORE AND WELL DATA—CHARNLEY SHEET AREA

Name	*Station*	*Grid Co-ordinates*		*G.S.W.A. Reg. No.*	*Depth (m)*	*Static Water Level (m)*	*Supply l/s*	*Salinity ppm T.D.S.*	*Aquifer*
Plover Hill Bore	Mount House	3543E	28615N	4064-III-1	16	8.7	2.25	505	Carson Volcanics
—(Dud bore)	Mount House	3523E	28662N	4064-III-2	10.7	—	—	—	Carson Volcanics
—(Dud bore)	Mount House	3527E	28678N	4064-III-3	11	—	—	—	Carson Volcanics
Herberts Bore	Mount House	3518E	28673N	4064-III-4	19	9.7	1.25+	low	Carson Volcanics
Allens Bore	Beverley Springs	3334E	29051N	3964-I-3	12	3	1.50	—	Alluvium
Pandanus Bore	Beverley Springs	3387E	29146N	3964-I-4	17	—	2.00	—	Alluvium
Tomahawk Bore	Beverley Springs	3342E	28933N	3964-I-5	16	—	0.75	—	Carson Volcanics
Beverley Springs Homestead Well	Beverley Springs	3385E	29106N	3964-I-1	7	4	0.82	35	Alluvium
—(Dry well)	Beverley Springs	3287E	28963N	3964-I-2	—	—	—	—	Carson Volcanics
Mount Hart Homestead Well	Mount Hart	2742E	28827N	—	—	—	—	—	Hart Dolerite

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APPENDIX 1

SUITABILITY OF HAWKSTONE CREEK KYANITE ROCK FOR TRADE REQUIREMENTS

The following trade information is from Varley (1965).

Kyanite, andalusite, and sillimanite, together with topaz, corundum, and dumortierite, are used in the manufacture of refractory bricks, etc. The process involves calcination at about 1500-1600°C to convert these minerals to a mixture of mullite and silica in the ratio 88/12. Depending on grainsize, the calcined material is then bonded to form bricks or refractory cements. Most of the material used industrially is in the form of crystal aggregates with grainsize from 2 mm to 1 cm.

Sillimanite is advantageous as a starting product, since it requires no calcination before bonding, and suffers from a 16 percent expansion in the conversion to mullite, but this can be used to offset shrinkage of other refractory material present. In the calcination of topaz, fluorine and water are driven off at 850-900°C, and the problem of fuming fluorides has deterred some manufacturers. However, the fluorine carries with it considerable iron and silica. Topaz has a low permanent expansion, a refractoriness of cone 40 (1875°C), and exerts a marked bonding action at higher temperatures. Pyrophyllite in limited quantities can be used to advantage in refractories, since it, too, acts as a bonding agent at high temperatures.

The U.S. stockpile specifications require a raw minimum grainsize of 4.7 mm for the manufacture of refractory bricks and as fine as 100 mesh for refractory cement. Coarse-bladed kyanite (with blades 3 cm long or more) is not very desirable, since it reduces load strength of the final product. Refractoriness is specified as Cone 37 for high-alumina (more than 45% Al_2O_3) bricks.

In general, corundum and topaz are usually regarded as beneficial because they increase the alumina content, but an excess of corundum makes drilling and grinding difficult.

Comparing these requirements with the Hawkstone Creek kyanite, the latter satisfies the refractoriness specifications of cone 37. The topaz and corundum in the deposit would only enhance this figure. Grainsize of the kyanite is variable, but there are large quantities of crystal aggregates of 2 to 5 mm grainsize, with scattered zones of bladed material, which probably would be suitable. Corundum and topaz appear to be present in certain areas, and could be selectively mined to enrich any bulk kyanite charge.

APPENDIX 2

CHEMICAL ANALYSES OF ROCKS FROM THE KYANITE DEPOSIT

The following analyses are taken from AMDL Report AN1852/67 and W. Aust. Government Chemical Laboratories Report 13/67. For comparison the U.S. Stockpile Specification for kyanite is also listed.

Oxide	1 66160301*	2 1010	3 1011	4 1012	5 1014	6 13031/66+	7 P-27
SiO_2	18.1	37.5	35.9	37.0	36.0	37.0	Max. 39
Al_2O_3	71.0	55.5	53.8	58.6	60.4	59.4	Min. 59
Fe_2O_3	0.13	0.18	0.19	0.11	0.10	} 0.76	Max. 0.75
FeO	0.19	0.21	0.08	0.10	0.12		
MgO	0.13	0.44	0.14	0.06	0.05	0.18 }	Max. 0.20
CaO	1.78	0.38	2.40	0.15	0.37	0.06 }	
Na_2O	1.58	0.52	1.53	1.00	0.24	0.96 }	Max. 0.20
K_2O	0.87	1.63	1.33	1.00	2.05	0.30 }	
H_2O+	3.30	1.69	2.45	1.03	0.31	1.34	
H_2O-	0.08	0.07	0.21	0.09	0.05	n.d.	
CO_2	0.02	0.01	0.02	0.04	0.03	n.d.	
TIO_2	2.35	1.55	1.60	0.44	0.55	0.30	Max. 1.25
P_2O_5	0.25	0.08	0.19	0.02	0.02	n.d.	
MnO	0.01	0.01	0.01	0.01	0.01	n.d.	

n.d. not determined

* BMR Registered Sample Nos.

† W. Aust. Govt Chemical Laboratories Number

1. Corundum-pyrophyllite-sericite rock—Analyst A. Jorgenson A.M.D.L.
2. Kyanite-tourmaline-dumortierite-pyrophyllite rock—Analyst A. Jorgenson A.M.D.L.
3. Kyanite-pyrophyllite-sericite-diaspore rock (Kyanite schist)—Analyst A. Jorgenson A.M.D.L.
4. Kyanite rock—Analyst A. Jorgenson A.M.D.L.
5. Kyanite rock—Analyst A. Jorgenson A.M.D.L.
6. Kyanite rock—Analyst J. Sims, W.A. Govt.
7. U.S. Stockpile Specification.

APPENDIX 3

COMPARISON OF STANDARD TOPAZ DIFFRACTION PATTERN WITH FINE-GRAINED TOPAZ MATRIX FROM KYANITE-TOPAZ ROCK

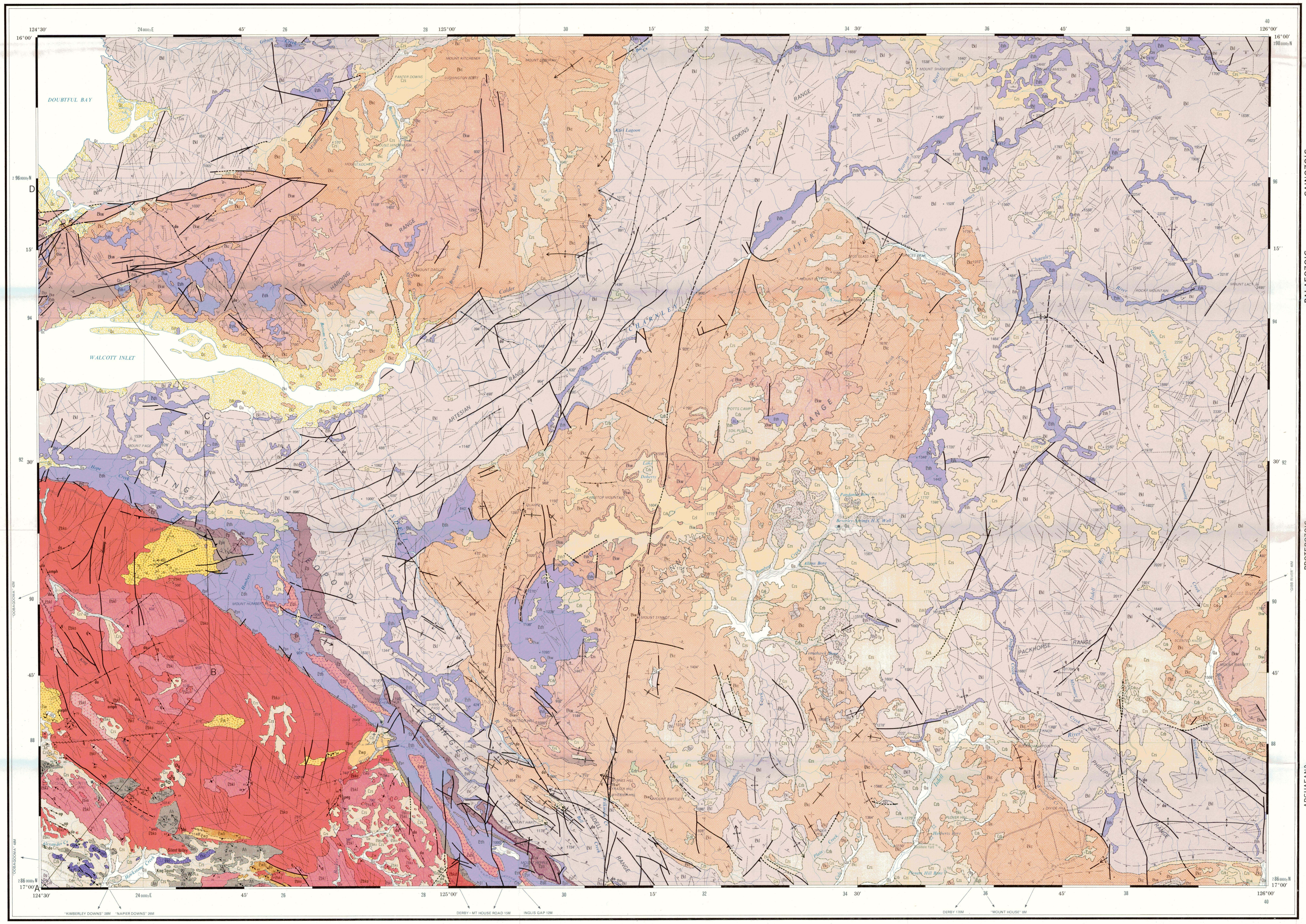
dA *Standard*	*dA* *Kyanite-topaz rock* *R67161043*	I/I_i
3.693	3.69	60
3.195	3.20	65
3.037	3.03	35
2.986	2.98	25
2.937	2.93	100
2.4804	2.48	20
2.3783	2.38	25
2.3609	2.36	45
2.1049	2.10	45
2.0555	2.06	25
1.8691	1.87	25
1.8553	1.86	25
1.6706	1.67	25

plus perfect matches in 17 other peaks with I/I_i less than 20, in the range 3.69 to 1.67.

AUSTRALIA 1:250,000 GEOLOGICAL SERIES

CHARNLEY
WESTERN AUSTRALIA

SHEET SE 51-4



- Geological boundary
- Anticline showing plunge
- Syncline showing plunge
- Monocline
- Plunge of minor anticline
- Plunge of minor syncline
- Plunge of minor drag fold
- Fault, attitude unknown (q indicates quartz filling)
- Normal fault, triangle on downthrown side
- Transcurrent fault showing relative horizontal movement
- Shear zone

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

- Strike and dip of strata
- Prevailing strike and dip of strata
- Strike and dip of strata with plunge of lineation
- Horizontal strata
- Dip <5° (air photo interpretation)
- Dip 5–15° (air photo interpretation)
- Dip 15–45° (air photo interpretation)
- Horizontal strata (air photo interpretation)
- Trend lines (air photo interpretation)
- Joint pattern (air photo interpretation)
- Top of bedding indicated by graded bedding
- Strike and dip of foliation
- Vertical foliation
- Strike and dip of foliation with plunge of lineation
- Vertical foliation with plunge of lineation
- Strike and dip of flow-foliation
- Prevailing strike and dip of flow-foliation
- Strike and dip of cleavage
- Strike and dip of cleavage and bedding coincident
- Strike and dip of cleavage with plunge of lineation
- Vertical cleavage
- Strike and dip of joint
- Direction of sedimentation from cross-bedding

- Measured section
- Dyke or vein; amph—amphibolite, do—dolerite, peg—pegmatite ap—aplite, porph—quartz feldspar porphyry, q—quartz
- Open cut or quarry abandoned
- Prospect
- •As Minor mineral occurrence
- As Arsenic
- Cn Corundum
- F Fluorine minerals
- Ky Kyanite
- Sn Tin
- W Tungsten

- Bore
- Abandoned bore
- Well
- Waterhole on stream
- Spring
- Lake, intermittent
- Mangroves

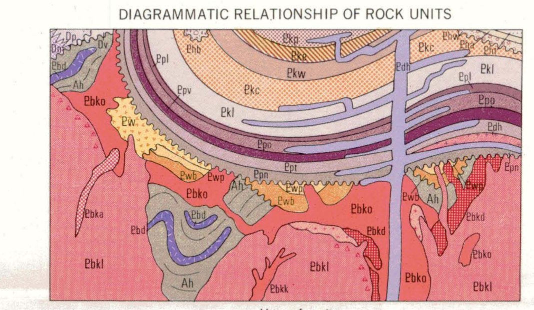
- Road
- Vehicle track
- Landing ground
- "Mt. Hart" Homestead
- Yd Yard
- Trigonometrical station
- Astronomical station
- •752' Elevation in feet, datum: mean sea level
- (PD) Position doubtful

Reference

CAINOZOIC	QUATERNARY		Qa	Alluvium
			Qc	Coastal sand, silt and mud; thin salt crust locally
			Czs	Soil, sandy soil, alluvium
			Czb	Black soil
			Czl	Ferruginous pisolitic sandy soil
	TERTIARY		Tp	Laterite
PALAEOZOIC	DEVONIAN: FRASNIAN TO FAMENNIAN	Pillara Limestone	Dp	Back-reef facies: yellow to light grey bedded stromatoporoid limestone, oolite, calcarenite and calcilutite
		Napier Formation	Dn	Fore-reef and inter-reef facies: calcarenite and calcirudite, magebreccia
	DEVONIAN: GIVETIAN? TO FRASNIAN?	Van Emmerick Conglomerate	Dv	Boulder, pebble and cobble conglomerate with arkose matrix
PROTEROZOIC (UPPER PROTEROZOIC)	Mount House Group	Throssell Shale	Ƥht	Grey-green shale; buff and grey-green fine-grained sandstone interbeds
		Traine Formation	Ƥha	Green to brown coarse-grained lithic sandstone. Minor sandy dolomite and dolomitic sandstone. Scattered glacial erratics
		Walsh Tillite	Ƥhw	Tillite, pink fine-grained pebbly sandstone, pink to brown dolomite. Minor purple-brown siltstone, algal dolomite
		Beverley Springs Member	Ƥhb	Pebbly quartz sandstone
PROTEROZOIC (LOWER PROTEROZOIC)	Kimberley Group	Hart Dolerite	Ƥdh	Granophyre; Dark grey and grey-green tholeiitic dolerite
		Pentecost Sandstone	Ƥkp	White to pale brown well sorted quartz sandstone, pale red-brown feldspathic sandstone and arkose; minor siltstone
		Elgee Siltstone	Ƥke	Red-brown shale, siltstone and fine-grained sandstone; minor pebble conglomerate at base
		Warton Sandstone	Ƥkw	White to pale brown quartz sandstone
		Carson Volcanics	Ƥkc	Tholeiitic basalt; minor agglomerate and feldspathic sandstone
		King Leopold Sandstone	Ƥkl	White, medium to coarse-grained quartz sandstone
	Speewah Group		Ƥp	Undifferentiated quartz sandstone, feldspathic sandstone
		Luman Siltstone	Ƥpl	Purple siltstone and fine-grained micaceous sandstone
		Landsdowne Arkose	Ƥpo	White to cream medium-grained quartz sandstone; minor feldspathic sandstone
		Valentine Siltstone	Ƥpv	Green and purple shale, siltstone and phyllite
		Tunganary Formation	Ƥpt	White, medium to coarse-grained quartz sandstone and feldspathic sandstone
		O'Donnell Formation	Ƥpn	Coarse-grained quartz sandstone and conglomerate; minor grey-green siltstone and shale
	Lamboo Complex		Ƥb	Undifferentiated. Section only
		Mount Amy Granite	Ƥbka	Fine-grained muscovite granite, aplite, pegmatite
		Kongorow Granite	Ƥbkk	Dark grey coarse-grained porphyritic granite: net-veined complex with Lennard Granite
		Lennard Granite	Ƥbkl	Pale grey, even-grained to porphyritic coarse-grained granite; Xenolith-rich zones; Coarse-grained porphyritic contaminated granite
		Mondooma Granite	Ƥbko	Medium-grained granite, porphyritic microgranite
		Mount Disaster Porphyry	Ƥbkd	Coarse-grained pale pink to grey quartz feldspar porphyry, minor porphyritic granite
		Whitewater Volcanics	Ƥw	Undifferentiated grey-green ash-flow tuff
			Ƥwp	Crystal-poor rhyodacitic ash-flow tuff; minor crystal-rich tuff
			Ƥwb	Dacitic and minor rhyodacitic biotite-rich ash-flow tuff
		Woodward Dolerite	Ƥbd	Dark grey-green porphyritic to even-grained amphibolite
ARCHAEAN? (ARCHAEAN OR LOWER PROTEROZOIC)	Halls Creek Group		Ah	Phyllite, minor quartzite; andalusite, chloritoid, staurolite and garnet-mica-schist. Minor kyanite schist and actinolite-garnet quartzite

Subdivisions of Precambrian time scale used by the Geological Survey of Western Australia shown in grey

DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



Unconformity

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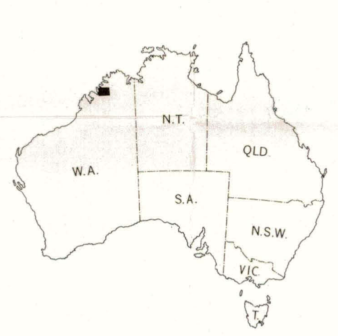

INDEX TO ADJOINING SHEETS
Showing Magnetic Declination 1970

INDIAN	BROWSE ISLAND SD 51-11	MONTAGUE SOUND SD 51-12	DRYSDALE SD 52-9	MEDUSA BANKS SD 52-10
OCEAN	CAMDEN SOUND SD 51-15	PRINCE REGENT SD 51-16	ASHTON SD 52-13	CAMBRIDGE GULF SD 52-14
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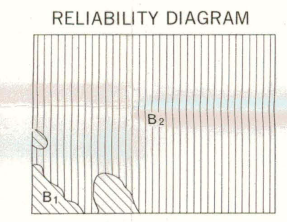
ANNUAL CHANGE 20'W

Scale 1:250,000

5 0 5 10 15 MILES
5 0 5 10 15 20 25 KILOMETRES

GREY NUMBERED LINES INDICATE THE 20,000 YARD TRANSVERSE MERCATOR GRID, ZONE 3 (AUSTRALIA SERIES)

RELIABILITY DIAGRAM



Geology: B1 Detailed reconnaissance—numerous traverses and air-photo interpretation

B2 General reconnaissance, few traverses, and air-photo interpretation

Geological photo-interpretation 1964 by W. J. Perry (BMR)
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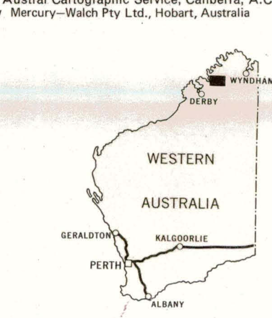

Section
Cainozoic sediments omitted
Attitude of faults not known
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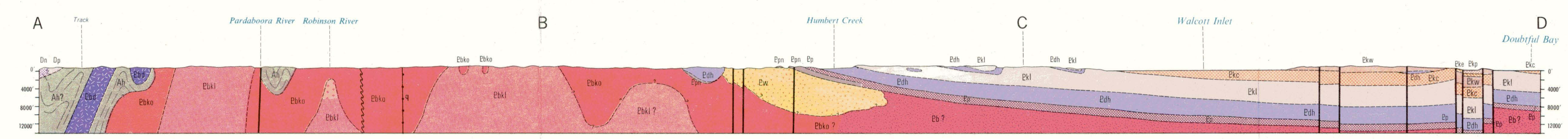

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