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GEOLOGY OF THE MONTAGUE SOUND 1:250,000 SHEET AREA (SD51-12) WESTERN AUSTRALIA

by

A.D. Allen
(Geological Survey of Western Australia)

The information contained in this report has been obtained by the Department of National Development, as part of the policy of the Commonwealth Government, to assist in the exploration and development of mineral resources. It may not be published in any form or used in a company prospectus without the permission in writing of the Director, Bureau of Mineral Resources, Geology and Geophysics.

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CONTENTS

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LIST OF PLATES

SUMMARY

The Montague Sound Sheet area includes about 1,700 square miles in the northwestern part of the Kimberley Plateau, Western Australia. The area is uninhabited, and poorly accessible. It is underlain by the lowermost formations of the Carpentarian Kimberley Group, namely, the King Leopold Sandstone, Carson Volcanics and Warton Sandstone, which are intruded by the Carpentarian or early Adelaidean Hart Dolerite. Dissected Cainozoic laterites overlie the Carson Volcanics and are preserved between the Mitchell and Lawley Rivers and on offshore islands. Quaternary coastal limestone occurs in two small areas.

The Kimberley Group has been folded into a series of northward trending folds; the Carson Volcanics and Warton Sandstone are preserved as outliers in two synclines. These are slightly assymetric and have steeper dips along their eastern limbs. Poorly defined cross folding with a northwest trend has interfered with the earlier folds. Numerous joints, probably the result of folding, are well displayed in the King Leopold Sandstone.

About 80 square miles of bauxitic laterites occur on the Mitchell Plateau, and analyses of grab samples are given in an Appendix. Water is abundant and the coastline has potential for tidal power generation.

INTRODUCTION

Location and Access

The Montague Sound Sheet area lies between latitudes 14°00'S and 15°00'S, and between longitude 124°30'E and 126°00'E, in the northwestern part of the Kimberley Land Division of Western Australia. The Sheet area covers about 7,000 square miles of which 1,700 square miles are occupied by the mainland, 100 square miles by outlying islands and the rest by sea.

The area between the Lawley and Mitchell Rivers is accessible by a very rough track leading off the Gibb River - Kalumburu Track at Grid ref. 423116. Parts of the coastline are accessible by boats with shallow draft, but the rest of the area is accessible only by helicopter.

A mining company investigating bauxite deposits in the area is expected to improve access to, and possibly construct an airfield on, the Mitchell Plateau.

Habitation and Industry

The area is uninhabited. A pastoral lease covers the area between the Lawley and Mitchell Rivers but is untenanted.

Bauxite deposits being investigated by the U.S. Metals Refining Co., if proved economic, may lead to the development of a mining industry in the area.

Climate

The climate is of the tropical savannah type, and is characterized by a distinct wet season in summer and a dry season in winter.

The Average Annual Rainfall Map of Western Australia (Bureau of Meteorology, 1962) indicates that the annual rainfall is about 50 inches along the western coastline and that it decreases northeastwards to about 40 inches. Most of the rain falls between November and March, generally in association with thunderstorms or with sporadic cyclones. The rest of the year is dry. In general, the rainfall is less reliable than in other parts of northern Australia (Slatyer, in Speck, et al, 1960).

Throughout the region, maximum temperatues of 85°F or over are experienced throughout the year and minimum temperatures seldom fall below 55°F around the coast. Inland, lower temperatues and occasional light frosts may occur in the winter months.

Relative humidity is highest during the wet season. Values are highest around the coastline and decrease inland.

Annual potential evaporation is about 90 inches and exceeds rainfall by a factor of about two.

Vegetation

Speck (in Speck, et al., 1960) described the vegetation of the North Kimberley area. He recognized two main vegetation groupings: (1) vegetation developed on sandstones and consisting of open eucalypt forests with shrubby undergrowth, spinifex and subordinate annual grasses; and (2) vegetation comprising eucalypt woodlands, with sparse shrubs and abundant perennial grasses developed on the volcanic rocks. Both groupings occur within the Sheet area.

Other special communities can also be recognized. Mangrove swamps are restricted to the seaward fringe of tidal mudflats in sheltered bays and inlets around the coast; communities of pandanus palms line permanent pools and drainage lines; and 'vine forests' consisting of small areas of jungle-like growth, grow on volcanic rocks in places below scarps of laterite. A more dense woodland, with some distinctive plants, such as palms, is preserved on the remnants of a lateritic surface between the Mitchell and Lawley Rivers. This may be a relict flora.

Aerial Photographs and Maps

There is complete coverage of the Sheet area by aerial photographs at a scale of about 1:48,000 flown in 1949 by the Royal Australian Air Force. The photographs are only of fair quality and in some places give distortions of the stereographic image (Perry and Richard, 1965). Mosaics based on these photographs, at scales of 1:250,000 and 1:63,360 are also available.

The most accurate topographical map of the area (Montague Sound SD51-12) was produced by the Royal Australian Survey Corps (1963) on a scale of 1:250,000. The Sheet area is also shown with reasonable topographic detail on (3108) Brunswick Bay, World Aeronautical Chart at a scale of 1:1,000,000 and in less detail on other small-scale topographic maps, lithographs and Admiralty Charts.

Survey Methods

The Montague Sound Sheet area was mapped as part of a joint geological mapping programme of the Kimberley Division carried out by the Bureau of Mineral Resources and the Geological Survey of Western Australia.

Initially the geology of the Sheet area was photo-interpreted by Perry and Richard (1965) of the Bureau of Mineral Resources. They used an existing geological map at 10 miles to the inch by Harms (1959) as the basis for their interpretation and produced a photogeological map at 1:250,000 scale. Areas of uncertainty or interest were outlined and these, together with other points, were studied on the ground during traverses by helicopter in 1965.

The map was recompiled, field information was added and the map superimposed on the Royal Australian Survey Corps 1:250,000 topographical base map.

PREVIOUS GEOLOGICAL INVESTIGATIONS

Navigators, early in the history of Australia, charted the coastline and named many of the prominent physiographic features (Sharp, 1963). However the Sheet area was not explored until 1921 when W.R. Easton, a surveyor, explored parts of the coastline. His report (Easton, 1922) described some of the physiography, and gave an outline of the agricultural potential, of the Sheet area. He recorded the occurrence of sandstone, basalt and laterite and noted the abundance of water.

Harms (1959) produced a geological map of the Kimberley Division and part of the adjoining Northern Territory at a scale of 1 inch to 10 miles (1:633,600). He interpreted the geology of the Montague Sound Sheet area from aerial photograph mosaics, and noted the occurrence of potentially bauxitic laterites in the area.

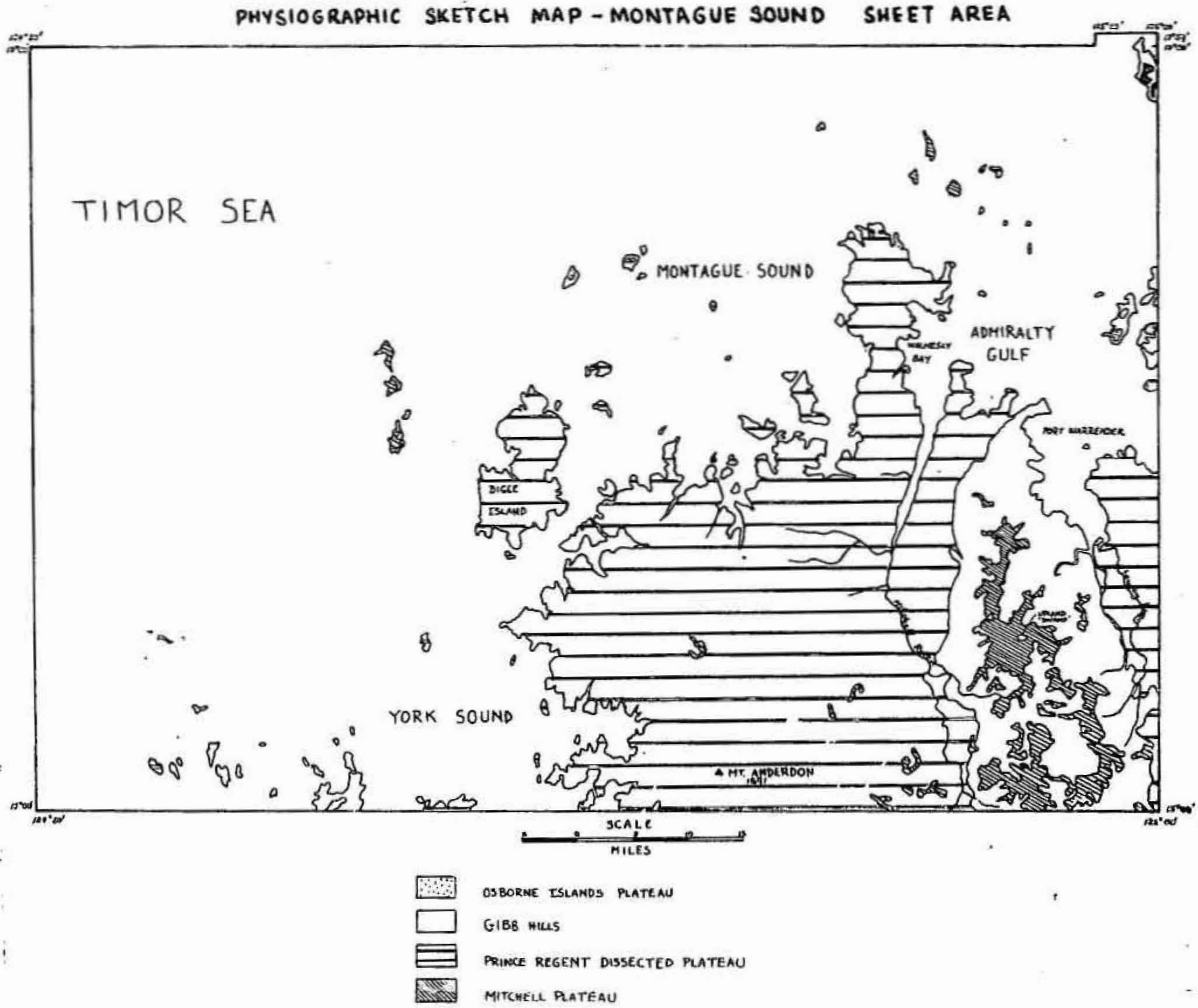
Speck produced a less detailed photo-geological map of the North Kimberley area at a scale of 1:1,000,000, and correctly depicted the main elements of the geology in the Sheet area (Speck et al., 1960).

Figure 1: Irregular shoreline backed by rugged country developed on flat-lying King Leopold Sandstone, near Mudge Bay.

Figure 2: View looking south up the estuary of Mitchell River. Dark mangrove swamps fringe the estuary and coastal mudflats (light coloured) are prominent in the rigth foreground. Flat-lying King Leopold Sandstone borders both sides of the river.

Fig. 3

PHYSIOGRAPHIC SKETCH MAP - MONTAGUE SOUND SHEET AREA



To accompany Record 1966/201

Prior to the present investigation, Perry and Richard (1965) produced a photogeological map at a scale of 1:250,000 and notes on the Sheet area.

PHYSIOGRAPHY

An account of the physiography of the Kimberley region, based on scanty topographical and geological information was given by Jutson (1934, revised 1950). The geomorphology of the North Kimberley region has been described by Stewart and others (in Speck, et al, 1960).

The most striking feature of the Sheet area is its highly irregular coastline, characterized by such features as York Sound; Montague Sound, separated by a prominent peninsula from Admiralty Gulf; and numerous small bays and irregular inlets (Figure 1). The shoreline is generally of low relief except for the western side of Port Warrender and in the south-west where inlets and bays are backed by precipitous cliffs up to 400 feet in height.

Numerous islands varying from rocks barely above sea level to very large rocky islands such as Bigge Island, are also notable features of the coastline. Limited bathymetric information shows that the configuration of the ocean bottom parallels the coastline and that deeper channels coincide with large joints.

There is no contoured topographical map of the area. The military 1:250,000 sheet shows a number of spot heights which indicate a gradual increase in elevation from the northern coastline toward the south, and southwest. The highest point is Mount Anderdon, with an elevation of 1,591 feet. The most extensive area with considerable elevation is the Mitchell Plateau about 1,000 feet to 1,200 feet above sea level.

The two major rivers in the Sheet area are the Mitchell and Lawley Rivers which drain into Admiralty Gulf. They are separated by a divide formed by the Mitchell Plateau. Both rivers are mainly subsequent and their courses parallel the contact between the King Leopold Sandstone and the Carson Volcanics or have reaches controlled by joints. Tributaries draining the King Leopold Sandstone have a rectilinear pattern controlled by joints whereas tributaries on the Carson Volcanics have a dendritic pattern.

The rivers flow permanently and are tidal in their lower reaches. On the Mitchell River, whose lower part is controlled by a large joint, a narrow tidal estuary over 20 miles long has developed (Figure 2). The rivers are incised 150 feet to 250 feet in their lower reaches, but at distances upstream there is a neck in the river profile and waterfalls have developed. Above the waterfalls the rivers have a gentle gradient.

The distribution of the various physiographic units is shown in Figure 3. Their classification is given in Table 1 and follows the scheme proposed by Plumb (in prep.).

Table 1

Classification of Physiographic Subdivisions - Montague Sound Sheet Area.

Province	"Sub-Province"	"Sub-Unit"
Kimberley Plateau	Gibb Hills	Mitchell Plateau Osborne Islands Plateau
	Prince Regent Plateau	

GIBB HILLS

The Gibb Hills topography has developed from the Carson Volcanics since the erosion of the laterite which forms the surface of the Mitchell Plateau.

The largest area covered by the Gibb Hills is in the Admiralty Gulf Syncline where they surround the Mitchell Plateau. They are rounded hills of moderate to low relief dissected by a dendritic pattern of tributaries. Around the northern fringe of the Mitchell Plateau individual resistant lava flows form conspicuous ledges giving rise to topography showing pronounced benches and mesa-like hills (Figure 4).

Mitchell Plateau

The Mitchell Plateau is a dissected laterite plateau, preserved chiefly along the drainage divide between the Mitchell and Lawley Rivers and also occurring as isolated remnants on some offshore islands.

At its highest point the Plateau has an elevation of about 1,200 feet and slopes gently toward the sea. Plateau remnants have an elevation of 310 feet on Descarte Island, 240 feet on West Montalivet Island and 106 feet on the Maret Islands. Small isolated buttes (not shown) occur near Cape Voltaire and southwest of Mitchell River.

The Plateau is best developed between the Mitchell and Lawley Rivers where conspicuous and extensive flat-topped hills are bordered by steep indented scarps, with relief between about 200 feet and 500 feet above the level of the major drainage lines. The Plateau is smooth and grass covered on the offshore islands and near the coast. Inland, it is forest covered and has a rough surface which is locally strewn with laterite boulders, possibly uprooted by fallen trees.

A dry upland swamp shown in Figure 5, about 200 acres in extent, occurs within the main body of the Mitchell Plateau at grid ref. 379129. It has internal drainage and is probably filled with water during the wet season. The perimeter of the lake is covered by a belt of grassland and the centre contains a dense growth of large trees.

Osborne Islands Plateau

Though of small extent, the Osborne Islands Plateau is a conspicuous physiographic feature formed by the resistant Warton Sandstone. The plateau is dissected into a number of small mesas, the most conspicuous of which is that developed on Steep Head Island. In this locality the island is 500 feet to 600 feet above sea level and surmounted by a flat-lying sandstone, the edge of which forms cliffs about 300 feet high (Figure 6).

PRINCE REGENT PLATEAU

The Prince Regent Plateau is underlain by the King Leopold Sandstone. Formerly it was overlain by a thin laterite profile co-extensive with the Mitchell Plateau, but this has now been removed by erosion and only small remnants of the laterite surface remain.

The highest part of the Plateau approximately coincides with the Mount Anderdon Anticline. The highest point is Mount Anderdon which has an elevation of 1591 feet. Flat-lying, jointed beds of sandstone have given rise to very rough topography (Figure 7) dissected by steep gorges. The drainage is controlled by joints and has a rectilinear pattern. Minor areas of subdued topography or smooth rounded hills are underlain by the Hart Dolerite.

Figure 4: Topography developed on the Carson Volcanics typified by prominent benches of resistant basalt. A coastal mudflat is in the foreground. View looking west from a prominent headland south of Warrender Hill.

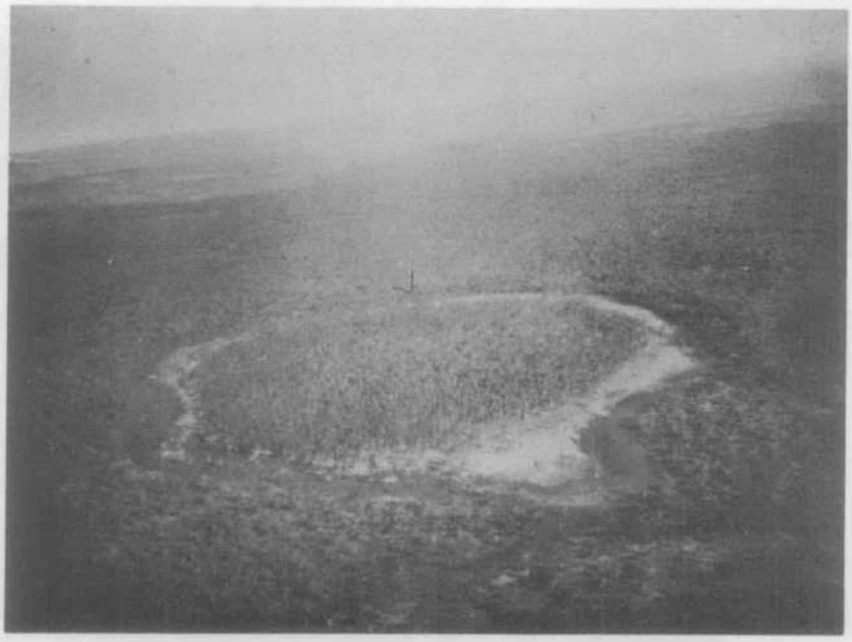


Figure 5: The upland 'swamp' developed on the lateritic surface of the Mitchell Plateau. The rim of the swamp is surrounded by grassland whereas the centre supports a dense growth of large trees. Laterites at this locality have a high alumina content. View looking north.

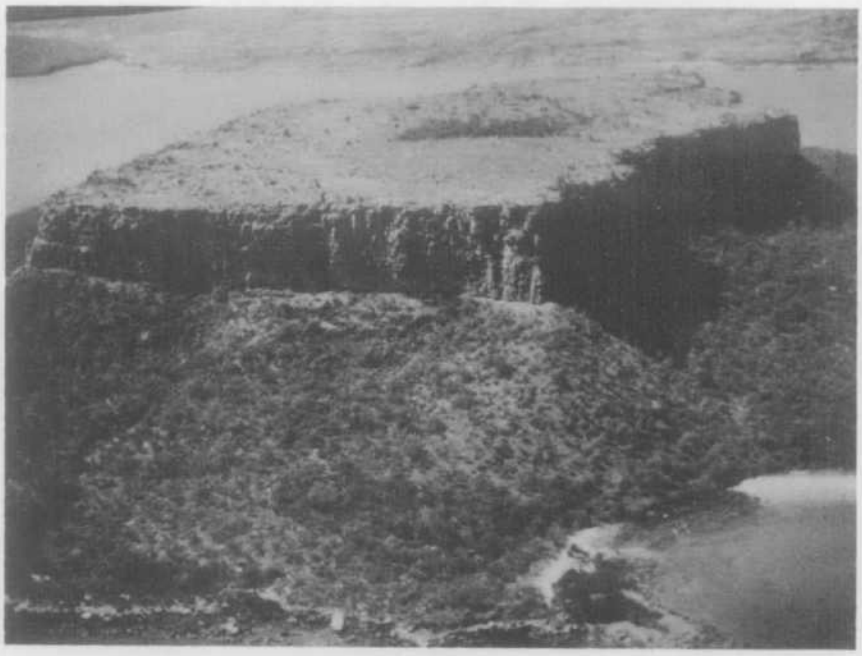


Figure 6: Steep Head Island. A remnant of the dissected Osborne Island Plateau formed by flat-lying Warton Sandstone. The light coloured formation in the distance is the King Leopold Sandstone. Carson Volcanics underlie the Warton Sandstone.

Figure 7: Flat-lying, medium-bedded King Leopold Sandstone. View looking east at about grid ref. 353183.

STRATIGRAPHY

The subdivison of the Precambrian time-scale in Australia is currently under review. The Bureau of Mineral Resources favours the recognition of two Eras, Proterozoic and Archaean, with a provisional boundary at about 2300 million years. Furthermore, within the Proterozoic, they recognize three time-rock divisions, called Systems. The corresponding time divisions are called Periods.

The oldest Period, with a base at about 2300 m.y. has not been named yet. The 'Carpentarian' has a base at about 1800 m.y. and the 'Adelaidean' has a base at about 1400 m.y. The top of the 'Adelaidean' is defined by the base of the Cambrian.

The Geological Survey of Western Australia (1965) favour a subdivision into Lower Proterozoic, Middle Proterozoic and Upper Proterozoic with lower boundaries at 2440 m.y., 1640 m.y. and 900 m.y. respectively. The two systems are compared in Figure 8. The Bureau of Mineral Resources nomenclature is used in this report.

Figure 8

COMPARATIVE PRECAMBRIAN TIME SUBDIVISIONS
GEOLOGICAL SURVEY W.A.
AND BUREAU OF MINERAL RESOURCES

G.S.W.A.	B.M.R.
UPPER PROTEROZOIC	
900 m.y.	ADELAIDEAN
MIDDLE PROTEROZOIC	1400 m.y.
1640 m.y.	CARPENTARIAN
	1800 m.y.
LOWER PROTEROZOIC	LOWER PROTEROZOIC
	2300 m.y.
2440 m.y.	ARCHAEAN
ARCHAEAN	

Most of the rocks exposed in the Sheet area are sandstone and basalt belonging to the Kimberley Group of Carpentarian age. They are intruded by the Hart Dolerite which may be Adelaidean but is probably Carpentarian in age. These rocks are overlain by Tertiary laterites which are then overlain by various Cainozoic soils.

The stratigraphy of the Sheet area is summarized in Table 2.

CARPENTARIAN

KIMBERLEY GROUP

The Kimberley Group was defined by Dow et al. (1964). It is divisible into five formations; from bottom to top: (1) King Leopold Sandstone; (2) Carson Volcanics; (3) Warton Sandstone; (4) Elgee Siltstone;

TABLE 2: STRATIGRAPHIC TABLE - MONTAGUE SOUND 1:250,000 SHEET AREA

ERA	AGE	THICKNESS (in feet)	ROCK UNIT AND SYMBOL	LITHOLOGY	TOPOGRAPHY	AIR PHOTO PATTERN	ECONOMIC GEOLOGY
CAINOZOIC	QUATERNARY		(Qa)	Beach sand: light grey, composed 50% subangular medium quartz sand and 50% angular well rounded shell and coral fragments; contains scattered shells and foraminifera.	Restricted to small sheltered bays between headlands; and on islands.	White tone, smooth relief.	(?) Suitable concrete aggregate
			(Qc)	Coastal deposits - grey, sticky chloropal mud impregnated with halite; contains scattered quartz grains. Some silt and fine sand.	Restricted to sheltered bays and estuaries.	White tone on inland margin; grey tone with anastomosing drainage intermediate zone; dark seaward fringe. Smooth relief.	Possibly suitable for some engineering structures.
		±10	(Qa)	Alluvium: light grey, white medium to coarse, angular to subangular, well sorted quartz sand.	Restricted to drainage lines.	White to light-grey tone, tree covered in places.	Suitable concrete aggregate and possible source of silica sand. Very limited quantities.
		±20	(Ql)	Limestone (coquina): light grey, cross-bedded, indurated, composed of abundant shell fragments; two distinct deposits, beach or shallow marine, unconformably overlain by friable aeolian deposits.	Restricted to landward side of small sheltered bays. Low relief.	White to light-grey tone smooth relief, not distinguishable from beach deposits.	Limited quantities suitable road metal and source of lime.
			(Czs)	Undifferentiated residual soils, pisolitic soils, sands, eluvium and ferricrete.	Restricted to lower edge of steep dipping bedding planes, drainage lines, and eluvium derived from basic volcanics.	Dark-grey tone, smooth relief.	Some ferricretes possibly useful aggregate, limited extent.
	(?)TERTIARY	5-30	Laterite (Tp & Tb)	Ferruginous and bauxitic laterite. Red-brown, cream, mottled, pisolitic, massive, cellular. Different composition on different rock types.	Flat capping preserved on interfluves and isolated hills.	Dark toned except where grass covered then light toned, flat relief.	Probable source of bauxite; useful aggregate and road metal.
U N C O N F O R M I T Y							
PROTEROZOIC	ADELAIDEAN OR CARPENTARIAN		Hart Dolerite (Pdh)	Dolerite: dark grey, medium to coarsely crystalline, fresh to slightly altered.	Smooth topography or low, rounded, boulder strewn hills.	Dark toned transgressive outcrops, smooth topography, low relief.	Probable good source aggregate, road metal, dimension stone and groundwater. Rare chalcopyrite.
	CARPENTARIAN	±300'	KIMBERLEY GROUP: Warton Sandstone (Pkw)	Sandstone: white, pink, purple, cemented by quartz in optical continuity with rounded, well sorted medium quartz grains; slightly feldspathic and micaceous towards base; ubiquitously cross-bedded in units 1-2 ft thick. Minor, purple micaceous siltstone at base.	Forms prominent mesas.	Light toned, bedded, moderately jointed, forms prominent cliffs and scarps.	Because of access it is not economic. Elsewhere suitable aggregate, road metal, dimension stone. Possible aquifer.

TABLE 2 (Contd.)

ERA	AGE	THICKNESS (in feet)		ROCK UNIT AND SYMBOL	LITHOLOGY	TOPOGRAPHY	AIR PHOTO PATTERN	ECONOMIC GEOLOGY
PROTEROZOIC	CARPENTARIAN	1000	KIMBERLEY GROUP	Carson Volcanics (Pkc)	Basalts: dark grey, black, green, fine-grained, amygdaloidal, extensively altered, tholeiitic; contain geodes of quartz, calcite, chlorite, epidote; felspars sericitised, altered to prehnite, augite altered usually to indeterminate mesostasis. Minor sandstone bed about 250' above base; well rounded, medium to coarse, well sorted quartz sandstone, cemented by quartz.	Forms smooth rounded hills, dendritic drainage pattern. Locally forms flat-topped hills with prominent benches.	Dark toned, smooth appearance; shows dark prominent bands and interbedded sandstone as light toned interbed.	Certain flows suitable aggregate road metal and dimension stone. Rare chalcopyrite. Source of good quality groundwater.
		2500+		King Leopold Sandstone (Pkl)	Sandstone: white, pink or buff medium to very coarse-grained; moderately sorted quartz grains well rounded, cemented by quartz; medium to thick cross-bedding; contains conglomeratic layers, rare very thin shale partings and clay pellets.	Forms rough dissected topography some mesas. Rectilinear drainage pattern.	Light toned rough surfaced, bedded, extensively jointed.	Suitable as aggregate dimension stone and possibly road metal. Source of good quality groundwater.

(5) Pentecost Sandstone. Of these only the lower three formations occur in the Montague Sound Sheet area.

King Leopold Sandstone

The name King Leopold Beds was first used by Guppy et al. (1958). It was modified to King Leopold Sandstone by Harms (1959) and its stratigraphic limits redefined by Dow et al. (1964).

The formation extends over at least two-thirds of the land area of the Sheet. It is flat lying and is readily distinguishable on aerial photographs by its light-toned, rough-surfaced and extensively jointed appearance.

The base of the formation is not exposed in the Sheet area. The top is conformably overlain by the Carson Volcanics and is well exposed at grid ref. 372158. The formation is intruded by sills and possibly dykes of the Hart Dolerite; the sills commonly intrude a soft sandstone bed in the upper part of the formation. Intrusions of dolerite are more common along the axis of the Mount Anderdon Anticline.

The thickness of the King Leopold Sandstone in the Sheet area is uncertain but is probably greater than 2,500 feet. The formation is well exposed except in minor depressions where it is covered by a thin skeletal soil.

En-masse the King Leopold Sandstone has a uniform appearance, but in detail there is a wide variation in colour, grain size, sorting and bedding. The sandstone is commonly friable, but in places, (e.g. in river and creek beds or below laterite), it is silicified, and has a glazed outer surface. The colour varies from yellow-brown, grey or pink on weathered surfaces, to white, buff, or mottled on fresh surfaces. Cross-bedding is ubiquitous and bedded units vary from 2 feet to over 20 feet in thickness. The sandstone readily parts along bedding planes and this tendency together with small-scale jointing, gives outcrops a blocky appearance.

The formation consists of fine, to coarse-grained quartz sandstone, minor fine conglomerate (Figure 9), conglomeratic sandstone, and rare very thin siltstone or shale partings. The conglomerates occur mainly in the upper part of the formation and consist mainly of scattered pebbles of well rounded vein quartz, quartzite, and chert in a sand matrix; subrounded mud pellets up to 2 inches long, occur in the uppermost beds.

Originally the sandstone was composed of rounded to well rounded quartz grains with moderate to high sphericity but quartz overgrowths have produced a mosaic of interlocking subhedral grains. The rounded shape of the original grains is outlined by a line of minute opaque inclusions, possibly the remnants of a former desert varnish. A very small proportion of interstitial clay occurs in some samples. The accessory minerals include rare muscovite, green tourmaline, zircon, ilmenite with a coating of leucoxene, and goethite (Appendix I).

The well rounded quartz grains, pebbles of vein quartz, quartzite and chert, together with the sparse heavy mineral assemblage and absence of feldspar, suggest that the formation was derived from pre-existing sedimentary rocks. The direction of origin of the sediments is uncertain. One hundred and thirty seven observations of the direction of current origin, indicated by cross-bedding made at 15 observation points in the upper part of the formation, indicate that the direction of current origin is overwhelmingly from the north. Table 2 is a summary of the data obtained.

Figure 9 : Thin layers of fine conglomerate composed of quartz and chert pebbles in the uppermost beds of the King Leopold Sandstone (Grid.ref. 394129).

Figure 10 : Hart Dolerite (lower) intrusive into King Leopold Sandstone. The contact is partially obscured by dense grass growing on a water seepage issuing from between the two formations.

TABLE 2

SUMMARY OF DIRECTIONS OF CURRENT ORIGIN, AS INDICATED BY CROSS-BEDDING.

Quadrant	No. of observations
Northwest - Northeast (315° - 044°)	118
Northeast - Southeast (045° - 134°)	13
Southeast - Southwest (135° - 224°)	5
Southwest - Northwest (225° - 315°)	1

The direction of current origin does not indicate the source of the sediments since many major currents run parallel to existing coastlines. Evidence of erosion of the Speewah Group and a southeastward transgression of the King Leopold Sandstone along the southeastern margins of the plateau suggest that some of the sediments may have been derived from around the margins of the present-day Kimberley Plateau.

Carson Volcanics

Basic volcanics which occur above the King Leopold Sandstone were called the Mornington Volcanics by Guppy and others (1958). This usage was continued by Harms (1959), but according to the Australian Code on Stratigraphic Nomenclature, the name was invalid due to prior usage, consequently Dow et al. (1964) re-named the formation the Carson Volcanics.

The formation is readily distinguishable on aerial photographs. It has a dark tone and generally forms smooth rounded hills, with a dendritic drainage pattern. An exception to this is in the Port Warrender area where flat-lying resistant flows form flat-topped hills with prominent benches. Rare interbeds of sandstone have a light tone and contrast markedly with the volcanics.

The formation is preserved in very shallow synclines surrounded by the King Leopold Sandstone and underlies almost one third of the land area of the Sheet. It is 900 to 1000 feet thick in the Port Warrender area but thins to between 200 feet and 400 feet in the Osborne Islands. The best exposures of the formation are in creeks or on ledges formed by resistant flows; elsewhere it is overlain by eluvium or thin soil.

The basal contact between the Carson Volcanics and the King Leopold Sandstone has controlled the courses of the subsequent Mitchell and Lawley Rivers. The contact is well exposed at grid ref. 372158, where a smooth bedding plane of conglomeratic King Leopold Sandstone is overlain by 1 foot of clayey extremely altered volcanics and then by over 60 feet of massive, altered basalt (Sample MS8-11-2 Appendix I). On the eastern limb of the Admiralty Gulf Syncline an interbed about 12 feet thick of silicified, quartz sandstone with well rounded quartz grains occurs about 250 feet above the base of the formation (Appendix I), but is not persistent and appears to lens out along its strike.

The upper part of the formation is exposed in the Osborne Islands. The contact with the overlying Warton Sandstone could not be visited, but was observed and photographed from an aircraft (Figure 6). Basalt is conformably overlain by pink siltstone and fine grained sandstone of the basal Warton Sandstone.

No sequence could be established in the flows, although three common types of basalt are recognized. The most abundant is a resistant dark grey, fine-grained rock (Specimen MS-10-68-2 Appendix I), which contains scattered grains of chalcopyrite. The other rocks of about equal abundance are a fine-grained, green-grey rock (Specimen MS-10-72-3A Appendix I), containing numerous quartz-filled geodes and vesicles of chlorite; and a dark green, moderately soft, altered rock (Specimen MS-9-55-1 Appendix I), containing numerous vesicles of epidote and chlorite.

In thin section all the rocks examined vary widely in mineralogy and show marked alteration. Plagioclase feldspar and possibly albite occur together in some specimens, but they are usually sericitized or altered to prehnite and epidote and are indeterminate. The augite is commonly altered to chlorophaeite or chlorite, or to an indeterminate mesostasis. Altered sphene, ilmenite, pyrite and (?) chalcopyrite occur as accessories. The mineralogy of the volcanics suggests that they are altered tholeiitic basalts.

The source of the volcanics is not known. The rapid thinning of the volcanics toward the Osborne Islands and the lack of tuffs or pillow lavas suggests that apart from an early marine phase when an interbedded sandstone was deposited, the volcanics may be of terrestrial rather than of submarine origin.

Warton Sandstone

The name Warton Beds was used by Guppy and others (1958) to describe the rocks overlying the Carson (originally Mornington) Volcanics on the Lennard River 1:250,000 Sheet. These beds were subdivided by Harms (1959) into three formations, the lowest of which he termed the Warton Sandstone.

On aerial photographs the formation is light toned, bedded, and moderately jointed. It commonly forms prominent cliffs and scarps, and is very similar in photo-pattern to the King Leopold Sandstone.

The formation is of only limited occurrence in the Sheet area. It forms a resistant capping over the Carson Volcanics in the Osborne Islands, and is particularly well exposed on Steep Head Island where it is about 300 feet in thickness.

The formation could not be visited on the ground but was observed from an aircraft (Figure 6). It is well exposed. At the base 30 to 60 feet of pink interbedded siltstones and fine-grained sandstones conformably overlie the Carson Volcanics. This is then overlain by a cliff of grey or pink medium-bedded sandstone. No rocks higher in the section are preserved.

In other parts of the Kimberley Plateau the resistant sandstone is white, pink or purple in colour and cross-bedded in units 2 feet to 3 feet thick. It consists of medium-grained, well rounded, well sorted, silicified quartz sandstone containing minor feldspar, interstitial clay and accessories.

ADELAIDEAN OR CARPENTARIAN

Hart Dolerite

The intrusive dolerites on the Lennard River Sheet were mistakenly interpreted by Guppy et al. (1958) as basalts which they called the Hart Basalt. Harms (1959) recognized that they were intrusive dolerites and renamed them the Hart Dolerite.

The intrusive nature of the formation is generally recognizable on aerial photographs. It has a dark grey tone and gives rise to areas of low, smooth relief.

In the Montague Sound Sheet area the Hart Dolerite crops out over an area of about 50 square miles. It intrudes only the King Leopold Sandstone but elsewhere in the region it intrudes the Carson Volcanics and younger formations. Generally it is poorly exposed and readily weathers to a thin soil containing rounded residual boulders, or is overlain by remnants of a laterite surface up to 18 feet thick. The best exposures occur in creek beds or along the coastline.

The age of the Hart Dolerite is uncertain. Preliminary radiometric results from elsewhere in the Kimberley Region indicate that the Dolerite is related to the Carson Volcanics. This may be the case in the Montague Sound area. Elsewhere it also intrudes formations younger than the Carson Volcanics and therefore more than one age of dolerite intrusion may be involved.

The dolerite is dark grey or dark green-grey and medium to coarsely crystalline. Prominent rectangular jointing is common. At grid ref. 326141 en-echelon intrusions of fine-grained dolerite and epidote about 30 inches long and 2 inches wide were recorded. Abundant crystalline quartz found at grid ref. 372164 is probably derived from geodes in the dolerite.

The formation comprises several sills which follow preferred bedding planes, or transgress strata in a series of steps. The various intrusions differ slightly in their petrography and degree of alteration.

A prominent sill occurs about 300 feet below the top of the King Leopold Sandstone where it has intruded a soft horizon. Outcrops of dolerite appear to be most frequent near the axis of the Mount Anderdon Anticline. Whether this is due to structural control or an accident of exposure is uncertain.

The contact between the Hart Dolerite and the King Leopold Sandstone is well exposed at grid ref. 361189 (Figure 10). The sandstone is silicified for about 6 inches above the contact but the rest of the sandstone appears unaltered. A chilled margin up to 2 feet wide is developed in the dolerite.

The dolerites have a well developed ophitic texture (Appendix I). They vary from fresh to extremely altered. In the altered specimens the feldspars are completely sericitized and indeterminate, probably the result of autometasomatism. The dolerites contain labradorite, diopsidic augite, (?)pigeonite and rare hypersthene. Chlorite and quartz occur in some specimens. Accessory magnetite occurs as inclusions in the augite, and at some localities it is sufficiently abundant to deflect a compass needle.

CAINOZOIC

Bauxitic and Ferruginous laterite (Tb and Tp)

The bauxitic and ferruginous laterites are the remnants of a once extensive lateritic sheet. Those developed over the Carson Volcanics have a potential economic importance as sources of bauxite and are shown separately on the geological sheet.

On aerial photographs the laterites appear as conspicuous cappings on the top of hills (Figure 11). They have a dark tone where they are covered by forest, but are light toned in coastal situations and on the offshore islands where they are grass covered (Figure 12).

The laterites are preserved on prominent mesas and buttes on top of the Mitchell Plateau. The profile varies between 18 feet and 30 feet in thickness on the volcanics, but forms only a thin ferruginous layer on the sandstones. Within the Montague Sound Sheet area the laterites extend over an area of 85 square miles of which about 80 square miles are potentially bauxitic.

Laterite profiles, which are exposed in scarps, show crude stratification into pisolitic layers of different colour and texture. A composite section from natural exposures and shallow pits is as follows:

Feet		
0 - 2	Laterite :	dark brown, ferruginous, massive or pisolitic, kaolinitic.
2 -c15	Laterite :	grey, cream, mottled pink, massive, porcellaneous, occasionally brecciated or pisolitic, bauxitic; contains some small cavities and ferruginous pisoliths.
c15-c20	Weathered bedrock (pallid zone),	mottled, poorly exposed, grading into or abruptly overlying fresh rock.

The age of the laterite is uncertain, but is tentatively regarded as Tertiary. It is probably the same age as the other high level laterites of northern Australia.

The smooth topography and relatively low relief of the Plateau and the thick development of laterites suggests (Stevens, 1946) that they were developed on a peneplain which has been subsequently dissected by a rejuvenation of rivers following Pleistocene changes in sea level. During lateritization the climate was probably more humid than at present.

<u>Undifferentiated Residual Soils</u> (Czs)

The symbol Czs includes eluvium, ferricrete, and residual soils which appear on aerial photographs as large dark toned areas of vegetation completely or partially obscuring underlying light-toned formations.

Eluvium is commonly derived from laterite, volcanics or dolerite and accumulates around mesas and along drainage lines. Ferricrete consisting of dark brown, highly porous pisolites in a sandy ferruginous matrix occurs along drainage lines in the Cape Voltaire area and as eroded remnants, particularly in pot-holes, along the main drainages. It probably results from the aggradation and re-cementation of lateritic debris along drainage lines. Residual and skeletal soils are developed on the down-dip edge of smooth bedding planes in the King Leopold Sandstone (Figure 7).

<u>Coastal Limestone</u> (Ql)

Two very small occurrences of limestone were found at grid refs. 354170 and 353162 on the western side of the Peninsula which separates Montague Sound and Admiralty Gulf. They are located on the landward side of small beaches and are not distinguishable from Recent beach sands.

Both occurrences are in very sheltered situations and it is possible that other small patches of limestone exist.

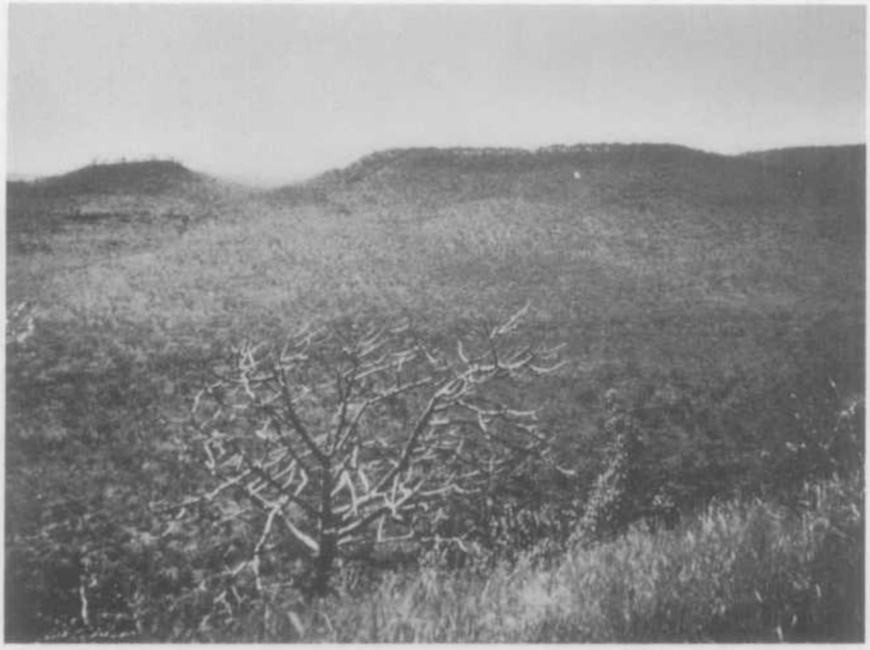


Figure 11: Flat-topped hills of bauxitic laterite(Tb) developed on Carson Volcanics. Note exposed benches of basalt and the dense vegetation growing on the laterite.

Figure 12: Bauxitic laterite (Td) exposed on Maret Island. The surface of the bauxite is grass-covered and about 100 feet above sea level.

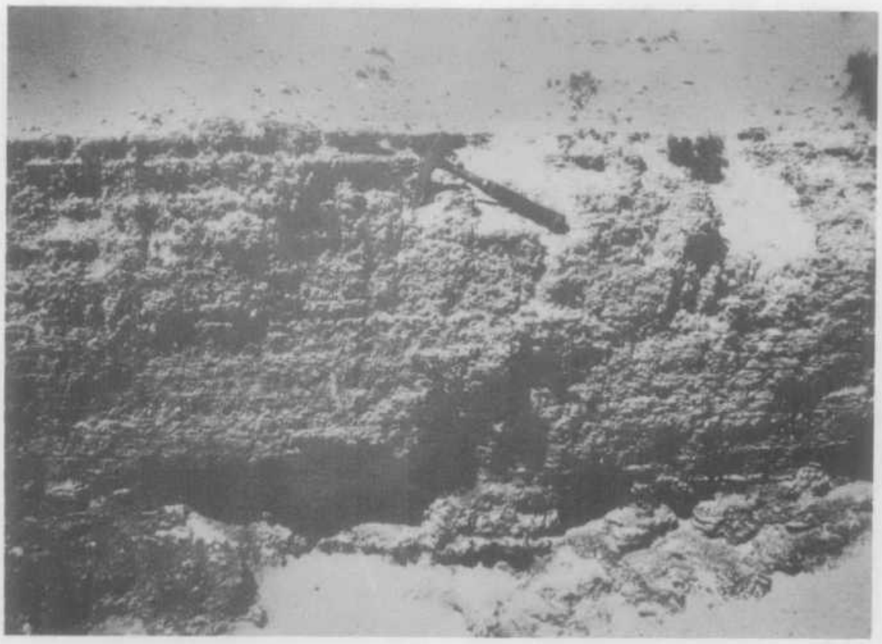


Figure 13: Friable, partially cemented coastal limestone overlain by a dune sand.

Figure 14: Lowermost unit of coastal limestone, overlain in the distance by the friable partly cemented dune sand (Figure 13). King Leopold Sandstone forms dark horizon. Note also cross-bedding in foreground.

Figure 15: Polygonal dessication cracks on salt encrusted coastal mudflats. King Leopold Sandstone in background.

A well exposed section was examined at grid ref. 354170 at the edge of a small creek. The section was as follows:

Feet	Description	
0-6	Dune sand:	white, medium to fine-grained, well sorted, composed of rounded grains of coral shell, bryozoa and about 50% subangular quartz grains; foraminifera abundant.
		DISCONFORMITY
6-11	Limestone:	white, dune-bedded, very friable, well sorted, composed predominantly of rounded and subrounded shell and coral fragments, minor quartz (Figure 13).
		DISCONFORMITY
11-17	Limestone:	grey, dense, cross bedded, composed entirely of shell fragments and occasional large unbroken shells and minor coralline material (colour of some shells and coral is still preserved) (Figure 14) (Specimen MS-7-82-1)
		UNCONFORMITY
		King Leopold Sandstone

The base of the lower limestone bed is about 4 feet to 6 feet below sea level (Figure 14). The bedding and sheet material suggest that the lower bed is the truncated base of dune sands, or possibly shallow-water marine beds deposited when the sea level was somewhat higher. The top of the overlying limestone bed (Figure 13) is about 6 feet above sea level and is apparently a former beach deposit also deposited during a higher stand of sea level.

Alluvium (Qa)

Recently aggraded material accumulated along drainage lines is mapped as alluvium. The only large deposit is along a small tributary entering the western side of the Mitchell River. It is recognizable on aerial photographs by its restriction to the river channel and its light colour tone.

The alluvium consists of clean, well sorted, angular to subangular medium-sized well sorted quartz grains. It is of variable thickness and width. Other rivers on the Sheet area appear to be degrading so that alluvium has not accumulated. The deposit on the Mitchell River tributary possibly owes its origin to the very friable King Leopold Sandstone in the area supplying more material than can be removed.

Coastal Sand, Silt and Mud (Qc)

Extensive littoral mudflats occur around the shores of sheltered bays and, particularly, in the estuaries of the Mitchell and Lawley Rivers (Figure 2). The mudflats generally contain three zones, viz. a mangrove-covered seaward fringe; a zone of soft mud alternately submerged and exposed by tides; and a landward fringe of dry mud inundated only during spring tides or storms.

The mudflats are readily recognizable on aerial photographs by their brilliant white tone and smooth relief fringed on their seaward side by darker areas. They may be traversed by incised meandering tidal creeks.

The inland fringe of the mudflats is quite firm. The surface has dried out and formed small polygonal shrinkage cracks about 3 inches across and is covered by fine salt crystals (Figure 15). At a few inches depth the mud is wet and sticky.

The muds are composed of chloropal (a member of the montmorillonite group of clays) impregnated with halite and a little silica (Appendix I and II). Silt and sand are present locally.

The mudflats appear to be the result of aggradation and the fixing of silt, clay and sand by mangroves, possibly on a shallow, wave-cut bench.

Beach Sands (Qs)

Beach sands are limited in their occurrence to small sheltered bays developed between prominent headlands or to beaches on some of the off-shore islands.

They are readily recognizable on aerial photographs by their brilliant white tone and smooth relief.

Most of the beaches shelve quite steeply toward the sea, and are littered with driftwood, shells and coral fragments. A hummocky, partially vegetated storm beach, 10 feet to 15 feet above sea level, composed of shells and corals, is common on the landward side of the beach. Sand dunes also occur in places at the back of the beaches.

The beach sand contains rounded shell and coral fragments, foraminifera, and subangular medium-grained quartz grains. No heavy mineral concentrations were noted, but a sample taken for heavy mineral analysis contained rare grains of limonite and ilmenite coated by leucoxene.

STRUCTURAL GEOLOGY

The main structural elements of the Sheet area are shown in Figure 16.

Folding

Two periods of very gentle folding, both probably of Proterozoic age can be recognized in the Sheet area. The early set of folds - the Augustus Island Syncline, Mount Anderdon Anticline and Admiralty Gulf Syncline, were folded along axes trending at about 350°. The Admiralty Gulf Syncline, and possibly the other folds, are slightly assymetric with the eastern limbs having steeper dips.

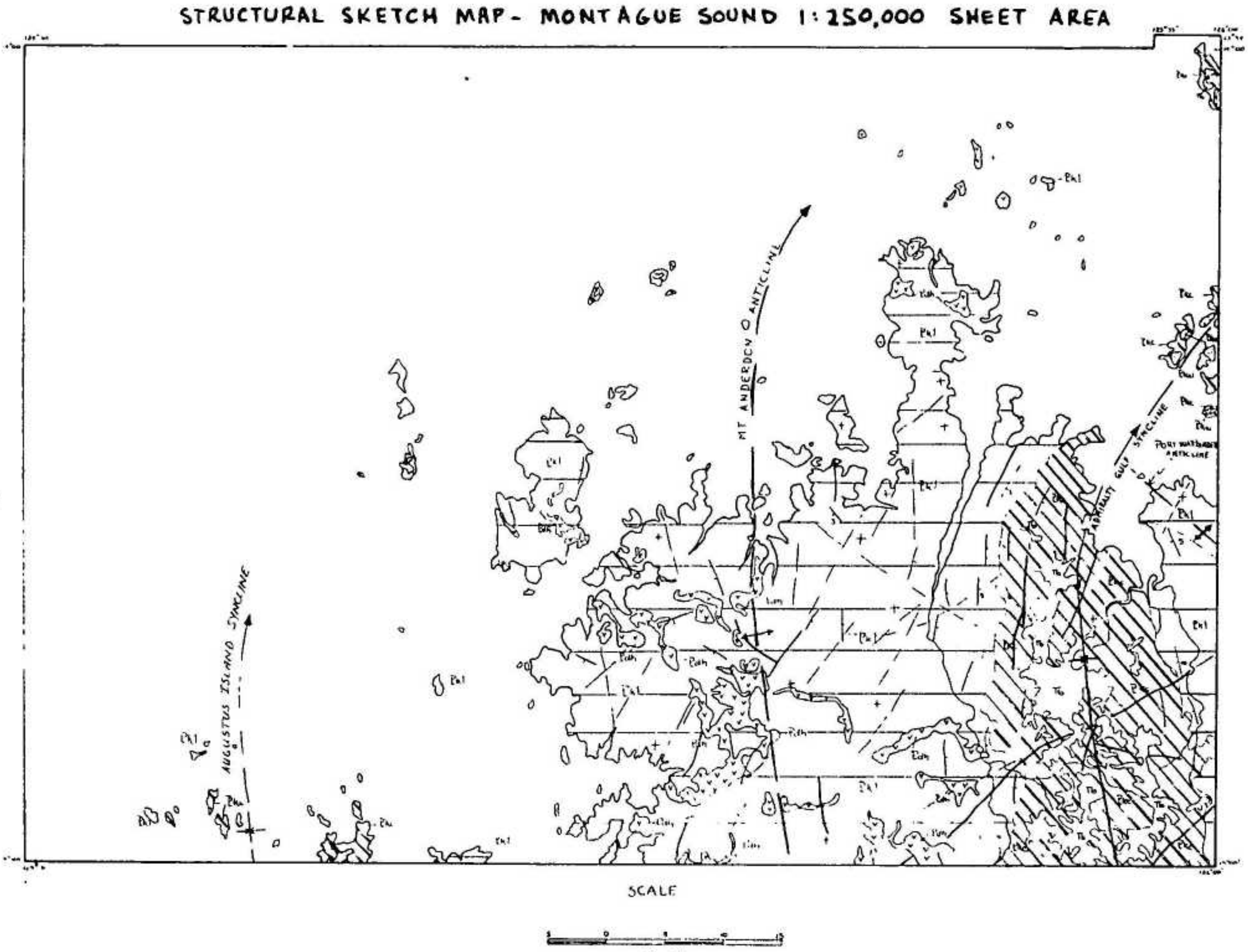
A younger fold, the Port Warrender Anticline, has an axis trending at 310°. The axial plane of this fold intersects the axis of the Admiralty Gulf Syncline in the position of Port Warrender to produce a shallow basin with a long axis trending about 040°.

Faulting

No major faults were recognized. Only small faults lacking any obvious preferred orientation occur. Most appear to be normal faults with small displacement but a small reverse fault with a throw of 15 feet was observed at grid ref. 394129. It dips at 20°E and has a zone of brecciation 1 foot to 2 feet thick.

Fig. 16

STRUCTURAL SKETCH MAP - MONTAGUE SOUND 1:250,000 SHEET AREA



FAULT

MAJOR LINEAMENTS

DIP AND STRIKE OF BEDDING

HORIZONTAL BEDDING

ANTICLINE

SYNCLINE

BAUXITIC LATERITE

HART DOLERITE

WARTON SANDSTONE

CARSON VOLCANICS

KING LEOPOLD SANDSTONE

To accompany Record 1966/201

Bureau of Mineral Resources, Geology and Geophysics, November 1966

D51/A12/4

Figure 17: Flat-lying King Leopold Sandstone cut by prominent master joints. View looking south on west side of Swift Bay.

The largest fault in the Sheet area strikes at 060° across the central part of the Admiralty Gulf Syncline. The contact between the Carson Volcanics and the King Leopold Sandstone, is offset slightly - and the fault is inferred to be a normal fault with downthrow to the north. The southwestern and northeastern extensions of the fault have no apparent offset so are mapped as joints. This fault and joints belong to a closely spaced set of strong lineaments extending for about 220 miles into the Prince Regent and Drysdale Sheet areas.

Jointing

Joints are particularly common in the King Leopold Sandstone, but are less common in the other formations. Prominent master joints in the Sandstone range from one to eight miles in length and have a density of 50 to 150 master joints per one hundred square miles (Figure 17). There are two major trends, one striking at 030° and the other at 330°. Joints are most numerous along the axis of the Mount Anderdon Anticline.

In the field, these master joints appear to be zones composed of close spaced parallel joints. They form steep trenches with precipitous sides and have controlled the local drainage.

In the Carson Volcanics the joints vary between 2 miles and 8 miles long and have a density of less than 40 per 100 square miles. The two sets of joints in this formation have similar orientations to those in the King Leopold Sandstone, but do not form trenches or control the drainage pattern.

Dolerite Intrusion

The relationship of the Hart Dolerite to the structure is not clear. Exposures along the axis of the Mount Anderdon Anticline may be related to the structure but are probably an accident of exposure.

GEOLOGICAL HISTORY

During the Carpentarian the Sheet area was part of an extensive sedimentary basin in which sediments and volcanics of the Kimberley Group were deposited. Dolerite sills were intruded either during or after sedimentation. Subsequently, probably during the Proterozoic, the rocks were slightly folded and faulted, elevated, and subjected to erosion.

No record of further sedimentation before the Cainozoic is preserved. Prolonged erosion during this time removed a thick section of rocks from the Sheet area.

In the Cainozoic, the region was reduced to a peneplain on which a lateritic surface developed. Subsequent lowering of sea level or epeirogenic uplift of the Kimberley Plateau at the beginning of the Pleistocene, led to rejuvenation of the rivers and almost complete erosion of the laterite surface.

The coastal limestone was deposited during a high stand of sea level, probably during the Pleistocene. A Recent rise in sea level has produced the present drowned coastline.

The geological history is summarized in Table 4.

ECONOMIC GEOLOGY

Aggregate, Dimension Stone, Road Metal and Ballast

Fresh King Leopold Sandstone, Hart Dolerite and the ferruginous varieties of laterite are suitable as aggregate. The fine-grained varieties of Carons Volcanics could also be utilized although some of the amygdaloidal and altered varieties may prove unsuitable because of the possibility that they would react with cement. The beach sands composed of about 50% subangular quartz and 50% shell and coral fragments may be useful aggregate.

The best source of dimension stone is in medium or thin bedded sequences in the King Leopold Sandstone. Blocks weighing several tons may be obtained.

Road metal and ballast should be readily available from the Hart Dolerite and fine-grained varieties of the Carson Volcanics. Pisolitic laterite would also make a useful road metal.

Bauxite

Laterites developed at Cape Bougainville, (the north-eastern extension of the Mitchell Plateau) were unsuccessfully tested for bauxite in 1958-59 by Reynolds Pacific Mines Pty Ltd.

In 1965 the United States Metals Refining Company discovered bauxitic laterites on the Mitchell Plateau, within the Sheet area. The Bureau of Mineral Resources/Geological Survey of Western Australia Kimberley Party, in the area at the same time, also examined the deposits.

The main deposits of bauxitic laterite occur on the Mitchell Plateau, preserved along a drainage divide between the Mitchell and Lawley Rivers. The deposits are developed on the Carson Volcanics and vary between 18 feet and 30 feet in thickness (see STRATIGRAPHY). They are described by Sofoulis (in press).

The analyses of five grab samples of bauxitic laterite are given in Appendix II. Total alumina varies between 47.5% and 61.9% and available alumina (four samples) varies between 42.2% and 57.7%. The alumina occurs principally as gibbsite (Appendix I), but kaolin, and possibly boehmite also occur in minor amounts.

The largest apparent deposit of bauxitic laterite occurs in the vicinity of a swamp developed on the Mitchell Plateau. This development may have been favoured by a high permanent water table. Ferruginous laterites such as those known to occur around the coast may have developed in conditions of fluctuating water table allowing oxidation and the deposition of iron oxides.

The bauxitic laterites in the Sheet area extend over an area of about 80 square miles and very large tonnages of bauxitic laterite are present. Close-spaced drilling to determine the extent, thickness and variation in grade is necessary, and is being undertaken by the U.S. Metals Refining Co.

Clay

Extensive deposits of chloropal (montmorillonite group) mud of uncertain thickness, containing quartz and halite occur in the coastal mudflats (Appendix II), but their suitability for engineering works is unknown. Clays in the pallid zone below the lateritic profiles may be useful.

TABLE 4

AGE		EVENT
ERA	PERIOD	
CAINOZOIC	RECENT	(?) RISE IN SEA LEVEL; DEPOSITION OF BEACH SANDS, SAND DUNES, COASTAL MUDFLATS AND ALLUVIUM; EROSION.
	QUATERNARY	(?) FALL IN SEA LEVEL; DEPOSITION AND CEMENTATION OF COASTAL DUNES: DEVELOPMENT OF NICK IN RIVER PROFILES; EROSION.
		(?) RISE IN SEA LEVEL: DEPOSITION OF BEACH AND SHALLOW WATER LIMESTONES IN COASTAL SITUATIONS, AND (?)PISOLITIC SOILS AND FERRICRETE, EROSION.
		(?) FALL IN SEA LEVEL, REJUVENTATION OF RIVERS, WIDESPREAD EROSION.
	(?)TERTIARY	POSSIBLE PENEPLANATION, DEVELOPMENT OF LATERITES, IN A HUMID CLIMATE
MESOZOIC		NO RECORD. MAINLY CONTINUING EROSION.
PALAEOZOIC		POSSIBLY SOME PERIODS OF SEDIMENTATION. SEDIMENTS SINCE ERODED.
PROTEROZOIC	ADELAIDEAN	
	ADELAIDEAN OR CARPENTARIAN	FOLDING AND FAULTING; UPLIFT; EXTENSIVE EROSION. POSSIBLE INTRUSION OF DOLERITE SILLS (HART DOLERITE)
	CARPENTARIAN	NO EVIDENCE, PROBABLE DEPOSITION OF SANDSTONE, SHALE AND CARBONATE OF THE PENTECOST SANDSTONE AND ELGEE SILTSTONE: POSSIBLE DEPOSITION OF BASTION GROUP.
		QUARTZ SANDSTONE DEPOSITION UNDER MARINE CONDITIONS IN RELATIVELY SHALLOW, EXTENSIVE BASIN. (WARTON SANDSTONE).
		CESSATION OR PETERING OUT OF VULCANISM. DEPOSITION OF PURPLE SHALE ON TOP OF VOLCANICS.
		PERIOD OF (?)TERRESTRIAL AND MARINE VOLCANISM OUTPOURING OF THICK THOLEITIC BASALTS DEPOSITION OF QUARTZ SANDSTONE IN QUIET PHASES SHORTLY AFTER BEGINNING OF VOLCANISM (CARSON VOLCANICS). PROBABLE INTRUSION OF DOLERITE SILLS (HART DOLERITE).
		LONG PERIOD OF UNIFORM CONDITIONS, AND DEPOSITION OF SHALLOW WATER MARINE QUARTZ SANDSTONES: SOURCE MATERIAL PROBABLY DERIVED FROM PRE-EXISTING SANDSTONES, PALAEOCURRENTS FROM THE NORTH (KING LEOPOLD SANDSTONE).

Copper

Rare grains of chalcopyrite were found in some specimens of the fine-grained basalts which occur in the Carson Volcanics and in the Hart Dolerite, but no significant mineralization was found.

Limestone

Two small occurrences of shell limestone noted in the area are too limited in extent and too inaccessible to be of any economic significance.

Phosphate

Minor deposits of guano associated with small colonies of sea birds were noted on the Montalivet Islands, but it is unlikely that they are of economic significance.

Quartz sand

Alluvium along a tributary of Mitchell River about 10 miles south of Swift Bay is the most extensive potential deposit of quartz sand suitable as a source of silica or aggregate. The deposit occurs in an irregular sand-filled channel up to 40 feet wide, but of an uncertain depth and consists of clean, medium to coarse, angular to subangular, well sorted quartz grains.

Water

An outline of the surface and groundwater resources of the region is given by Allen (1966).

Good quality surface water varying between 20 and 200 ppm total dissolved solids occurs along most of the drainage lines in pools in their upper reaches or as permanent flow towards their mouths. Surface water is more scarce on the volcanic rocks.

Standard analyses of three samples of surface water are given in Appendix II. Sample MS-11-97-1A was taken from a tidal pool and is not representative.

Groundwater with less than 1,000 parts per million of total dissolved solids should be available from fractures within all the formations of Carpentarian age. Yields are likely to range up to 2,000 gallons per hour. Best results will be obtained from wells or bores drilled up to 350 feet into hard rock.

Dam sites

The only large rivers are the Mitchell and Lawley, with drainage basins of 1,150 square miles and 200 square miles respectively. The gorge along the lower part of the Mitchell River could provide a small storage basin, but because of the jointed nature of the terrain, no other suitable dam sites are likely to occur.

Harbour sites

Detailed bathymetric information is required before sites for harbours suitable for other than shallow draft vessels can be recommended. Some sites which may be suitable are Mudge Bay, Swift Bay and some of the small bays on the western side of Port Warrender.

Tidal Power Resources

Mean spring tides along the coast have a rise and fall of 21 feet to 24 feet. The tides together with the favourable physiography of the coastline make the region suitable for tidal electricity generation.

The feasibility of various sites in the region has been assessed by Lewis (1962). He recognized potential sites at Bigge Island, two sites in Montague Sound, Mitchell River Estuary, Port Warrender and Admiralty Gulf.

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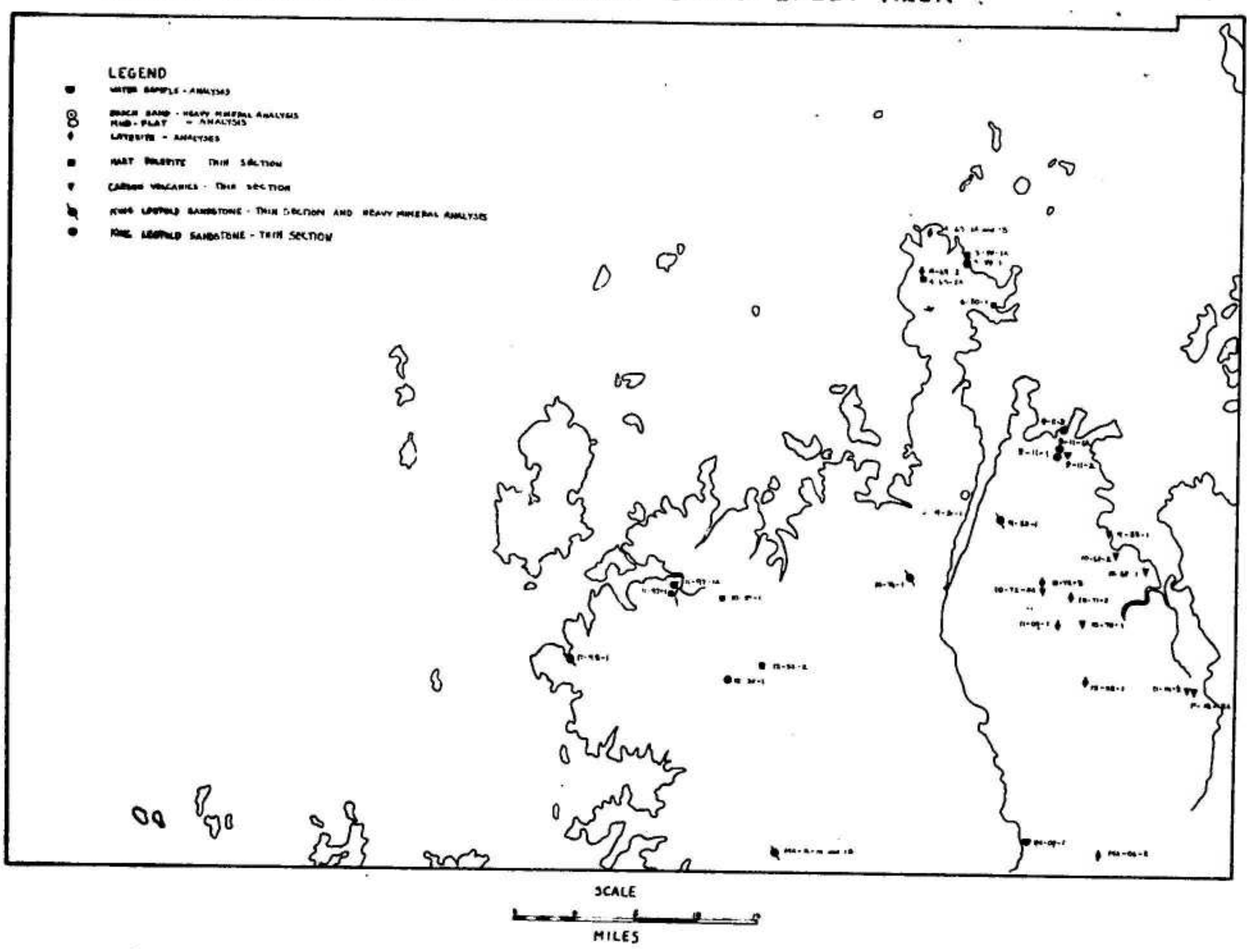
SAMPLE LOCALITY MAP - MONTAGUE SOUND SHEET AREA



To accompany Record 1966/201

APPENDIX I

THIN SECTION AND HEAVY MINERAL DESCRIPTIONS

King Leopold Sandstone (Pkl)

M.S. 8-11-1 Orthoquartzite

In hand specimen the rock is yellow-brown in colour, silicified, and shows faint cross-bedding.

Under the microscope the rock shows obvious sedimentary sorting into two bands of different thickness, grain size, and sorting. The coarse layer is composed of well rounded quartz grains 0.5 to 1.0 mm in length, cemented by interstitial quartz. It contains accessory zircon and rare interstitial mica. The fine-grained layer consists of a mosaic of interlocking angular to subangular quartz grains 0.05 to 0.20 mm in diameter, and is moderately sorted. Some grains appear to be stained by red-brown limonite. Rounded grains of sericitized feldspar make up 3% of the rock. Zircon, ilmenite and a strongly pleochroic, green tourmaline occur as accessory minerals.

M.S. 12-32-1 Orthoquartzite

The rock is dark grey, dense and silicified in hand specimen. It shows indistinct banding.

Microscopically, the rock appears to be a mosaic of angular interlocking quartz grains, but under ordinary light it appears as well sorted and well rounded quartz grains 0.50 to 1.00 mm in diameter, cemented by quartz which has grown in optical continuity with the grains. Some crystal faces are developed on the grains. Rare grains of chert occur. Zircon is a rare accessory.

M.S. 3-88-1 Orthoquartzite

In hand specimen the rock is white to light grey on fresh surfaces, and pale yellow on weathered surfaces. The rock is dense and fine-grained. It is indistinctly bedded and contains rare, thin, clayey laminae.

Microscopically, the rock consists of a mosaic of subangular quartz grains 0.05 to 0.30 mm in diameter. The nucleii of the subrounded grains are rounded quartz grains cemented by an overgrowth of quartz. Several of the quartz grains contain acicular inclusions of a colourless mineral; and others appear to be composed of detrital vein quartz or chert. Small amounts of clayey material occur as an interstitial matrix. Observed accessories were an opaque mineral (?), ilmenite and well rounded grains of green pleochroic tourmaline.

M.S. 14A-16-1A Orthoquartzite

In hand specimen the rock is pink on fresh surfaces and purple-grey on weathered surfaces. It is a friable medium to coarse conglomeratic quartz sandstone, and contains a pink clayey material interspersed among some of the grains.

Under the microscope the rock appears as a mosaic of interlocking angular to subangular quartz grains 0.05 to 1.5 mm in diameter. Under ordinary light some grains can be seen to be well rounded and to be cemented by a quartz overgrowth. About 5% of the rock is made up of interstitial clayey material. The only observed accessory was an opaque mineral, probably ilmenite.

A heavy mineral separation yielded the following minerals in order of abundance: tourmaline (well rounded), zircon, and ilmenite coated with leucoxene.

M.S. 14A-16-1B Orthoquartzite

In hand specimen the rock is a well rounded pebble, yellow brown on its weathered surface and white on fresh surfaces. It is dense and hard.

Microscopically it consists of a mosaic of poorly sorted interlocking, very angular quartz grains 0.01 - 0.50 mm in diameter. Some grains appear to show solution effects along their interfaces. Clayey material is a common interstitial material making up about 5% of the rock. Muscovite, rare garnet, zircon and an unidentified colourless acicular mineral occur as accessories.

M.S. 11-95-1 Orthoquartzite

In hand specimen the rock is pink with scattered purple mottles, friable, medium-grained and moderately sorted.

Under crossed nicols the rock appears as a mosaic of angular interlocking crystals 0.30 to 1.00 mm in diameter, but under ordinary light the original composition of subrounded to rounded quartz grains cemented by quartz in optical continuity, can be seen.

The outline of the original grains is outlined by thin lines of minute opaque inclusions. Occasional grains appear to be composed of vein quartz or chert. A finely disseminated opaque mineral in an indeterminate groundmass occurs in irregular areas up to 5 mm in diameter. The areas of opaque mineral coincide with the mottled areas seen in the hand specimen. Some interstitial areas are strongly outlined by a black opaque material possibly limonite or goethite and by a clay mineral. Tourmaline and an opaque mineral, probably ilmenite, occur as accessories.

A heavy mineral separation yielded the following minerals in order of abundance: ilmenite with marked rim of leucoxene, tourmaline, zircon.

M.S. 9-53-1 Orthoquartzite

In hand specimen the rock is pink on fresh surfaces, grey on weathered. It is medium-grained, friable and appears poorly sorted.

In thin section, under crossed nicols the rock appears as a mosaic of angular interlocking quartz grains 0.20 to 1.50 mm in diameter, but under ordinary light is seen to consist of well rounded quartz grains, cemented by quartz in optical continuity. Some quartz grains appear to be of vein quartz or chert. Interstitial clay is absent. The only observed accessory was scattered grains of ilmenite.

A heavy mineral separation yielded the following minerals in order of abundance: goethite, ilmenite, zircon and tourmaline. The assemblage is finer grained than observed in other samples.

M.S. 10-14-1 Orthoquartzite

The rock, in hand specimen, is grey-brown on weathered surfaces, and pink on fresh surfaces. It is medium to coarse-grained, and well sorted. A clayey mineral can be seen cementing some grains.

Microscopically it is a mosaic of interlocking angular to subrounded quartz grains 0.20 to 0.50 mm in diameter. Under ordinary light original well rounded grains are cemented in optical continuity by interstitial quartz. Some grains of chert are present. Interstitial clayey material constitutes about 3% of the rock. An opaque mineral and zircon were the only accessories observed.

A heavy mineral separation yielded the following minerals in order of abundance: well rounded tourmaline, and zircon, and ilmenite rimmed with leucoxene.

Carson Volcanics (Pkc)

M.S. 10-72-3A Basalt (altered)

In hand specimen the rock is yellow-brown on weathered surfaces and pale green on fresh surfaces. It is fine-grained and displays conspicuous small dark green blebs. Conspicuous large geodes, containing two generations of quartz - one cryptocrystalline and horizontally layered and the other of crystalline quartz with well developed terminations, are a notable feature of the rock.

Under the microscope the rock is fine-grained and has a porphyritic texture. Sericitized feldspar laths vary between 0.50 to 1.50 mm in length, and show occasional twinning. Some larger plagioclase crystals 2.50 to 4.00 mm in length and 2.5 mm in width are also present. They show varied degrees of alteration to a golden yellow slightly pleochroic mineral - possibly chlorophaeite - which constitutes about 5% of the rock. Vesicles in the rock are infilled either by colourless or zoned green and brown banded varieties of chlorite or chlorophaeite. They constitute about 15% of the rock. The groundmass is fine-grained, almost isotropic and indeterminate and is probably altered augite.

M.S. 10-68-1 Basalt (altered)

In hand specimen the rock is brown on its weathered surface with some of the feldspars etched out. On fresh surfaces it is dark green, fine-grained and with conspicuous small dark blebs of chlorite.

Under the microscope the rock is very fine-grained, porphyritic and is extensively altered. Fine, sericitized laths of plagioclase range between 0.20 to 1.00 mm in length and 0.05 to 0.001 in breadth. Chlorite or chlorophaeite, constitute about 18% of the rock. Epidote occurs as irregular masses in the groundmass and constitutes about 5% of the rock. Rare vesicles of calcite also occur. The remainder of the groundmass is dark brown, almost isotropic and indeterminate.

M.S 8-11-2 Basalt (altered)

The rock in hand specimen is pale green on fresh surfaces and brown on weathered surfaces. It contains irregular vesicles of massive quartz and thin quartz veins.

Microscopically no definite texture is evident and the rock appears to be extremely altered. The most abundant mineral is prehnite probably replacing feldspar. It constitutes about 40% of the rock. Quartz in irregular vesicles and veins constitutes about 20%.

The groundmass is colourless and pale green brown in colour, some of the material is fine-grained prehnite but the rest is indeterminate. Irregular and partially altered crystals of sphene make up about 5% of the rock. Pyrite occurs as an accessory mineral.

M.S. 10-70-1 Basalt (altered)

In hand specimen the rock is dense and hard. It is brown on weathered surfaces, but dark green with a hackley appearance on fresh faces and contains small blebs of chlorite.

Under the microscope the rock has a porphyritic texture and is only moderately altered. Feldspar laths vary between 0.25 and 2.0 mm in length and up to 0.20 mm in breadth. The crystals tend to be acicular and some show occasional twins. They are also sericitized but not extensively. Partially altered laths of feldspar constitute about 28% of the rock. Chlorophaeite forms irregular masses in the groundmass of the rock, of which it comprises about 10%. The rest of the groundmass is dark, fine-grained and indeterminate. No accessory minerals were observed.

M.S. 11-14-2A Basalt (altered)

On weathered surfaces the rock is dark brown and on fresh surfaces grey-green, speckled with small light and dark green blebs. It is dense and fine-grained.

Microscopically the rock has a porphyritic texture. It appears extensively altered. Thin acicular laths of plagioclase (?labradorite) range in size from 0.02 to 0.05 mm in length. The feldspars are partly altered to sericite and are occasionally twinned. Relict crystals of augite occur as indistinct stubby or occasionally acicular crystals. Chlorite or chlorophaeite occurs within the groundmass and in vesicles. The vesicles consist of an outer layer of chlorite infilled with quartz. Irregular clots of calcite occur in the groundmass which is an indeterminate semi-opaque mesostasis. Accessory magnetite or ilmenite occurs in the groundmass.

M.S. 9-55-1 Basalt (altered)

In hand specimen the rock is olive-green in colour, relatively soft and contains numerous quartz and chlorite spherules up to 5 mm in diameter.

Under the microscope the rock appears extensively altered. Feldspars are absent and the dominant mineral is a highly birefringent epidote, some crystals of which show well developed cleavage. Extensively altered sphene comprises about 10% of the rock and the rest is made up of vesicles of chlorite or composite vesicles composed from the outside to the centre, of chlorite, quartz and calcite. Radiating needle-like inclusions of an indeterminate mineral occur in some of the quartz grains. Ilmenite occurs as an accessory.

M.S. 10-68-2 Basalt (altered)

In hand specimen the rock is dark grey, dense and fine-grained.

Microscopically it has porphyritic texture and is extensively altered. Feldspar occurs as sericitized acicular and rarer prismatic crystals ranging from 0.05 to 0.50 mm in length. Chlorite and epidote ocurrs as infillings in vesicles. The groundmass is semi-opaque and indeterminate.

M.S. 11-14-2 Orthoquartzite (interbed in volcanics)

In hand specimen the rock is a pale red-brown on fresh surfaces and mottled dark grey and red-brown on weathered surfaces. It is dense, hard, and contains rare mudflakes.

Microscopically under crossed nicols the rock appears as a mosaic of interlocking angular quartz grains. Under ordinary light it consists of subrounded to rounded quartz grains, 0.25 to 0.75 mm in size cemented by interstitial quartz.

It contains rare grains of (?) sericitized feldspar and accessory muscovite.

Hart Dolerite (Pdh)

M.S. 6-50-1 Dolerite

In hand specimen the rock is dark green-grey and coarsely crystalline.

Under the microscope the rock appears extensively altered and the sub-ophitic texture is not readily discernible. The feldspar occurs in crystals 1.00 to 2.00 mm in length of indeterminate composition. They are extensively sericitized. Augite occurs as subhedral crystals containing large inclusions and exsolution structures of magnetite (5%). Smaller grains of magnetite and sericitized feldspar occur in an indeterminate mesostasis. Chlorite and quartz occur as minor accessories.

M.S. 3-83-1A Dolerite

In hand specimen it is a dark grey, medium-grained rock.

Under the microscope the rock has ophitic texture. The feldspars are prismatic to acicular in shape and moderately to extensively sericitized. They range in length from 1.00 to 2.00 mm and their composition measured from a combined carlsbad-albite twin in Bytownite (Ab25 An75). The augite forms subhedral crystals 1.50 to 2.50 mm in length. They are occasionally twinned and contain inclusions and exsolution structures of magnetite (5%). Quartz and chlorite occur as minor accessories.

M.S. 4-65-2A Dolerite

In hand specimen the rock is dark grey in colour, dense and fine-grained.

When examined in thin section the rock has ophitic texture. The feldspars are euhedral and tabular to prismatic in shape and commonly show albite twinning. Some crystals are slightly sericitized. From angles of combined carlsbad-albite twin the composition of the feldspars is approximately labradorite (Ab45 An55). Anhedral augite with numerous inclusions of magnetite comprises 35% of the rock; magnetite 3%. Rare hypersthene with neutral to pale green pleochroism occurs as an accessory.

M.S. 10-81-1 Dolerite

In hand specimen the rock is dark grey, dense and coarsely crystalline.

Examined in thin section the rock is coarse grained, with sub-ophitic texture. The feldspars are euhedral and tabular to prismatic in form and range between 0.50 to 4.00 mm in length. They display albite and carlsbad twinning and are sericitized to varying degrees. Their composition is uncertain but is probably about labradorite. Anhedral augite with inclusions of skeletal magnetite constitutes about 40% of the rock, magnetite constitutes about 3%. Rare chlorite occurs as an accessory.

M.S. 11-97-1 Dolerite

In hand specimen the rock is dark grey, coarsely crystalline. On weathered surfaces it is dark brown with a slag-like appearance.

Examined in thin section the rock has ophitic texture. The feldspars are euhedral and vary in size between 0.10 and 1.00 mm and are slightly sericitized. Carlsbad and albite twins are common. The composition of the feldspar is uncertain but it is probably about labradorite. Anhedral augite (35%) with inclusions of skeletal and massive magnetite (3%) shows many examples of intergrowth with the feldspars. Chlorite occurs as an accessory in the groundmass.

M.S. 12-32-2 Dolerite

In hand specimen the rock is dark grey, crystalline and with a slightly weathered appearance.

Under the microscope the rock has ophitic texture. The feldspar range between 0.50 mm and 1.0 mm in length. Numerous crystals are twinned and a few crystals show sericitization. The composition of the feldspar is labradorite (Ab40 An60). Augite (30%) occurs as anhedral grains intergrown with feldspar and with inclusion of magnetite. Magnetite comprises about 3% of the rock and many small grains occur in the groundmass. Chlorite also occurs in the groundmass and constitutes about 5% of the rock. Rare quartz occurs as an accessory mineral.

M.S. 8-11-3 Beach Sand

Beach Sand: A heavy mineral separation yielded in order of abundance, angular grains of ferruginous laterite and rounded grains of ilmenite coated with leucoxene.

Bauxitic Laterite

Field Number: M.S. 10-72-3

Rock Description: Bauxite

Laboratory No.: 10588/65[1]

Result of examination: A specimen of bauxite composed of massive, fine-grained gibbsite, with nodules of fibrous gibbsite, voids lined with crystalline gibbsite and containing a little dispersed anatase.

Coastal Mud:

Field Number: M.S. 9-51-1
Rock Description: Mud
Laboratory No.: 10589/65[1]
Result of examination: Chloropal[2] mud impregnated with halite and containing a little quartz.

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1. Examination made by West Australian Government Chemical Laboratories.
2. Chloropal is a silicate of ferrous and ferric iron and alumina and and belongs to the montmarillonite group of minerals. Nontronite is a synonym.

APPENDIX II

Chemical Analyses

Analyses made by West Australian Government Chemical Laboratories

Field Number	MS4-65-1A	MS4-65-1B	MS4-65-2	MS10-72-3	MS9-51-1
Rock Description	Ferruginous pisolitic laterite	Ferruginous Laterite	Pisolitic Ferricrete	Bauxite	Mud
Lab. No. (1965)	10585	10586	10587	10588	10589
		per cent on dry basis			
SiO_2	1.12	1.16	27.6	0.86	40.1
Al_2O_3	17.2	30.6	11.6	60.7	13.8
Fe_2O_3	65.2	46.3	49.2	2.53	7.11
FeO	2.19	n.d.	0.06	n.d.	0.26
MnO	0.02	0.04	0.04	0.01	0.11
H_2O_+	0.2	17.6	9.29	32.3	12.0
Ni	0.02	$<$0.01	n.r.	n.r.	n.r.

n.d. = not detected

n.r. = not requested

Field Number	MS10-71-2	MS11-09-1	MS14A-08-2	MS12-22-1
Rock Description	Bauxite	Bauxite	Bauxite	Bauxite
Lab. No. 1965	11719	11720	11721	11722
		per cent on dry basis		
Available Al_2O_3	42.2	53.3	48.7	57.7
Total Al_2O_3	47.5	58.8	61.9	59.4
Reactive SiO_2	1.00	1.60	1.31	1.20
Total SiO_2	1.24	1.64	1.38	1.24
Fe_2O_3	15.6	4.59	4.15	3.57
TiO_2	10.2	4.99	4.09	4.32

(From Sofoulis (in press))

Water Analyses

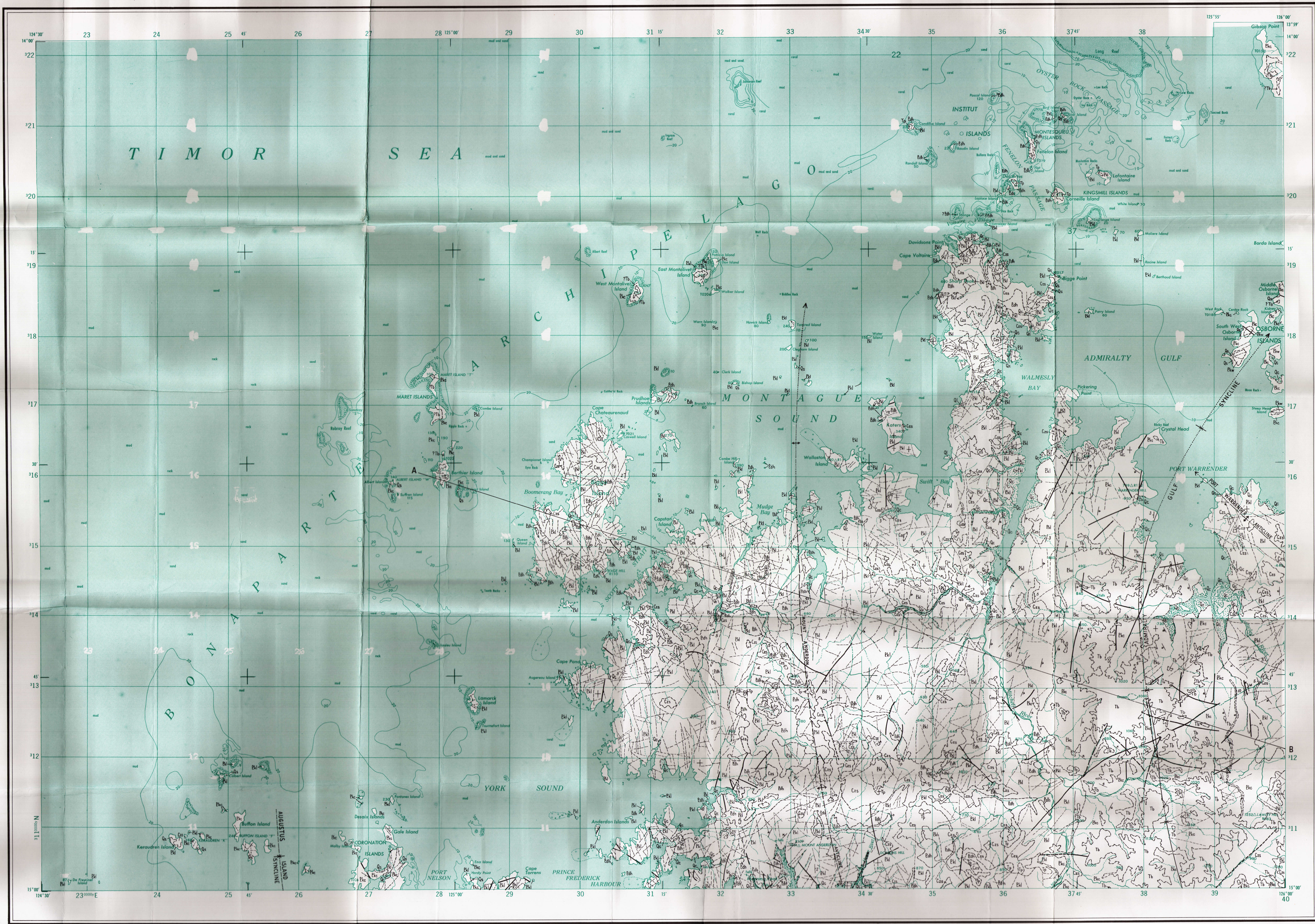
Name	Mitchell River	Un-named Creek	Un-named River
Field No.	MS14A-09-1	MS3-11-1A	MS11-97-1A
Lab. No. (1965)	10429	10428	10426
Specific conductivity 20° micromhos	50	310	1400
Appearance	Clear	Clear	Very slightly cloudy
Colour	Colourless	Colourless	Colourless
Odour	Nil	Nil	Nil
pH	7.3	8.6	5.9
Mineral matter parts per million			
Calcium Ca	3	18	11
Magnesium Mg	2	22	27
Sodium Na	8	25	246
Potassium K	<1	1	9
Bicarbonate HCO_3	24	165	12
Carbonate CO_3	Nil	9	Nil
Sulphate SO_4	3	2	58
Chloride Cl	8	28	437
Nitrate NO_3	Nil	Nil	Nil
Silica SiO_2	Nil	Nil	Nil
Iron Fe	0.1	0.1	0.1
Total by conductivity	35	220	980
Total by evaporation	40	200	810
Hardness calculated as ppm $CaCO_3$			
Total hardness	15	135	139
Bicarbonate hardness	15	135	10
Non-carbonate hardness	Nil	Nil	129
Calcium hardness	8	45	28
Magnesium hardness	7	90	111

AUSTRALIA 1:250,000 GEOLOGICAL SERIES

MONTAGUE SOUND

WESTERN AUSTRALIA

SHEET SD 51-12



PRELIMINARY EDITION, 1966

SUBJECT TO AMENDMENT

NO PART OF THIS MAP IS TO BE REPRODUCED FOR PUBLICATION WITHOUT THE WRITTEN PERMISSION OF THE DIRECTOR OF THE BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS, DEPARTMENT OF NATIONAL DEVELOPMENT, CANBERRA, A.C.T.

Reference

CAINOZOIC	QUATERNARY		Qa	Alluvium
			Qc	Coastal sand, silt and mud; thin salt crust in places
			Ql	Fragmental shelly limestone
			Qs	Quartzose beach sands; pebble and shell-bearing in places
	UNDIFFERENTIATED		Czs	Sand, soil, eluvium
	TERTIARY		Tb	Bauxite, aluminous laterite
			Tp	Laterite, undifferentiated
PROTEROZOIC	ADELAIDEAN OR CARPENTARIAN	Hart Dolerite	Pdh	Dark grey to black, medium to coarse-grained dolerite
	CARPENTARIAN (LOW. PROT. UNDIFF.*)	Kimberley Group: Warton Sandstone	Pkw	White to purple-grey medium-grained quartz sandstone; minor feldspathic sandstone
		Kimberley Group: Carson Volcanics	Pkc	Grey-green to black locally amygdaloidal basalt; minor quartz sandstone and feldspathic sandstone (stippled) and purple shale near top
		Kimberley Group: King Leopold Sandstone	Pkl	White to pink, medium to coarse-grained quartz sandstone and pebbly quartz sandstone

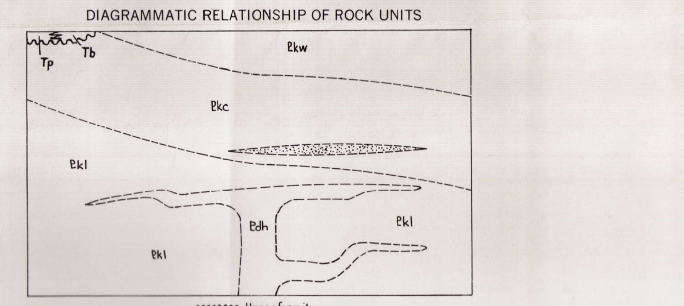
* Subdivisions of the Precambrian time-scale used by the Geological Survey of Western Australia, shown in grey

- Geological boundary
- Anticline, showing plunge.
- Syncline, showing plunge
- Fault, high angle reverse

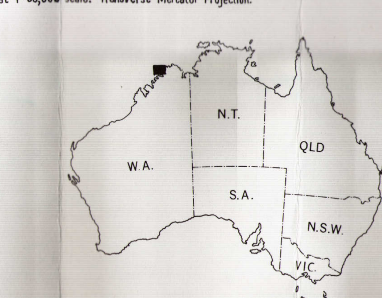
Where location of boundaries, folds and faults is approximate; line is broken, where inferred, queried; where concealed, boundaries and folds are dotted, faults are shown by short dashes

- Strike and dip of strata
- Horizontal strata
- Dip < 5 (air-photo interpretation)
- Dip 5-15 (air-photo interpretation)
- Trend line (air-photo interpretation)
- Joint pattern (air-photo interpretation)
- Mangroves
- Astronomical station
- Trigonometrical station
- Height in feet, datum: mean sea level
- Coral reef

DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS

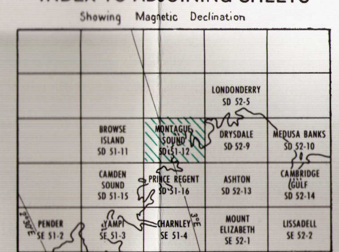


Compiled and issued by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development, in conjunction with the Geological Survey of Western Australia. Topographic base compiled by the Royal Australian Survey Corps. Aerial photography by the Royal Australian Air Force; complete vertical coverage at 1:50,000 scale. Transverse Mercator Projection.



INDEX TO ADJOINING SHEETS

Showing Magnetic Declination



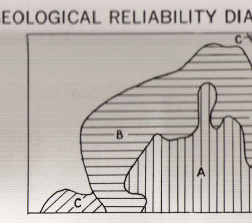
ANNUAL CHANGE -0°30'

Scale 1:250,000

5 0 5 10 15 MILES

5 0 5 10 15 20 25 KILOMETRES

GEOLOGICAL RELIABILITY DIAGRAM



A Helicopter traverses with air-photo interpretation

B Aerial reconnaissance and air-photo interpretation

C Air-photo interpretation

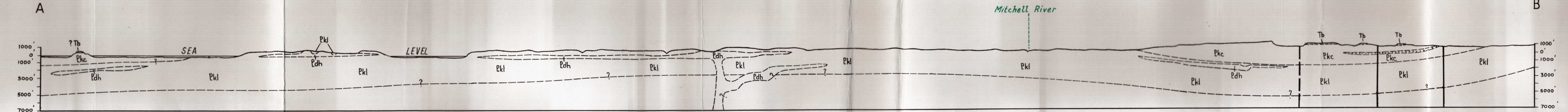
Geological Photo Interpretation, 1964 by: W. J. Perry (B.M.R.)
Geology, 1965, by: A.D.Allen, J Sofoulis (G.S.W.A)
Compiled, 1965, by: A.D.Allen, J.L.McGovern
Cartography by: Geological Branch B.M.R.

Section

Attitude of faults not known

Cainozoic sediments, excepting Tertiary laterite, omitted from section

Scale: $\frac{V}{H} = 2$



MONTAGUE SOUND

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