COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

# BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS

**RECORDS:**

1966/81



# GEOLOGY OF THE ASHTON 1:250,000 SHEET AREA SD52/13 WESTERN AUSTRALIA.

by

G.M. Derrick



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FIGURES:-

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## SUMMARY

The Ashton Sheet area lies near the centre of the Kimberley Plateau in the north of Western Australia, and extends from Lat. 15°00'S to Lat. 16°00'S, and from Long. 126°00'E to 127°30'E.

The dominant land forms on the Sheet area are broad, partially soil-covered cuestas and gentle undulating plateaux. Dissection of some of the plateaux in the south-west corner of the Sheet area has produced some rugged topography. Remnants of a laterite surface are common in the north-west.

Many large semi-permanent superimposed streams drain the Sheet area, notably the Drysdale, Durack, King Edward and Carson Rivers. The latter is markedly subsequent, though the Drysdale, Durack and King Edward Rivers are both subsequent and consequent for various parts of their courses.

The rocks of the Sheet area are mainly mature quartz sandstone, and minor feldspathic sandstone, siltstone, mudstone and volcanics of the Kimberley Group, and siltstone, quartz sandstone and feldspathic sandstone of the Bastion Group. The Kimberley Group of Carpentarian age is 8000 feet thick and contains the King Leopold Sandstone at the base, overlain by the Carson Volcanics, Warton Sandstone, Elgee Siltstone and Pentecost Sandstone, all of which are conformable. Also of Carpentarian age is the Bastion Group, which overlies the Kimberley Group conformably and contains the Mendena Formation, of which only the basal 115 feet are preserved. The King Leopold Sandstone is intruded by the Hart Dolerite, which generally crops out in the cores of gentle anticlines and domal structures. The Hart Dolerite may be of either Adelaidean or Carpentarian age. Superficial sand, soil and laterite deposits are of Cainozoic age. The quartz sandstone in all of the formations is well-sorted and fine- to coarse-grained. Some feldspar is present, but is generally less than 5% of the sandstone. Silica overgrowths are common, and tourmaline, zircon, and to a lesser extent epidote, are the major heavy minerals. Glauconite occurs in fine-grained sandstone near the base of the middle Pentecost Sandstone. Most of the sandstone in the Sheet area displays large-scale current bedding, while ripple-marks and small-scale current bedding are common features of siltstone. Some of the siltstone within the Pentecost Sandstone is cupriferous, while that of the Elgee Siltstone is calcareous.

The sediments of the Kimberley Basin have been derived from older sedimentary rocks which themselves have been derived from an acid igneous terrain. A basic igneous source area, possibly areas of outcrop of Carson Volcanics, has provided small amounts of additional detritus, notably epidote, to younger formations of the succession. All of the sediment has been distributed by paleo currents which trend predominantly from the north-west.

Structural features of the Sheet area include shear and tension joints, faults and folds which are all closely related. Cross-folding and jointing are dominant, and all structures are a result of a north-south regional compression which has been contemporaneous with or was followed by an east-west compression.

Small bauxite deposits are associated with laterite which has been developed primarily over the Carson Volcanics. The bauxite is high-grade and massive, and consists mainly of gibbsite. Some of the laterite is sufficiently ferruginous to be considered a source of iron ore. In the Pentecost Sandstone apatite is a common accessory in glauconitic sandstone, while malachite is present in small amounts in siltstone which assays at 0.36% copper. Copper is also present in small amounts in the Elgee Siltstone and Carson Volcanics, which also contain traces of galena.

# INTRODUCTION

## Present Investigation

This report presents the results of a geological survey of the Ashton 1:250,000 Sheet area carried out by a combined party from the Bureau of Mineral Resources and the Geological Survey of Western Australia. This Sheet was one of eight* mapped during the period May to July, 1965, as part of a programme commenced in 1962 to map the Precambrian rocks of the Kimberley Division at 1:250,000 scale. The Ashton Sheet area was mapped by G.M. Derrick and D.C. Gellatly (B.M.R.) and I.R. Williams (G.S.W.A.)

## Location and Access

The Ashton 1:250,000 Sheet area extends from latitudes 15°00'S to 16°00'S, and from longitudes 126°00'E to 127°30'E. It lies near the centre of the Kimberley Plateau, in the north of Western Australia. Drysdale Crossing, the site of the base camp during the survey, is approximately 300 road miles north-east of Derby.

Access to the Sheet area is from Gibb River Station, about 40 miles south of the southern margin of the Sheet area. A newly constructed beef road joins Derby to Mount House and Gibb River Stations, and a poorly formed track links Wyndham to Gibb River via Karunjie Station. A single track extends northwards from Gibb River Station to Drysdale Crossing in the Ashton Sheet area. From Drysdale Crossing a track follows the Carson Escarpment to Kalumburu Mission, in the Drysdale Sheet area. Another track runs north-north-west from near Drysdale Crossing towards the King Edward River and provides an alternative route to Kalumburu. The Carson and King Edward tracks were surveyed and constructed in 1954 by Morgan (see "Previous Work"). Construction and grading of a new track linking Gibb River and Kalumburu commenced in 1965, and this road is expected to follow closely the King Edward track via Drysdale Crossing. The Gibb River - Karunjie - Wyndham track passes through the south-east corner of the Sheet area, where a series of scarps are negotiated via the New York Jump-Ups. Vehicular traffic away from the tracks is restricted by rugged sandstone outcrops and continuous scarps, but locally extensive soil cover is readily negotiable by 4-wheel drive vehicles. Throughout the wet summer season the tracks are usually impassable for long periods.

Gibb River Station is serviced fortnightly by DC3 aircraft from Derby and Wyndham, and a poorly formed light aircraft landing strip is located on the north bank of the Drysdale River at Drysdale Crossing.

## Population and Industry

There are no towns within the Sheet area, and the only habitation is at Doongan, a small pastoral holding near Crossland Creek. The population is semi-permanent, and numbers approximately a half dozen people engaged in cattle-raising, the only industry of the area. Large numbers of nomadic aboriginals present in the more remote areas until at least the late nineteen-fifties have now disappeared.

* Ashton, Drysdale-Londonderry (Gellatly, in prep.), Mount Elizabeth (Roberts and Perry, in prep.), Montague Sound (Allen, in prep.), Camden Sound-Prince Regent (Williams and Sofoulis, in prep.) and Medusa Banks (Plumb and Perry, in prep.). Portions of Charnley and Lennard River were also mapped, but mapping of these sheets will not be complete until late 1966.

Climate, Vegetation and Soils

The Ashton Sheet area experiences a monsoonal to tropical savannah climate (Slatyer, 1960), with a distinct "dry" season from April to October, and a "wet" season from November to March. The annual rainfall isohyets trend north-east, and rainfall decreases from 38 inches in the north-west corner to 28 inches per annum in the south-east corner of the Sheet area. Nearly all of the rainfall is received in the "wet season" mainly from thunderstorms and monsoonal and cyclonic disturbances. Average maximum temperatures range from 80°F. in the coolest month, July, to 100°F. in the hottest month, November. The maximum temperature is depressed slightly in the wettest months, December to February, mainly because of an increase in the amount of cloud cover. Average minimum temperatures range from 45°F in the winter to 75°F. in the summer. Frosts are occasionally experienced in the winter months, and at Drysdale Crossing (elevation 1200 feet above sea-level) during June and July, 1965, at least six frosts occurred, the lowest temperature recorded being 28°F. Strong easterly winds are characteristic of the dry season, but winds from the west and north-west are experienced during the wet season.

The vegetation of the Sheet area has been described in detail by Speck (1960), who delineated vegetation and soils which were developed over shale, sandstone and volcanic bedrock.

Areas of shale are characterised by skeletal deposits, consisting mainly of shale and siltstone fragments with finer textured red-brown soils filling interstices. Pastures are mainly of soft spinifex (Plectrachne pungens), annual orghum and kerosene grass (Aristida hygrometrica). Trees are low (10' to 15') and often gnarled and stunted, small paperbarks and acacia being common (see Fig. 1). Baobabs are ubiquitous in sandy areas, and bauhinia trees occur near permanent water.

Areas of subdued sandstone outcrop are covered by deep yellow sands, supporting soft spinifex, sorghum and cockatoo grass, cypress pine and a varied community of eucalypts. In areas of more rugged sandstone outcrop the yellow soils are thinner and less extensive, and support poor spinifex, sorghum pastures and scattered eucalypts, mainly yellow box, iron bark and messmate (E. tetradonta).

Basaltic areas are commonly well-grassed open woodlands (see Fig. 2), and provide the highest stock-carrying potential. Areas of red and grey soils are extensive, with black soil incursions. The former soil types contain sinkholes or "crabholes" covered by spear grass or other grasses such as blue grass, sorghum, white grass and kerosene grass. Skeletal laterite soils are common, and support a similar suite of pastures. The open woodlands contain abundant messmate, cabbage gum, ironbark, woolybutt and many other varieties of eucalypt. Tall cabbage palms are common around seepage flats, and along watercourses pandanus palms, large ghost gums and tall paperbarks are ubiquitous.

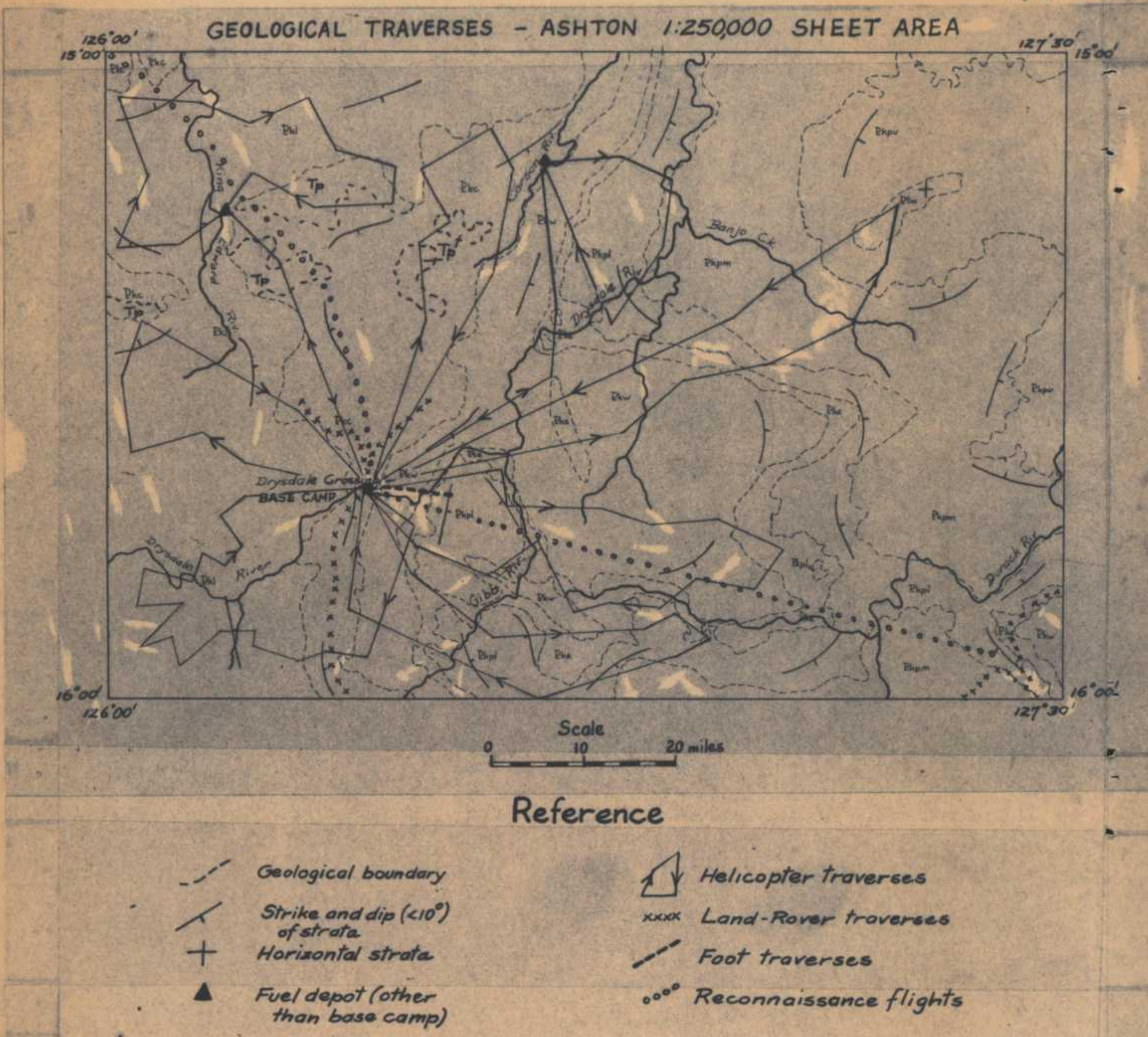
Survey Methods and Maps

Geological investigations were carried out by means of helicopter traverses, supplemented by foot and Land Rover traverses (Fig. 3). A photo-interpreted geological map of the Ashton Sheet area was compiled at 1:250,000 scale by the B.M.R. photogeological group (Perry and Richard, 1965), and this proved of benefit in outlining areas worthy of detailed investigation and when planning helicopter traverses. Geology was plotted directly on to overlays of aerial photographs, which were produced in 1949 by the Royal Australian Air Force. The geological data were transferred to photo-scale compilations, which were then photographically reduced to 1:250,000 scale. From the reductions geological information was traced onto a plate at 1:250,000 scale, using the grid of a 1:250,000 topographic plate compiled in 1961 by the Royal Australian Survey Corps. The geological and topographic plate were then superimposed. Also available were air photograph mosaics compiled at 1:63,360 and 1:250,000 scales by the Department of Lands and Surveys of W.A. and the Department of National Mapping respectively.

Fig. 1. Pentecost Sandstone overlying Elgee Siltstone. The boundary between the formations is mid-way between the uppermost prominent black scarp and the top of the hill. Skeletal soil, rock fragments, soft spinifex and stunted trees common in valley.

Fig. 2. Open eucalypt woodland covering basaltic areas. Dark patches are areas of burnt pasture.

Fig. 3




To accompany Record No 1966/81

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Previous Investigations

Explorers in the Kimberley region during the late nineteenth century confined their efforts to the south and west Kimberley, where access was relatively easy. One of the first parties to traverse the north Kimberley was that of the surveyors Brockman and Crossland (1901), Crossland Creek being named after the latter. Attached to this party were geologists Gibb-Maitland and Gibson who were "searching for a reputed gold field on the Carson River between 15° and 16° latitude". They recognized "the staple formation was made up of a series of quartzites and shales....associated with...... andesite, dolerite and diabase....sometimes amygdaloidal and containing nodules of zeolite and agates". (Gibb-Maitland, (1907)). A collection of these rocks was made by Gibb-Maitland, and another by Fitzgerald (1907), who accompanied a further expedition by Crossland in 1905.

These two collections of basic volcanic rocks were examined in detail by Edwards (1942), though a study of the geological map of Easton (1922) contained in Edwards' report shows that none of the specimens was from the Ashton Sheet area. Further general references to the volcanic rocks of the north Kimberley were made by Gibb-Maitland (1928).

In 1914, an account of the physiography of the region, based on scanty geological and topographical information, was given by Jutson (1950, revised).

A comprehensive report concerning the Ashton Sheet area was written by Morgan (1955) who, in 1954, led a survey and road construction team from Gibb River Station to Kalumburu Mission. The few geological observations in this report were generalised; however, many topographic features were named by Morgan, some of which are Gattenhoff Hill and Abandon, Hair and Laurie Creeks.

Traves (1955) wrote a short report on the geology of the King Edward-Drysdale area, based on photo interpretation, and Harms (1959) revised Traves' nomenclature and produced a map and report which have provided the framework for all subsequent mapping in the area. Speck (1960) compiled a generalised geological map based on consultation with Harms and on the work of Traves (op. cit), and noted in his report that "extensive areas of lateritised volcanic rocks should be examined as possible sources of bauxite". Harms (op. cit) noted that the laterites in the coastal areas of the north Kimberley warranted further investigation. Perry and Richards (op cit) compiled a photo-geological map of the Ashton sheet area which provided a basis for detailed planning of the 1965 field mapping programme.

## PHYSIOGRAPHY

### Drainage

The Ashton Sheet area is drained by a number of large semi-permanent streams. Five drainage basins are recognised (Fig. ) named after the most prominent stream in that basin. They are as follows:-

a. Durack
b. Forrest
c. Drysdale
d. King Edward
e. Mitchell

The Durack Basin contains the Durack River and the smaller Ellenbrae Creek. They are superimposed and consequent for some of their length, but are subsequent where their courses are controlled by siltstone of the Pentecost Sandstone and Elgee Siltstone respectively.

The Forrest Basin includes the Forrest, Ernest and Berkely Rivers, which are consequent and are superimposed. They are incised into meandering gorges which are up to 300 feet deep, and which are up to 500 feet deep on the adjoining Cambridge Gulf Sheet area (Plumb and Veevers, 1965).

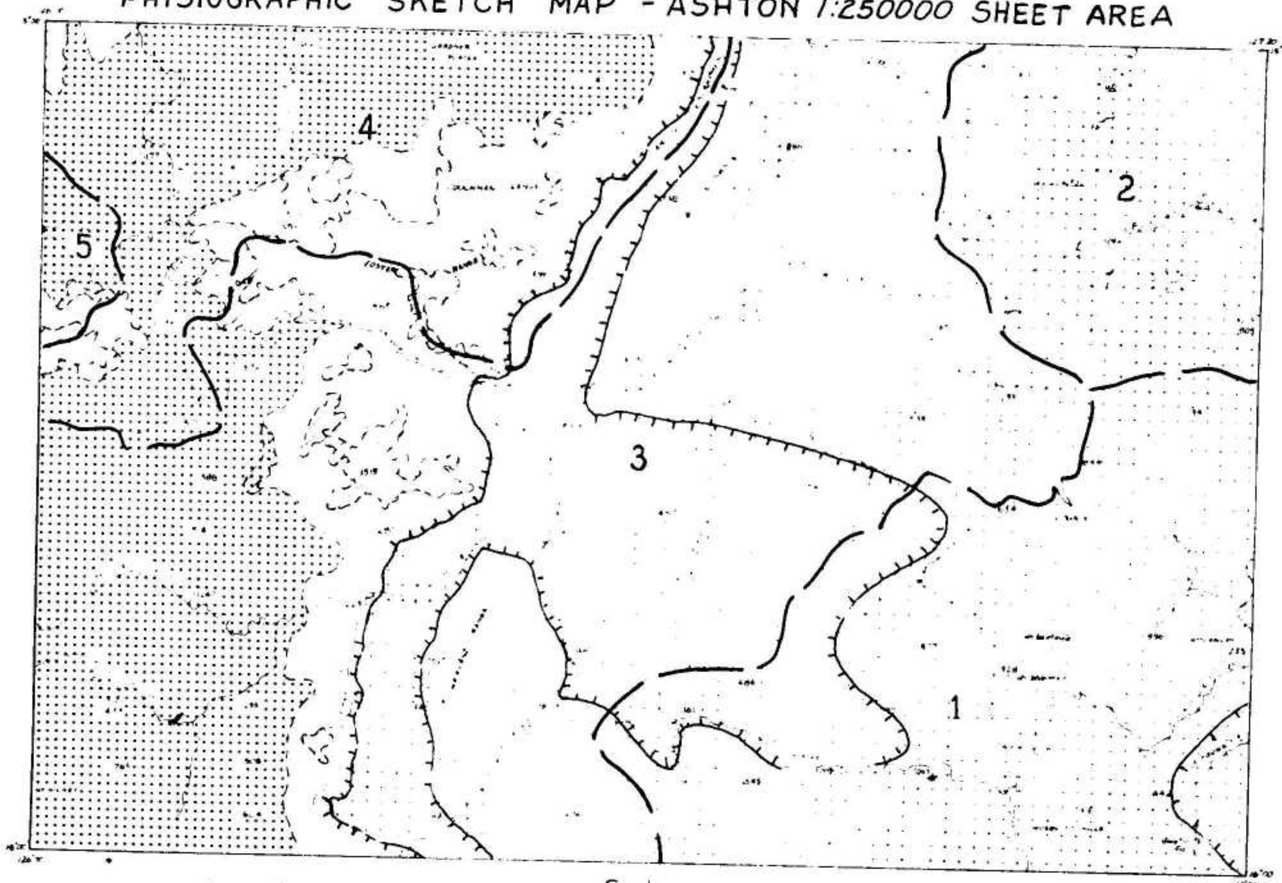
The Drysdale Basin contains the Drysdale, Gibb and Woodhouse Rivers, and Crossland, Damper and Banjo Creeks which drain almost two-thirds of the Sheet area. The streams contain almost two-thirds of the surface water available in the Sheet area, and most of them are superimposed. The course of the Woodhouse River is partly controlled by joints and gentle anticlinal folds in the sandstone bedrock. In the latter case the course of the stream follows anticlinal fold axes, along which tension fractures and valley forming dolerite occur. The Drysdale and Gibb Rivers flow for parts of their courses in small shallow gorges which cut escarpments of Warton Sandstone, Elgee Siltstone and Pentecost Sandstone. The Drysdale River is a radial consequent stream similar to the Charnley, Prince Regent and Roe Rivers which flow westwards radially from Mount Hann, which is situated in the adjoining Sheet area to the west, Prince Regent. In detail however the Drysdale River is subsequent for part of its length, and is controlled by beds of glauconitic sandstone and siltstone which also influence part of the course of the Durack River. Crossland Creek drains volcanics of relatively uniform weathering characteristics, and shows a dendritic drainage pattern which is incised into alluvial flood plains.

The King Edward Basin contains the King Edward, Morgan and Carson Rivers. The King Edward and Morgan Rivers are incised into the resistant King Leopold Sandstone, and their courses are controlled mainly by joints. The King Edward, like the Woodhouse River, appears to follow anticlinal crests for part of its course and the Carson River follows the subsequent valley developed at the contact between the Carson Volcanics and the more resistant Warton Sandstone.

The Mitchell Basin contains the Mitchell River, which rises on the Ashton Sheet area but which flows through the Prince Regent Sheet area to the west. For much of its course it flows along the contact between volcanics and King Leopold Sandstone.

Fig. 4

PHYSIOGRAPHIC SKETCH MAP - ASHTON 1:250000 SHEET AREA




Scale

0 10 20 Miles

Reference

Prince Regent Plateau

Gibb Hills

Karunjie Plateau

Laterite surface

Drainage divide

·893 Spot height (in feet)

Escarpment

1 Durack Basin
2 Forrest Basin
3 Drysdale Basin
4 King Edward Basin
5 Mitchell Basin

To accompany Record No 1966/81

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Fig. 4a

CONTOUR SKETCH MAP - ASHTON 1:250,000 SHEET AREA - INTERVAL 200'

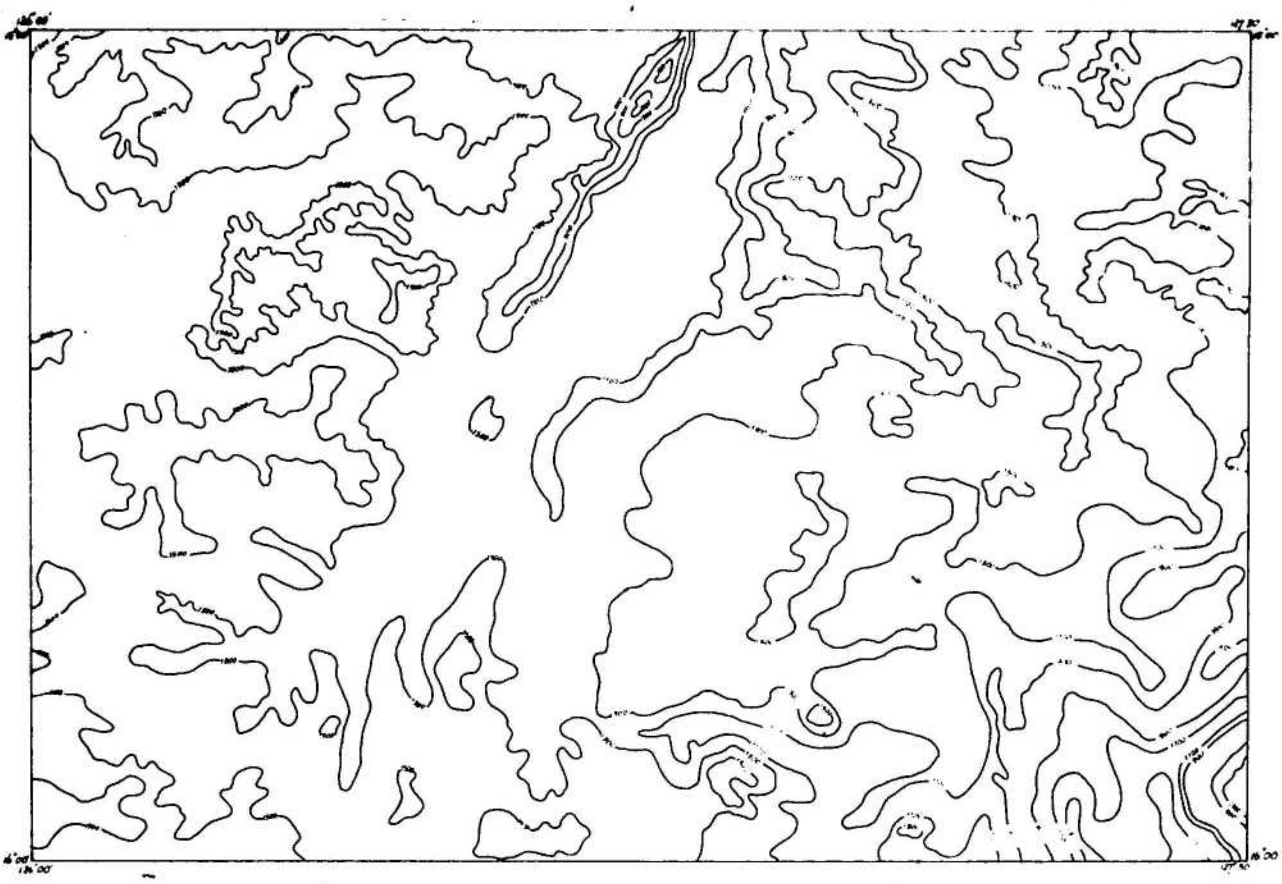

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Fig. 5. Typical jointed sandstone surface of Prince Regent Plateau in north-west of Sheet area.
Length of waterhole ca. 300 yards.

Physiographic divisions

The Ashton Sheet area lies in the North Kimberley Division of Jutson (op. cit.) and Wright (1964), who recognised the Kimberley Plateau Province as "constituting the core of the North Kimberley Division". The Plateau is a broad, uplifted and dissected peneplain formed mainly on flat-lying Kimberley Group rocks.

Plumb (in prep.) has divided the Kimberley Plateau Province into a number of subprovinces. These divisions do not include a laterite plateau which is present in the Ashton Sheet area, and which is considered also to be of subprovince status. The following subprovinces are recognised in the Sheet area:-

a. Prince Regent Plateau
b. Gibb Hills
c. Karunjie Plateau
d. Laterite Plateau

The Prince Regent Plateau occupies the western portion of the Sheet area and is underlain by uniform lithologies of the King Leopold Sandstone. It changes from a gently undulating surface in the north-west part of the subprovince (Fig. 5), to a more rugged and highly dissected surface in the south-west. The average elevation is 1400 feet, with peaks of 1800 feet in the south-west.

The Gibb Hills (Fig. 6) are formed on flat-lying or gently dipping Carson Volcanics. The surface is generally flat and soil covered, particularly south of Crossland Creek, but towards the north it is undulating and rugged. Due to variation in rates of weathering of the volcanic flows and the inter-bedded sandstone, mesas and terraces are common features. Parts of the area are as high as 1560 feet, but the average elevation is about 1100 feet above sea level. Much of the subprovince is covered by a large proportion of the Laterite Plateau.

The Karunjie Plateau occupies the central and eastern portions of the Sheet area, and is underlain by rocks of the Warton Sandstone, Elgee Siltstone and Pentecost Sandstone. The erosion and weathering of interbedded siltstone with resistant sandstone has produced a series of scattered mesas and broad soil-covered cuestas whose frontal escarpments are low and continuous (Fig. 7), throughout the subprovince. The average elevation is approximately 1200 feet. The western margin of this subprovince is the consistent scarp (part of which is known as the Carson Escarpment) formed at the base of the Warton Sandstone.

The Laterite Plateau (Fig. 6) is best developed as erosional remnants on volcanic rocks in the Couchman and Foster Ranges. It caps mesas and conforms approximately to the 1500 foot contour in the southern and central areas of the Sheet but occurs at progressively lower elevations towards the north. This plateau, now dissected, represents a tilted and uplifted ?Tertiary peneplain.

Discussion

The High Kimberley Surface described by Wright (op cit) may be represented on the Sheet area by the isolated plateaux higher than 1500 feet above sea-level. This surface is not as prominent on the Sheet area as in areas to the south e.g. Durack Ranges.

Reference to the contour map (Fig. 4a) shows that between 1500 feet and 1100 feet, and particularly between 1300 feet and 1100 feet there is an area whose outlines parallel the major drainage of the area. This is probably the Low Kimberley Surface which forms "dissected plains in the main headwater valleys of the eastern plateau region" (Wright, op cit).

The surface of the Laterite Plateau is higher than the postulated Low Kimberley Surface on the Sheet area (Fig. 6), but is lower than the ?High Kimberley Surface. The Laterite Surface and Low Kimberley Surface are, however, closely related, since both are best developed over areas of volcanic rock.

It is probable that all three Surfaces become inseparable and converge towards the north of the Kimberley Division because of a tilting northwards of the whole Kimberley Block.

Wright (op cit) has suggested that the High Kimberley Surface is a Jurassic land form, and is equivalent to the Ashburton Surface of Central Australia. The younger (lower) Low Kimberley Surface is probably the Australian Surface of King (1950), and is equivalent to the Tennant Creek Surface of Central Australia (Hays, pers. comm.).

## STRATIGRAPHY

The stratigraphy of the Ashton 1:250,000 Sheet area is summarised in Table 1. The nomenclature used will be defined in Plumb (op. cit), and current usage is derived from the redefinition of the work of Guppy et al (1958) and Harms (1959). In the Sheet area Harms, in particular, provided a framework of stratigraphic divisions which has been modified only slightly on the basis of the present work.

The rocks on the Sheet area are Proterozoic and are covered in places by Cainozoic soil and laterite. Two Groups are represented, the Kimberley Group and Bastion Group which form part of the Kimberley Basin succession and are Carpentarian; Hart Dolerite intrudes the Kimberley Group and is Adelaidean or Carpentarian.

The terms "Carpentarian" and "Adelaidean" are time-rock units which are favoured by the Bureau of Mineral Resources. They are sub-divisions of the Proterozoic which are based on sequences in the Carpentarian region of the Northern Territory and the Adelaide geosyncline of South Australia. On present geochronological evidence the base of the Adelaidean Period is at about 1400 million years, and that of the Carpentarian Period at about 1800 million years.

## PROTEROZOIC

### CARPENTARIAN

#### Kimberley Group

The Kimberley Group is 8000' thick, and is predominantly an arenite sequence, with subordinate lutite and basalt. The Group is overlain conformably by the Bastion Group. Within the Group the following formations are recognised and from top to bottom they are:

Pentecost Sandstone
Elgee Siltstone
Warton Sandstone
Carson Volcanics
King Leopold Sandstone

#### King Leopold Sandstone

The King Leopold Sandstone is the basal formation of the Kimberley Group, and is overlain conformably by the Carson Volcanics. On the Ashton Sheet area the King Leopold Sandstone is 2400 feet thick, and its base is not exposed. Elsewhere in the Kimberley region the King Leopold Sandstone is underlain by the Speewah Group.

Fig. 6. Gibb Hills: low rounded hills, capped with laterite (Laterite Surface) projecting from broad soil-covered plains (?Low Kimberley Surface).

Fig. 7. Soil-covered cuestas of Karunjie Plateau; Low scarp of Warton Sandstone in right centre, and scarp of Elgee Siltstone in background.

The King Leopold Sandstone crops out in a north-trending belt approximately 20 miles wide along the western margin of the Sheet area. In the north-west of the Sheet area this belt turns abruptly to the east and north-east and extends into the Drysdale Sheet area. The formation occupies approximately 1200 square miles, and gives rise to a rugged dissected plateau in the south-west with numerous joint-controlled gorges, and less rugged and undulating plateaux with scattered soil cover elsewhere.

The dominant lithology in this formation is quartz sandstone. It is commonly massive, thick-bedded and well-jointed, white to pale brown in colour, and in hand specimen appears poorly sorted, with grains ranging in size from 0.2mm to 1.5mm. Some pebbly bands occur throughout the sequence.

No detailed section has been measured, and the following composite section has been estimated from air photographs and field observations.

Locality: Along line of latitude 15°57'S, terminated by lines of longitude 126°00'E and 126°18'E.

| | Thickness (feet) | |
|---|---|---|
| | | Carson Volcanics |
| | 700 | Quartz sandstone, white to purple-brown, medium- to coarse-grained, silica-cemented, current-bedded, some ripple marks; minor granule sandstone and pebble conglomerate. |
| | | Dolerite sill |
| | 1150 | Quartz sandstone, white, pink and light buff, medium- to coarse-grained, massive, well-jointed, current-bedded; cliff-forming at base. |
| | 60 | Quartz sandstone, brown to buff, fine-grained, micaceous, flaggy and thin-bedded. |
| | 490 | Quartz sandstone, white to pink, medium-grained, well-sorted, massive to blocky, thin-bedded. |
| Total | 2400 | Base not exposed |

The fine-grained micaceous sandstone, cropping out only in the south-west corner of the Sheet area, may be a correlative of a flaggy siltstone unit recorded from the Lansdowne Sheet area (Gellatly, Derrick and Plumb, 1965). Current bedding of the trough type shows planar and concave lower bounding surfaces, and is common throughout the formation. The foreset units dip from 5° to 30° and their thickness ranges from 9 inches to 12 inches. Paleocurrent directions are predominantly from the north-north-west, though some local reversals occur in the south-west corner of the Sheet area (see Fig. 18). Ripple marks are not as widely distributed as the current beds. At a point 5 miles east of Mount Hickey abundant asymmetric and interference ripple marks have been observed, with amplitudes of up to 3 cm. Current bedding at this locality is uncommon.

In thin section most of the quartz sandstone shows grains with high (approximately 0.8 to 0.9) coefficients of rounding and sphericity, particularly in the coarser grades. The grains are sutured and embayed and are cemented by overgrowths of silica. Flakes of sericite and finely divided iron ore are present in the interstices. Composite grains of fine-grained sandstone and coarse-grained siltstone constitute up to 0.5% of the rock. Accessory minerals are microcline and plagioclase feldspar and the heavy minerals tourmaline, zircon and less commonly epidote and apatite. Tourmaline commonly shows euhedral overgrowths, some of which appear abraded.

Carson Volcanics:

The Carson Volcanics are overlain conformably by the Warton Sandstone and underlain conformably by the King Leopold Sandstone. The formation crops out mainly in a north-north-east trending belt which parallels the eastern margin of the King Leopold Sandstone. This belt is 4 to 5 miles wide in the north and south of the Sheet area, but in the Foster and Couchman Ranges it expands considerably, and is 20 miles wide in places. Small outcrops of volcanics occur in the north-west of the Sheet area, and these are parts of large expanses of outcrop on the Prince Regent, Drysdale and Montague Sound Sheet areas.

The Volcanics consist dominantly of fresh and altered basic lavas, with numerous arenite interbeds which appear to be laterally discontinuous. Fine-grained green-grey to buff siltstone occurs at the top of the formation, and underlies current-bedded feldspathic sandstone of the Warton Sandstone. The lavas are amygdaloidal and massive, the former type generally being more common lower in the sequence than the latter. Amygdaloidal varieties crop out poorly in valley floors, and form terraces or benches on hillslopes. The massive basalts are more resistant to erosion and form rounded hills with boulder-strewn scree slopes.

In general the basalts are fine- to medium grained, and grey-green to almost black in colour, the lighter colours indicating a higher degree of alteration of the basalt. Amygdales constitute up to 60% of the rock, and contain chlorite and calcite most commonly, and epidote, quartz and chalcopyrite to a lesser extent. They range in diameter from 0.1cm to 1.5cm., and though usually spherical are also oblate and dumb-bell shaped. In some of the basalt numerous veins and segregations are present and consist of quartz, feldspar and epidote; some contain crystalline galena and coatings of botryoidal prehnite.

The arenites are predominantly white, brown and pale purple feldspathic sandstone, with minor quartz sandstone and arkose. They are less massive than those of the King Leopold Sandstone and are commonly blocky to flaggy and thin-bedded. The more massive sandstone shows current bedding which indicates current directions from the north-west and north-east. (See Fig. 18).

A section of the Carson Volcanics measured by Gellatly in the Drysdale Sheet area (Gellatly, in prep.) is also representative of the sequence in the far north of the Ashton Sheet area. Total thickness of the formation estimated from air photographs and field observations is about 1800 feet. Fine-grained basic dykes and quartz veins crop out near the Foster Ranges, but they are uncommon.

Thin section examination shows the unaltered basalts to be tholeiitic. Even-grained varieties are common, with an average grain size of 0.5 mm.. Texture is subophitic and plagioclase laths range up to 1.5 mm in length. The composition of the plagioclase is approximately An35.

Pyroxene is present as augite and pigeonite and many of the anhedral to subhedral grains are partly replaced by chlorite and ?iron ore. Altered basalts are generally highly amygdaloidal and spilitic. The plagioclase crystals are intensely sericitised, and range in composition from An20 to An5. Chlorite, epidote and calcite are the dominant amygdale fillings. In fresh and altered basalt large grains (up to 1 mm.) of skeletal iron ore or ilmenite are common. The fine-grained porphyritic varieties of basalt contain devitrified volcanic glass in the interstices between phenocrysts.

Epidosite layers and segregations are common, and consist of aggregates of large euhedral to subhedral grains of epidote and quartz. Some of the latter show comb structure, and contain numerous apatite and bubble inclusions. Dispersed through the epidosite are numerous brown grains, some of which are subhedral and zoned with high birefringence and a faint orange-brown pleochroism, while others are ragged and show white in reflected light. The former may be allanite, possibly metamict, and the latter leucoxene.

Veins and segregations of quartz, feldspar and minor epidote are also widespread throughout the sequence. The quartz-feldspar intergrowths do not show the micropegmatitic texture typical of granitic segregations, but instead display an irregular radial structure in which elongate, tapered and fan-like blades of twinned and segmented plagioclase are arranged in groups or clusters. They are contained in large subhedral grains of strained quartz, with epidote occupying the interstices. The plagioclase is a sodic andesine, An32. Potash feldspar is massive and invariably clouded with a red-brown ?ferruginous clay mineral.

In hand-specimen some of the arenites are feldspathic. Arenites which were examined in thin-section, however, contained less than 5% feldspar. Sorting is average, and roundness and sphericity coefficients range from about 0.6 to 0.9. The grains are bonded by silica, and show a pronounced pattern of ?Bohm deformation lamellae. Potash feldspar is altered to clay and brown ferruginous material, and the few volcanic rock fragments present are similarly altered. Tourmaline, possibly of two generations, and zircon are the major heavy minerals. A quartz sandstone underlying a thick lateritic profile showed complete disruption of the original "sedimentary" texture by silicification (Fig. 11) which is probably related to movement and precipitation of silica downwards in the laterite profile.

<u>Warton Sandstone</u>

The Warton Sandstone lies conformably on the Carson Volcanics and is overlain conformably by the Elgee Siltstone. The formation crops out mainly in a north-north-east belt approximately 4 miles wide which runs north to south across the centre of the Sheet area. From near Crossland Creek this narrow belt enlarges considerably to the south-east, where the middle and upper units of the formation crop out in a semi-circular domal structure which occupies approximately 570 square miles. In the extreme south-east corner of the Sheet area the Warton Sandstone crops out in the core of another domal structure which is known locally as Menuairs Paddock.

The gently-dipping Warton Sandstone forms prominent cuestas. The continuous scarp which contains most of the lower and middle units of the formation is breached only by the Gibb and Drysdale Rivers and Crossland Creek. North of Crossland Creek the scarp is most prominent, and forms the Carson Escarpment which is 300 feet high. The upper units of the formation are characteristically soil-covered except where dips are greater than $5^{\circ}$.

The lower 200 feet of the sequence of the Carson Escarpment has been measured in detail, and the remainder has been compiled from air photographs and field observations.

A composite section of the Warton Sandstone is as follows:-

a. 5 miles south-east of Couchman Range, (Lat. 15°15'S long. 126°38'E).

b. 3 miles east of Drysdale Crossing, (Lat. 15°40'S long. 126°25'E)

| Thickness (feet) | Lithology |
|---|---|
| | Elgee Siltstone |
| b. 120 | Feldspathic sandstone, white, brown and grey-green, medium-grained, blocky to flaggy; some mud pellets and strongly developed current bedding |
| b. 940 | Quartz sandstone, white to buff, medium- to coarse-grained, thick- to thin-bedded, current bedded, overturned current bedding. |
| a. 110 | Feldspathic sandstone, white, buff and pale purple, medium- to coarse-grained, massive, current bedded. |
| a. 36 | Micaceous siltstone, red-brown to buff, fine-grained, poorly-bedded, with some slumping at base. Interbeds of pink to white feldspathic sandstone, well current-bedded; minor disconformities and overlap of sandstone and siltstone units. |
| a. 3 | Mud-pellet conglomerate, with matrix of medium- to coarse-grained micaceous siltstone. |
| a. 4 | Feldspathic sandstone, white to buff, fine- to medium-grained, massive, current-bedded; some overturning of current beds. Forms small scarp. |
| a. 50 | Feldspathic sandstone, white to pale purple, fine- to coarse-grained, flaggy to blocky, thin-bedded, some current-bedding. |
| a. 10 | Feldspathic micaceous sandstone, grey, fine- to medium-grained, blocky and thin-bedded. Interbeds of coarse- to medium-grained flaggy siltstone. |
| | ========================== |
| | Carson Volcanics |

Quartz sandstone constitutes approximately three-quarters of the total thickness. Feldspathic sandstone is common in the basal and upper portions of the sequence, and siltstone occurs interbedded with the feldspathic sandstone near the base of the formation.

Current-bedding is ubiquitous, and is most prominent in the massive thick-bedded quartz sandstone. Overturned and ?slumped current-beds have been recorded throughout the formation (see Fig. 18), but these structures are not common. Ripple marks also are uncommon, and are generally confined to the thin-bedded and fine-grained sediments.

The upper and lower boundaries of the Warton Sandstone crop out poorly on the Ashton Sheet area. Where outcrop is present the upper boundary is defined by the appearance of red-brown mudstone and siltstone of the Elgee Siltstone interbedded with feldspathic sandstone. Where outcrop is absent the upper boundary is best defined by a marked change in soil colour from pale yellow to red-brown. The lower boundary of the formation is well defined topographically and is readily photointerpreted. It occurs at the base of a prominent sandstone scarp and separates current bedded feldspathic sandstone from flaggy buff and green-grey fine-grained siltstone. The latter is considered a part of the Carson Volcanics. The former is overlain by pale purple coarse- to medium-grained siltstone, and is considered a part of the Warton Sandstone.

In thin section the quartz sandstone of the formation is medium- to coarse-grained and moderately well sorted. The quartz grains are well-rounded to sub-rounded, and show optically continuous silica overgrowths. Turbid feldspar, sericite, tourmaline and zircon are the major accessory minerals. Feldspathic sandstone which forms the basal portion of the formation is fine- to coarse-grained, with microcline constituting from 5% to 10% of the rock. Muscovite and biotite are present, the latter showing pleochroism from apple-green to colourless. This indicates a biotite with a relatively high $Fe_2O_3$ and a low $TiO_2$ content. Along the cleavage planes of some flakes ?hematite specks are abundant. The cementing medium of the feldspathic sandstone appears to be an aggregate of sericite and limonitic iron ore. Epidote, tourmaline, zircon and rare monazite and apatite are the major heavy minerals.

## Elgee Siltstone

The Elgee Siltstone conformably overlies the Warton Sandstone and is conformably overlain by the Pentecost Sandstone. The formation crops out in the north, central, south and south-eastern parts of the Sheet area as a narrow sinuous belt.

Generally up to two-thirds of the total thickness of the formation crops out in scarp which is capped by Pentecost Sandstone. The remainder of the formation is valley-forming, and is mostly concealed by red-brown soils. The best exposures are found in scoured creek beds. The escarpment attains a maximum height of approximately 350 feet in Menuairs Paddock, and a minimum height of a few feet at one or two localities in the central part of the Sheet area.

The following section has been measured with Abney level near the point with co-ordinates Lat. 15°53'S long. 127°26'E. :-

| Thickness (feet) | Lithology |
|---|---|
| | Pentecost Sandstone |
| 25 | Quartz sandstone, white, fine- to medium-grained, massive and cross-bedded; interbeds of siltstone and red-brown mudstone; Mud pellets common. |
| 21 | Siltstone and mudstone, red-brown, laminated, with a 2' interbed of quartz sandstone, white, fine-grained, blocky to massive, cross-bedded. |
| 14 | Sandstone, red-brown and fine-grained, massive and thick-bedded at base, flaggy near top; some mud pellets, and thin interbeds of mudstone. |
| 6 | Interbedded siltstone and mudstone, red-brown, laminated. |
| 10 | Sandstone, brick red to brown, fine-grained, massive to blocky, small-scale cross-bedding, some scour-and-fill structures. |
| 32 | Siltstone, red-brown to white, calcareous, laminated to fissile, with mud-pellets and scour structures, interbedded with green-grey to red-brown mudstone. |

| | |
|---|---|
| 24 | Mudstone, red-brown, poorly bedded. |
| 5 | Siltstone, laminated, cross-bedded, with mud pellets. Forms prominent ledge. |
| 23 | Mudstone, red-brown and green-grey, with thin red-brown laminated siltstone near top. |
| 4 | Siltstone, blocky to flaggy, laminated, with thin (1"-2") layers rich in small mud pellets. Forms prominent ledge. |
| 89 | Mudstone, red-brown and grey, poorly bedded and conchoidally fracturing; small circular green-grey spots common. Thin interbeds of siltstone, pink, buff and red-brown, fine- to coarse-grained, blocky to flaggy, laminated, poorly micaceous, small scale cross-bedding, some slumping. |
| 1 | Subgreywacke, quartzose, grey, coarse-grained, with abundant mud pellets and siltstone fragments; calcareous, with micaceous matrix. |
| 70 | Sandstone, pink to brown, fine-grained, micaceous, thick-bedded to laminated, massive to blocky; interbeds of flaggy fine-grained sandstone and red-brown mudstone. |
| Total 396 | |

Warton Sandstone

A highly distinctive feature of the siltstone and mudstone in the formation is the red-brown coloration imparted to the rocks by the large amounts of ferric oxide present.

The upper and lower boundaries of the Elgee Siltstone are well defined. The lower boundary is marked by the first appearance of siltstone and mudstone, while the upper boundary is marked by the abrupt disappearance of these lithologies. The quartz sandstone in that part of the sequence above the thickest and most prominent dark-coloured ledge (see Fig. 1) is white, medium-grained, well sorted and strongly current-bedded, and in these respects is identical with the basal lithology of the overlying Pentecost Sandstone. However, since red-brown siltstone is interbedded with the quartz sandstone, the latter has been included in the Elgee Siltstone.

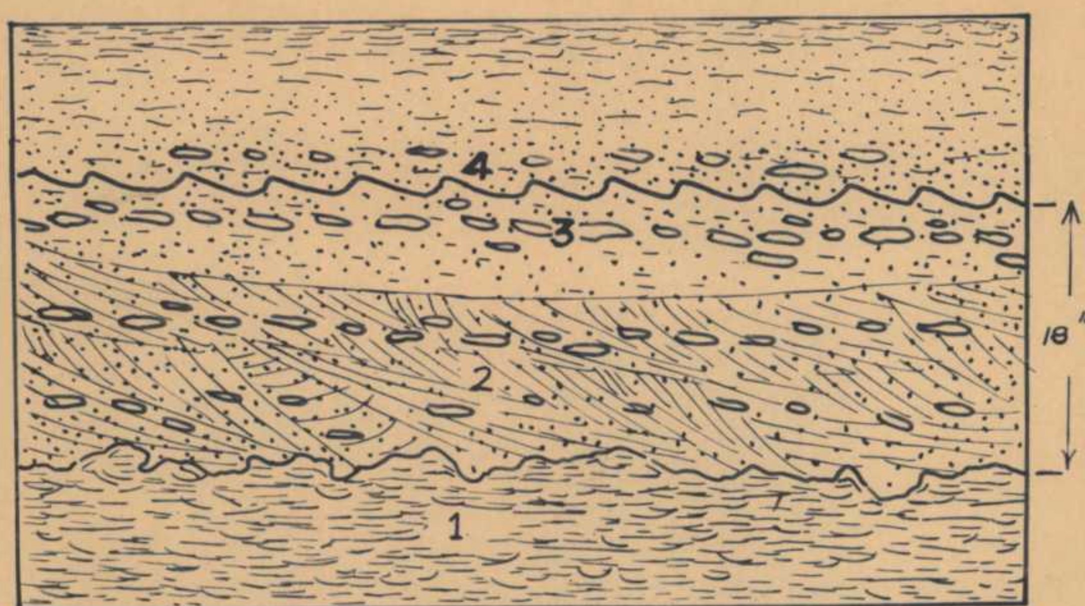
Also apparent from Fig. 1 is the relative increase in the proportion of sandstone and siltstone to mudstone upwards in the section, where the more resistant siltstone and fine-grained sandstone form small but prominent benches.

Much of the siltstone and mudstone in the lower one-third of the sequence contains sporadic sub-spherical patches which are grey-green in colour. These patches have been recorded from the Lansdowne Sheet area (Gellatly et al, op. cit) and may have been derived from the chemical reduction of ferric oxide by organic matter.

Sedimentary structures in the formation include asymmetric, symmetric and interference ripple marks, small-scale current bedding and slumps, and rare mud cracks.

Fig. 8. Poorly bedded mudstone overlain by current bedded fine-grained sandstone with an upper ripple-marked surface.

Fig. 9




TYPICAL RHYTHMIC SEQUENCE IN ELGEE SILTSTONE

1. poorly bedded red-brown mudstone
2. finely current-bedded f.g. sandstone, with few clay pellets.
3. intraformational band rich in clay pellets, overlain by asymmetric ripples
4. f.g. sandstone with some clay pellets, grading into poorly bedded mudstone

clay pellets

current bedding

To accompany Record No 1966/81

D52/A13/6

Interbedded siltstone, sandstone and mudstone form a rhythmic sequence which occurs sporadically throughout the formation. This sequence is shown in Fig 9. and photographed in Fig. 8. At the base of this rhythmic sequence is mudstone which shows a scoured and irregular upper boundary. This is overlain by thin-bedded current-bedded fine-grained sandstone which contains some mud pellets. The scoop-shaped current beds are small-scale structures. The current beds become less prominent near the top of this sandstone bed, and a narrow intraformational band rich in mud pellets is characteristically developed immediately below a ripple- marked upper surface. The ripple marks are of the asymmetric and interference type, and they are overlain by a mud pellet-bearing silty sandstone which grades rapidly upwards into poorly-bedded mudstone.

In thin section most of the siltstone and fine-grained sandstone are calcareous and contain up to 25% calcite and dolomite. In general the rocks are well sorted, and contain sub-angular to sub-rounded grains of quartz and feldspar. Sodic and potassic varieties of feldspar constitute up to 5% of the rock. Muscovite, sericite and limonitic iron ore are present in the matrix and heavy minerals such as tourmaline, zircon and epidote are commonly concentrated in narrow bands. The carbonate in the fine-grained sandstone occurs as

a. small-scale concretions

b. interstitial cement

c. fine-grained mud pellets

The small-scale concretions are up to 6mm. diameter and the carbonate mosaic consists of clear calcite and dolomite. The latter is present as small euhedral rhombs, and the former as massive clear grains slightly larger than the quartz grains which they enclose. Rare lustre mottling is present.

The calcitic and dolomitic interstitial cement is similar in form and grain size to carbonate in the concretions. The mud pellets consist entirely of a turbid mosaic of carbonate too fine-grained to positively identify optically as either calcite or dolomite. Some of the mud pellets are over 1 cm. in length.

Quartz sandstone near the top of the formation is well sorted and fine- to medium-grained, with grain sizes ranging from 0.1 to 0.3 mm.. Suturing of the grain margins and abundant silica overgrowths obscures the original roundness and sphericity of the grains. Feldspar constitutes about 1% of the rock and tourmaline and zircon, the most abundant heavy minerals, form 0.02% of the rock. A subgreywacke from near the base of the formation contains well-rounded coarse-grained to granule size quartz grains (70% to 80%), siltstone and mudstone fragments (20%), calcite, sericite and silica overgrowths (5% to 10%), and zircon as an accessory mineral.

## Pentecost Sandstone (general)

The Pentecost Sandstone conformably overlies the Elgee Siltstone and is overlain conformably by the Mendena Formation. It crops out strongly in the eastern part of and occupies more than one-third of the Sheet area. The most common physiographic expressions of the formation are prominent and continuous cuestas and small terraces.

The Pentecost Sandstone has been informally subdivided on lithology into a lower, middle and upper unit. These subdivisions have also assisted in the delineation of regional structures. In this area total thickness of the Pentecost Sandstone is approximately 3450 feet.

The upper boundary of the lower Pentecost Sandstone occurs at the foot of a dip slope which forms part of a heavily wooded cuesta. This cuesta is readily identifiable because it is overlain by a sequence of siltstone and glauconitic sandstone, which shows a distinctive soft-toned dark grey photo-pattern.

The following section is a composite one, compiled from field observations in the vicinity of the following localities:-

a. Lat. 15°27'S Long. 126°55'E
b. Lat. 15°58'S Long. 127°27'E

| Thickness (feet) | Lithology |
|---|---|
| | middle Pentecost Sandstone |
| a, b 40 | Quartz and feldspathic sandstone, grey-white, fine-grained, massive to blocky, thick-bedded, current-bedded. |
| b. 400 | Quartz sandstone, pale purple to white, medium-grained, thick-bedded to laminated, massive; well current-bedded, poorly sorted, red-brown mud pellets common. |
| a. 10 | Quartz sandstone, fine-grained, flaggy and thin-bedded, minor micaceous siltstone. |
| a, b 220 | Quartz sandstone, white to pale purple, medium- to coarse-grained, blocky; mud pellets common; current-bedded, with some overturning of current beds; thin micaceous laminae interbedded with sandstone. |
| b. 50 | Quartz sandstone, white to buff and pale purple, medium-grained, thick-bedded, blocky to massive; current-bedded, with some overturning of current beds. |
| Total 720 | Elgee Siltstone |

Minor interbeds of siltstone and varying degrees of cementation of the quartz sandstone have partly contributed to the development of well-formed cuestas observed in this sequence.

Large-scale current bedding is well developed, and overturning of current beds is common. Measurements of current bedding indicate a current direction predominantly from the north-west, (Appendix 1).

Thin section examination shows the quartz sandstone to be moderately sorted. Some specimens are poorly sorted, with quartz grains ranging in size from 0.03mm. diameter (coarse-grained silt) to 2mm. (granule), though the average grain size diameter throughout the sequence is 0.04 mm.. In general, interstitial material such as sericite and iron oxide is rare, and siliceous overgrowths are the dominant cementing media. Some of the quartz grains contain abundant apatite and ?monazite inclusions. Some rounded fragments of fine-grained siltstone are present, and well-rounded grains of tourmaline, minor zircon, epidote and apatite constitute the heavy mineral suite.

The middle unit of the Pentecost Sandstone is composed of quartz sandstone, minor feldspathic sandstone and, near the base, glauconitic sandstone and siltstone. The lower boundary of the unit is taken at the base of the glauconitic sandstone and siltstone, whose soft-toned dark-grey photo pattern contrasts with that of the underlying quartz sandstone. The upper boundary is taken to be at the base of a well-jointed coarse-grained quartz sandstone which generally caps a small scarp of medium-grained sandstone of the middle division.

The quartz sandstone gives rise to a characteristic irregularly striped photo-pattern, which reflects the alternation of beds of resistant sandstone with beds of partly sand-covered friable sandstone.

The following composite section, the lower 200 feet of which is measured, has been compiled from field observations in the vicinity of the point Lat. 15°59'S Long. 127°27'E.

| Thickness (feet) | Lithology |
|---|---|
| | Upper Pentecost Sandstone |
| 1040 | Quartz sandstone, white, off-white, buff and grey, fine- to coarse-grained, massive to flaggy, thick- to thin-bedded, sometimes friable; minor feldspathic sandstone. |
| 30 | Quartz sandstone, white, medium-grained, well-sorted, massive to blocky, thick- to thin-bedded, current-bedded. |
| 60 | Feldspathic sandstone, pale purple-brown to white, massive, laminated, well current-bedded; interbedded with micaceous siltstone, rich in mud pellets, and poorly-bedded purple-grey mudstone. |
| 70 | Feldspathic and quartz sandstone, pale purple to orange-brown, fine-grained, thick bedded to laminated, blocky. |
| 15 | Glauconitic quartz sandstone, purple-grey, medium-grained, flaggy to blocky, laminated, strongly current-bedded; mud pellets common, some current beds highly slumped. |
| 28 | Feldspathic sandstone, grey, white and orange-brown, fine- to medium-grained, flaggy to blocky, thin-bedded to laminated, small-scale current bedding. |
| 4 | Glauconitic quartz sandstone, micaceous, deep purple-brown, fine-grained, laminated to thick-bedded, blocky, small-scale current bedding. |
| 6 | Siltstone, siliceous and micaceous, medium-grained, grey, fissile, slumped in parts; malachite on bedding planes; interbedded with flaggy laminated siltstone with alternate pink and green laminations. |
| 20 | Feldspathic sandstone, purple, fine- to medium-grained, flaggy to blocky, ferruginous. |
| Total 1273 | |
| | Lower Pentecost Sandstone |

In thin section, quartz sandstone is well to moderately sorted, and generally medium-grained, though both fine- and coarse-grained varieties are present. Silica overgrowths on quartz grains are common, and sericite and fine-grained ferruginous material occur between the grain boundaries. Feldspar is present, but amounts to only 1% or 2% of the rock; rock fragments, predominantly ferruginous chert and siltstone, are common. Some quartz grains contain inclusions of sagenitic rutile and apatite, and most grains contain bubble trails. Tourmaline, zircon and rare epidote is evident, and in one case tourmaline constituted nearly 1% of the rock. Zircon grains are subhedral to euhedral and a large proportion show birefringence which may be as low as .012 in longitudinal section. This suggests that the zircon is metamict.

The micaceous siltstone contains subangular to sub-rounded quartz grains of approximately 0.05mm diameter, and up to 5% feldspar. Muscovite and green biotite are common, and sericite and chlorite occur interstitially. Tourmaline, zircon and epidote are the major heavy minerals, but epidote is by far the most abundant. Malachite appears as opaque discontinuous apple-green laminae up to 0.5 cm. in length which are conformable with adjacent bedding planes.

Glauconite is present in ferruginous quartz sandstone as small pellets which are spherical to oblate. They are commonly altered to a fine-grained aggregate of sericite, ?chlorite and clay minerals. Between 3% and 5% of the altered glauconite pellets contain subhedral to anhedral grains of apatite, which in some cases constitutes up to 90% of a single pellet. The apatite-bearing pellets and the altered glauconitic pellets appear genetically related, and the apatite is probably a recrystallised precipitate from marine waters and not pegmatitic or other igneous detritus.

Little is known of the upper Pentecost Sandstone in the Sheet area because of poor outcrop. Only the basal beds have been examined, and these are generally scarp-forming, though the scarp is not a prominent one.

The most common lithology is coarse-grained quartz sandstone. The basal unit of the upper Pentecost Sandstone is a white granule sandstone, poorly sorted and generally strongly jointed, with a distinctive photo-pattern. This unit contrasts strongly with the medium-grained quartz sandstone of the lower Pentecost Sandstone. The boundary between the upper Pentecost Sandstone and the overlying Mendena Formation is obscured by soil in the north-east of the Sheet area and an accurate estimate of thickness is not possible. An approximate estimate of thickness is 800 feet.

## Bastion Group

### Mendena Formation

The Bastion Group lies conformably on the Kimberley Group, and in the Ashton Sheet area is represented by only a small portion of the basal unit, the Mendena Formation.

This formation crops out in the north-east part of the Sheet area as small low mesas rising from featureless soil-covered plains. The mesas are capped with sandstone, though the formation contains abundant siltstone and mudstone.

A section of the formation was measured with Abney level at the following locality:- Lat. 15°17'S, Long. 126°12'E

| Thickness (feet) | Lithology |
|---|---|
| | Top eroded |
| 8 | Quartz sandstone, with alternations of feldspathic sandstone; white to grey, medium- to fine-grained, blocky, current bedded. |
| 15 | Mudstone conglomerate, highly kaolinitic, with interbeds of fine-grained quartz sandstone. |
| 30 | Siltstone, medium- to fine-grained, purple, flaggy, thin-bedded to laminated. |
| 40 ca. | soil cover |
| 20 | Quartz sandstone, white, fine-grained, massive, well-sorted, some ripple marks and current bedding. |
| ? | soil cover<br>base not exposed |
| Total 115 ca. | |

Pentecost Sandstone

The fine-grained quartz sandstone near the base is similar to much of the sandstone within the upper Pentecost Sandstone, but besides some current bedding contains abundant ripple marks, most of which appear symmetrical. The sandstone crops out as small "windows" in the soil plains of this particular area, and inclusion in the Mendena Formation must be regarded as tentative.

A distinctive feature of the Formation is the comglomerate which constitutes much of the mesas. The conglomerate contains many rock fragments of large pebble and small cobble size embedded in a massive white kaolinitic matrix. The fragments are mainly orange-brown to buff mudstone and siltstone, and resemble the flaggy and laminated siltstone etc. which underlies the conglomerate. It is likely the conglomerate is intraformational. The interbeds within the conglomerate are of fine-grained and laminated quartz sandstone, and form irregular lenses in the sequence.

In thin section, the quartz sandstone is relatively well-sorted, with an average grain size of 0.2 mm.. Embayed grain margins and silica overgrowths are common features, and rare grains of siltstone are present. Feldspar is rare, but is evident in some of the hand-specimens.

The siltstone is fine-grained, with an average quartz grain size of 0.01mm.. Muscovite and finely divided sericite are common, and kaolinite forms the bulk of the matrix. The conglomerate contains rock fragments which are mainly highly sericitic mudstone and siltstone. Iron ore, commonly with rims of orange-brown chlorite, is a common accessory, but the most striking feature is the abundance in the heavy mineral suite of epidote, which is at least twice as prevalent as tourmaline and zircon, the other heavy minerals present in significant amounts.

## ADELAIDEAN OR CARPENTARIAN

### Hart Dolerite

The Hart Dolerite crops out in the western part of the Sheet area, and intrudes only the King Leopold Sandstone. This is in marked contrast to other Sheet areas to the south (e.g. Lansdowne) where the Hart Dolerite intrudes every formation of the Kimberley Group except the Warton Sandstone. The dolerite occurs in steep-sided depressions and irregular valleys in the sandstone, and exposures are generally not good. The floors of the depressions and valleys contain much sand and soil, resting in which are boulders of dolerite, while small pavements of dolerite are exposed in the creeks. Larger depressions (up to three miles across) contain small boulder-strewn hills near their centres.

The Hart Dolerite is exposed mainly in the cores of gentle cross-folds and domal structures, and this structural control is responsible for the isolated nature of the outcrops and for their generally sub-circular to oblate shape. Near Lat. 15°50'S, Long. 126°07'E a dolerite sill contains a small roof pendant of King Leopold Sandstone. This roof pendant is flat-lying and unmetamorphosed, and represents an erosional remnant of the sandstone stratum which lies immediately above the dolerite sill. The dolerite at this point is 220 feet thick.

The dolerite is generally dark green-grey to black in hand-specimen, and displays a typical ophitic to sub-ophitic texture. It is massive and medium- to coarse-grained. Only one specimen was examined in thin section, and this was coarse and relatively even-grained (average grain size 1.5 mm.) with plagioclase and clinopyroxene the dominant minerals. Plagioclase is unaltered except along micro-fractures, where small epidote grains are present. The plagioclase is a labradorite, An54 (using the normal to "a" method), and is subophitically intergrown with clinopyroxene.

The clinopyroxene is augite, with an estimated 2V = 60°. Some of the grains are marginally altered to ragged green grains of amphibole, or are recrystallised along their edges to a granular aggregate of finer-grained augite.

Interstices of the rock contain dull orange-fawn to grey zeolite. Long narrow microlites up to 5mm. in length are common, but the average length is from 0.01mm to 0.1mm.. The zeolite is fibrous, and the fibres show both positive and negative elongation. The birefringence is low, between .006 and .010, and the mineral is optically negative with a moderate axial angle. Extinction is subparallel, but is generally wavy and undulose. These data indicate the zeolite to be <u>stilbite</u>. It is associated with apple-green chlorite, and quartz, and a zonal arrangement of these minerals is present. The free quartz present is typical of other saturated tholeiitic dolerites, though zeolite variety stilbite has not been recorded from the extensive sills of dolerite in the Lansdowne Sheet area (Gellatly et al, op. cit.).

## CAINOZOIC

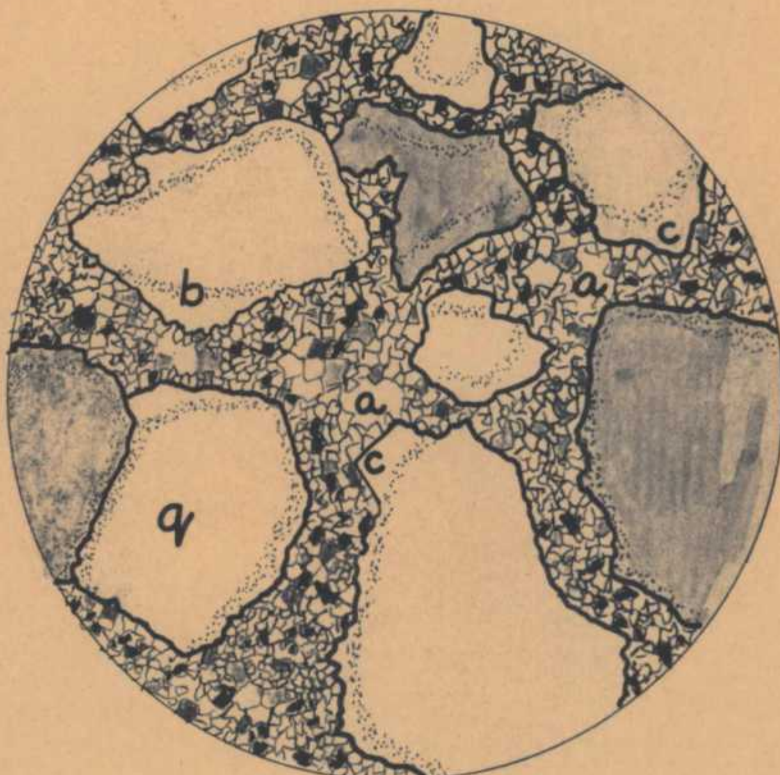
### TERTIARY

#### Laterite (undifferentiated), aluminous laterite and bauxite.

In the central western and north-western parts of the Sheet area remnants of a laterite profile of ?Tertiary age, crop out in the upper parts of prominent mesas which range in area from one-tenth to twenty square miles. Over 90% of the laterite area overlies the Carson Volcanics, while the remainder overlies the King Leopold Sandstone (see fig. 10) with a disconformity or slight angular unconformity.

Fig. 10. Aerial photograph of laterite overlying volcanics (grey) and quartz sandstone (white).

Fig. 11




RESILICIFICATION OF QUARTZ SANDSTONE UNDERLYING A LATERITE PROFILE

q - original detrital quartz grain

b - inclusions between detrital grain and silica overgrowth

c - remnants of clear silica overgrowths

a - fine-grained mosaic of quartz recrystallising and replacing overgrowths, and disrupting original sedimentary texture.

Crossed nicols, x48

The laterite is ferruginous, and it is this variety to which the field term "laterite" is applied. With decreasing iron content of the laterite the term "aluminous laterite" becomes applicable, and when iron is rare or absent the term "bauxite" is used. This field classification is based on colour, the laterite being red-brown, and aluminous laterite pale pink to brown, and the bauxite creamy-pink to off-white. The divisions between these varieties are arbitrary.

Thickness of the laterite profiles throughout the Sheet area ranges from 20 feet to 100 feet. The average thickness is about 50 feet, but lower boundaries of the laterite profile are difficult to locate because of scree deposits.

Textures of the laterites vary considerably. A pisolite zone is present, but in many profiles is thin or absent. The underlying cellular and nodular zones are massive and well-developed, though the mottled and pallid zones are rarely exposed. Earthy ferruginous laterite is quite common. Deposits of ferruginous laterite are present in many of the valleys adjacent to the laterite mesas, and many of these are pisolitic and aluminous. Many of the pisolites in these ferricretes in the valleys have probably been transported from the pisolitic zone at the tops of many of the profiles.

Below the mottled and pallid zones of the laterite profile, altered basalt grades downwards to fresh basalt. In rocks too highly altered to be positively identified as basalt, relict pipe amygdales of chalcedonic silica are convincing evidence of the volcanic nature of the original rock. Sandstone which occurs beneath a laterite profile is commonly highly silicified (see Fig. 11). In two cases sandstone was dipping steeply, up to 50°, in an area where dips were of the order of 5°, and this local deformation may have been instrumental in the development of profiles up to 70 feet thick over sandstone.

Bauxite and aluminous laterite crop out in the far north-west corner of the Sheet area, and in isolated patches within the laterites of the Couchman Range. Some of the bauxite from the latter area is pisolitic. The bauxite deposits of the north-west corner are mainly massive and fragmental, though some areas are covered by up to 18 inches of pisolitic soil. In hand specimen the massive and fragmental bauxite contains angular pieces of aluminous material, aluminous pisolites and other pebbly material, set in a fine-grained aluminous matrix. The rock is commonly well-cemented, and fractures across the pisolites or other fragments. Thickness of the bauxite ranges up to 11 feet in the Montague Sound Sheet area but there six to seven feet is an average thickness.

In some profiles angular blocks of sandstone are embedded in cellular laterite approximately 20 feet from the top of the profile. The significance of the presence of these blocks and their position is not definitely known. It is possible that they represent debris contained in fossil ferruginous soils, which have since been lateritized. Further addition of soil etc. to the profile by transportation and subsequent lateritization could account for the position of the blocks. Many of the laterite mesas are covered by a ferricrete, in which pebble and cobble size detritus is common. These ferricretes are a result of cementation of transported debris.

Such movement of lateritic material could account for the presence of some of the laterite overlying silica-cemented quartz sandstone of the King Leopold Sandstone which by itself cannot provide sufficient iron etc. for the development in situ of laterite profiles up to 70 feet thick. It is significant also that the laterite which is found overlying the King Leopold Sandstone occurs immediately to the north and north-west of large expanses of laterite which overly volcanic rock. Since the regional dip of the laterite surface is to the north, the stream flow and accompanying movement of material on this surface would be to the north also.

In thin section the minerals of the laterite and bauxite are not identifiable. Some cryptocrystalline quartz or chert is present, and in pisolitic varieties many aluminous pisolites contain a nucleus of ferruginous material, indicating replacement of the latter by the aluminous material.

Rock analyses and results of mineral identification are presented in Appendices 2, 3 and 5.

## UNDIFFERENTIATED

### Ferruginous lateritic soil

These soils are skeletal, and are most commonly found resting over volcanic rocks, where for the most part they are closely related to the outcrops of laterite, and over ferruginous siltstone and sandstone. Small ferruginous pisolites, oolites and numerous quartz sand grains are generally intimately mixed with fine red-brown clay and soil.

### Black soil

Black soils are developed mainly as residual deposits on rocks of the Carson Volcanics, Warton Sandstone, and, to a lesser extent, on the Hart Dolerite. In the volcanics black soil occurs as small incursions in sandy red loams, and along swamps and marshes. In the Warton Sandstone many "clay pans" are composed predominantly of grey and black soils of heavy texture. Black soil developed on the Hart Dolerite is not extensive because of the generally small size of the outcrops and the dilution of any black soil present with sand and sandy soil from adjacent sandstone areas.

The black soils are heavily grassed, and commonly display deep pot-holes and a very irregular surface. Desiccation cracks are common in the dry season, and such cracking allows considerable recharge of subsurface water supplies during the wet season.

### Soil, sandy soil, eluvium

Grey, brown, red and yellow soils and sandy laoms are the most common surficial deposits on the Sheet area. All formations are susceptible to soil development where dips are low, but the Carson Volcanics, Warton Sandstone and Mendena Formation are particularly well-covered by soil and sand. The yellow soils and sands are more common over sandstone, and red-brown and yellow-grey soils more common over volcanics. The sandy loams developed over sandstone are commonly coarser grained than those developed over volcanics.

Eluvium is common on scree slopes adjacent to scarps of laterite, shale and sandstone.

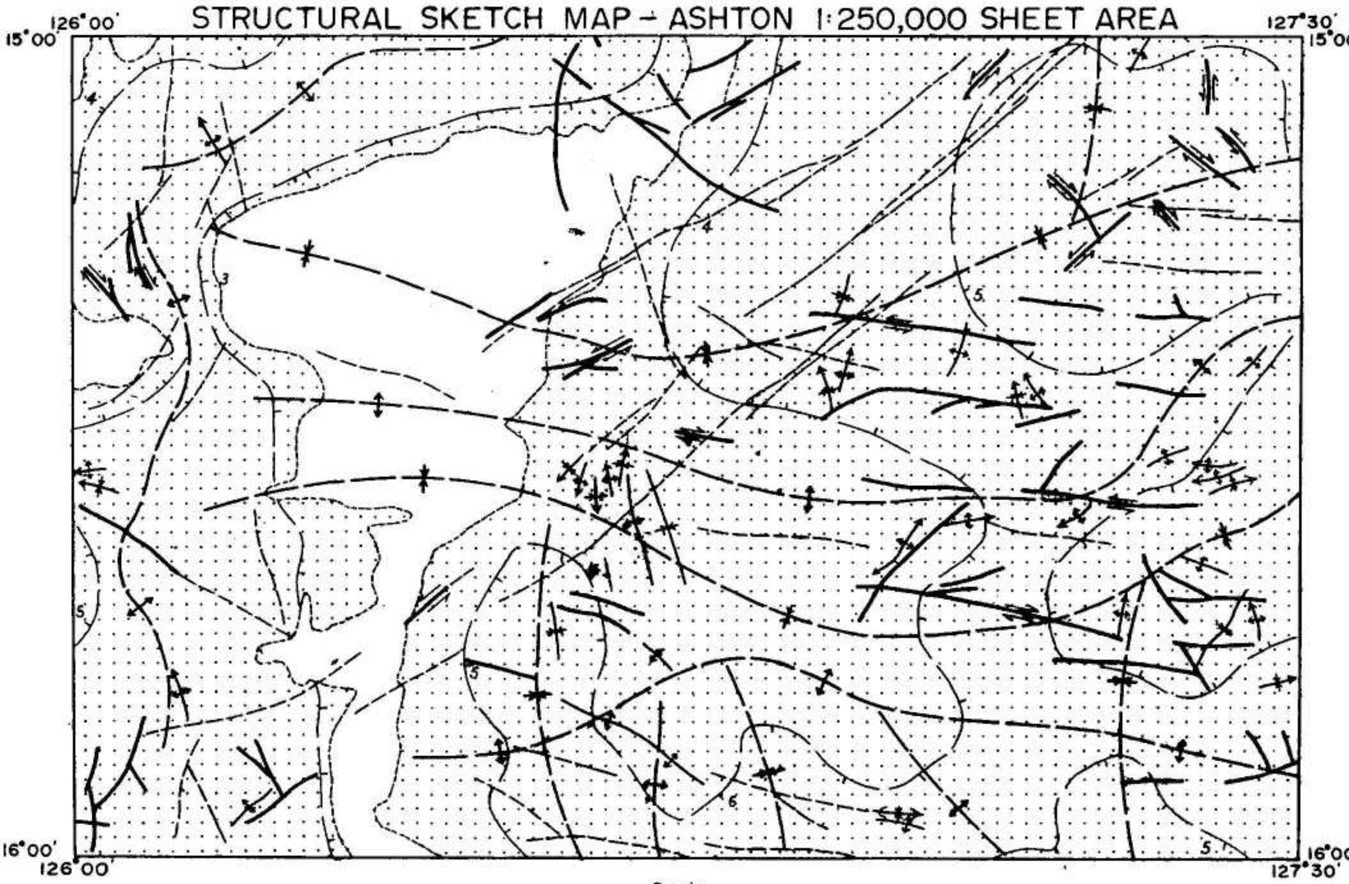
## QUATERNARY

### Alluvium

The alluvium in the Sheet area is confined to rivers and creeks, and consists of levee soils and grey-brown loams and sands, fine to coarse gravels and rare boulder deposits. Crossland Creek is incised into a flood plain of alluvial material, and many of the larger rivers are lined with prominent levees up to 10 feet high.

Fig. 12

# STRUCTURAL SKETCH MAP – ASHTON 1:250,000 SHEET AREA




Scale

0 10 20 Miles

Reference

PROTEROZOIC
- Kimberley Group Sediments
- Kimberley Group Volcanics

} KIMBERLEY BLOCK

Fault showing relative horizontal movement

Major lineaments

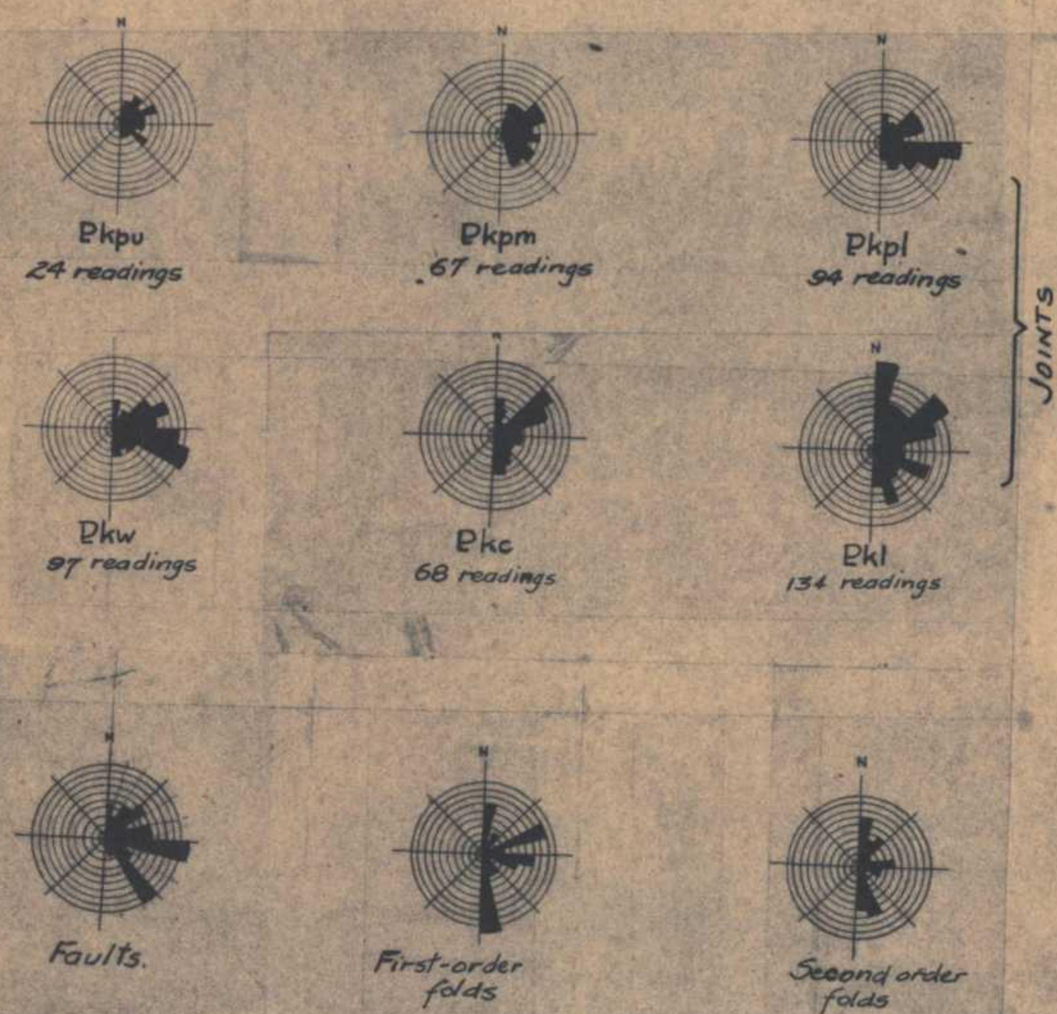
Anticline
Syncline
} First order (regional) fold axes.

Anticline
Syncline
} Second order (minor) fold axes, showing direction of plunge

5 Trend and dip of bedding

*To accompany Record No 1966/81* D52/A13/7 JLM

Fig. 13




Rosette diagrams of structural features.

To accompany Record No 1966/81

D52/A13/9

## STRUCTURAL GEOLOGY

The rocks of the Ashton Sheet area are part of the stable Kimberley Block of Traves (1955) Faults, joints and folds are the main structural features present, and all are genetically related. Because of the abundance of quartz sandstone in the sequence, jointing is a particularly prominent structural feature, and the gentle folding is concentric in style. A sketch map of the structure of the Sheet area is shown in Fig. 12.

### Faulting

All of the faults in the Ashton Sheet area are minor. The displacement alongthe faults is generally only a few feet, and the strike lengths of the faults range from a half-mile to 16 miles. Parts of the middle Pentecost Sandstone and King Leopold Sandstone show the greatest density of faults, which appear to be predominantly the strike slip type, though one or two small faults showing vertical movement are present.

The trends of all faults in the Sheet area are shown in the rosette diagrams of Fig. 13. The most prominent trends are 100° and 140°, less prominent trends being 045° and 0°. In some localities, notably the north-east portion of the Sheet area, a conjugate set of faults is evident, trending in a south-east and north-east direction. Faults which trend along 100° show horizontal and vertical movement.

### Jointing

Joints are a ubiquitous feature of the sandstone and volcanic units in the Sheet area. The trends of the joints which occur in each of the stratified Proterozoic formations are shown in the rosette diagrams of Fig. 13, the most persistent being 045° and 130°. The joint trends tend to parallel the fault trends. In the King Leopold Sandstone, however, and to a lesser extent in the Carson Volcanics and Warton Sandstone, there is a distinct set of joints which trend from 355° to 005°. This particular set of joints is less prominent in the younger formations of the Sheet area.

Discontinuous lineaments* which trend in a north- easterly direction are the most striking structural feature of the Ashton Sheet area. They can be traced with certainty for over 100 miles from the south-eastern part of the Drysdale Sheet area to the south-west part of the Ashton Sheet area. The lineaments are arranged en echelon, but the en echelon pattern is not consistent i.e. facing in a south-westerly direction, some of the en echelon patterns show a progressive displacement of each lineament towards the north-west, while others show a displacement to the south-east. This suggests that the observed pattern of en echelon structures is a result of more than a single deformation. The en echelon structures are essentially large-scale tension gashes.

### Folding

Folding in the Sheet area is open in style and very gentle. Two fold types are recognised, first-order folds and second-order folds.

<u>First-order folds</u> are those which are defined by the regional pattern of outcrop. Their axes extend for up to 80 miles across the Sheet area, and plunge of the axes is commonly not evident.

* Any straight physiographic element which may, in this case, be either a large joint or fault.

Second-order folds are much smaller features whose axes extend for less than 10 miles, and which show definite directions of plunge. They are defined by local variations in dip which are readily mapped or photo-interpreted.

The first-order folds trend in both a northerly and easterly direction (see Fig. 13), and cross-folding is common. The east-trending folds are the more prominent of the first-order structures, and appear to be refolded by the north-trending set. This cross-folding affects at least the Drysdale, Mount Elizabeth and Lansdowne Sheet areas to varying degrees, and the pattern is typical of the style of deformation affecting the whole Kimberley Block.

As might be expected the trends of the second-order folds in most cases parallel those of the first-order folds (see Fig. 13), and in general the former appear to be large-scale concentric crenulations on the limbs of the latter.

Synthesis

From a study of the pattern of outcrop in the south-east corner of the Sheet area, it is clear that there are two directions of folding. From a study of the en echelon joint patterns it is also evident that there are at least two deformations to consider. A comparison of the trends of joints, faults, first-order folds and second-order folds shows a remarkable parallelism of the major trends, indicating a close relationship between all four structural elements.

It is thought that after compaction etc. of the sediments of the stable Kimberley Block, the first structures to develop were gentle east-west folds, which were a direct result of a north-south-compression. The conjugate shear directions developed by such a compression are represented by the north-easterly and south-easterly trend of many of the joints and faults. Some of the latter, particularly in the north-east of the Sheet area, show transcurrent movement consistent with the predicted movement along the conjugate shears (Anderson, 1951). One of the two en echelon patterns of some of the north-east trending lineaments are a result of the north-south compression also. This is the pattern which shows, facing to the south-west, a displacement of the lineaments to the north-west. Many of the north-trending joints in the King Leopold Sandstone, Carson Volcanics and Warton Sandstone are, theoretically, tension joints. These are related also to this north-south compression, or more precisely, to the tensional forces acting at right angles to the compression.

An east-west* compression, either contemporaneous with or slightly post-dating the north-south compression, resulted in the development of a series of north-south folds which refolded very gently those trending east-west. The conjugate shear planes associated with this compression overlap and coincide with those related to the north-south compression. Hence the joints etc. which trend north-east and south-west cannot confidently be differentiated from one another, since they are related to both postulated compressions. The en echelon pattern in which facing to the south-west, the lineaments are displaced to the south-east, is due to an east-west compression, as are the numerous east-west trending tension joints and small high-angle faults located in the south-east corner of the Sheet area. These latter structures are, strictly speaking, a direct result of the tensional forces acting at right angles to the east-west compression.

Dyke formation is characteristically associated with tensional stresses, and it is very significant that some of the east-west tension joints on the Ashton Sheet area, and also the north-south joints on the adjoining Prince Regent Sheet area contain quartz dykes up to 5 miles in length.

* These directions are generalised. The compression is not considered to be acting strictly in a north-south or east-west direction, but to be acting in a narrow zone of up to 15° arc about a north-south or east-west axis.

A comparison of the joint rosettes for each of the Proterozoic formations (Fig. 13) shows that joints which trend north-south decrease in numbers upwards in the stratigraphic column, and eventually disappear in the middle Pentecost Sandstone. This disappearance is probably a reflection of the diminishing effect of particular basement stresses on overlying sediment as the thickness of the sedimentary cover increases. It is also possible (but less likely) that this particular set of north-south joints developed before the younger units, such as the middle and upper Pentecost Sandstone, were deposited and/or compacted and lithified.

It is probable that the structure on the Ashton Sheet area is a result of movement and reactivation in underlying basement along lines of weakness or old fundamental faults.

## ECONOMIC GEOLOGY

The Ashton Sheet area contains minor mineral occurrences of galena, copper and apatite, and more important deposits of bauxite, iron and copper. Groundwater and constructional materials are other mineral resources which may assume a greater importance in the near future.

### Bauxite

The bauxite deposits are located in the Couchman and Foster Ranges and in the north-west part of the Sheet area. The deposits are remnants of an extensive bauxitic plateau which extends onto the Montague Sound Sheet area. Those deposits in the Couchman Ranges are scattered and less prominent, but more detailed mapping and sampling of the laterite in this area may show the bauxite to be more extensive than was first thought.

The bauxite was discovered in May, 1965, by Malcolm, a geologist of the United States Metals Refining Company, which at present holds a number of temporary reserves (T.R.'s 3500H, 3501H, 3502H and 3503H) covering the principal deposits of the North Kimberley, mainly those south of Admiralty Gulf (Sofoulis, 1966). The company is actively engaged in evaluation of the deposits by diamond drilling, sampling and chemical analysis, and results so far have proved encouraging (see Appendix 3). The bauxite is massive, cellular and pisolitic, in places earthy but more commonly light-coloured and porcellanous. Pisolitic varieties are not as common as brecciated and recemented types. These contain angular fragments of pebbles and pisolites set in a fine-grained, massive and oolitic matrix. Ferruginous material occurs in the centre of some concentrically layered pisolites, which indicates a later development of bauxite from ferruginous laterite.

Depth of the bauxite on the Ashton Sheet area is not known, but in the Couchman Range pits up to 6 feet deep were still in bauxite. On the Montague Sound Sheet area, at least 11 feet of high grade bauxite were encountered in exploration pits.

The following analyses are of selected specimens of high-grade bauxite from the Couchman Range and the north-west corner of the Sheet area.

| | | |
|---|---|---|
| Regd. No. | 65.16.2054 | *65.16.1060 |
| Field No. | A4.78.3c | Dy 15.08.1a |
| Locality | Couchman R.<br>4278000E<br>3067500N | N.W. corner<br>402700E<br>3100400N |
| Total $SiO_2$ | 4.15 | 2.10 |
| Reactive $SiO_2$ | 3.95 | 2.04 |
| Avail. $Al_2O_3$ | 54.06 | 63.9 |
| Total $Al_2O_3$ | 58.8 | 67.5 |
| Ferric oxide | 2.25 | 5.20 |
| Ferrous oxide | 0.63 | |
| $H_2O^+$ | 29.8 | 20.6 |
| $H_2O^-$ | 0.69 | 0.76 |
| $TiO_2$ | 3.90 | 3.10 |

* Analysis incomplete. Iron present is total iron ($FeO+Fe_2O_3$)

Analyses of altered (lateritised) basalt, unaltered basalt and laterite are also available. These are as follows:-

| Element oxide | Laterite[1] % | Altered basalt[2] % | Fresh basalt[3] % |
|---|---|---|---|
| $SiO_2$ | 24.6 | 36.1 | 51.40 |
| $Al_2O_3$ | 20.6 | 20.6 | 16.38 |
| $Fe_2O_3$ | 1.98 | 31.7 | 1.26 |
| FeO | 9.40 | 0.35 | 12.78 |
| MgO | 4.70 | 0.01 | 2.30 |
| CaO | 7.0 | 0.01 | 7.32 |
| $Na_2O$ | 3.55 | 0.04 | 3.14 |
| $K_2O$ | 2.80 | 0.04 | 1.72 |
| $H_2O^+$ | 2.35 | 9.4 | 0.12 |
| $H_2O^-$ | 0.47 | 0.87 | 1.99 |
| $TiO_2$ | 1.42 | 1.04 | 1.06 |
| $P_2O_5$ | 0.11 | 0.02 | - |
| MnO | 0.14 | 0.03 | tr |
| $CO_2$ | 0.06 | 0.01 | - |

1. Reg'd No. 65.16.1055. Field No. Dy 9.24.1 Locality 476900E, 3148100N Drysdale Sheet Area.

2. Reg'd. No. 65.16.2001. Field No. A8.25.1a Locality 440800E, 3040000N

3. No. 3749, two-pyroxene andesine basalt from A.B. Edwards, (1943).

A comparison of these two sets of analyses shows that development of bauxite from fresh basalt involves:

a. A marked decrease in $SiO_2$, which is leached and generally lost to the lateritic profile proper. The remaining silica forms part of the clay fraction and free quartz or chalcedonic material.

b. A concentration of alumina by solution and reprecipitation from weakly acidic to alkaline groundwaters of pH 4.1 to pH 10.9 (Prescott and Pendleton, 1952).

c. A change in the oxidation state of the iron from ferrous to ferric iron, though this is more applicable to laterite. In the bauxite the little iron present is in the ferric state.

d. The complete removal of alkalis and alkaline earths, which are selectively leached by acid ground-waters.

e. An increase in the $H_2O^+$ content, which is present as hydroxyl groups in kaolinite and gibbsite.

f. A concentration of $TiO_2$ in the bauxite.

The mineralogy of the bauxite is relatively simple. X-Ray diffraction and differential thermal analysis show that the major aluminous mineral present is gibbsite, $Al_2O_3 \cdot 3H_2O$, which contains 65.35% $Al_2O_3$. The only other aluminous mineral is kaolinite, and earlier reports that boehmite, $Al_2O_3$, $H_2O$, was present have not been substantiated. The only iron mineral positively identified was hematite, and it is likely that the bulk of the iron present is amorphous. Silica present in the bauxite was not recorded during the diffraction programme, and it is probable that it is in a colloidal or non-crystalline state.

A detailed account by Pontifex (1966) of the X-ray programme, with results, is presented in this report as Appendix 5. Other appendices include analyses of a laterite sequence, details of up-grading of the bauxite by screening and washing, and tables showing trace element concentration in the bauxite and laterite. (Appendices 2, 3 and 4 respectively).

From a study of the bauxite analyses it is evident that it is suitable for the manufacture of abrasives, refractories and chemicals, as well as raw alumina (Malcolm, pers. comm.). For abrasives, $TiO_2$ must lie between 2.75% and 4.5%, silica should be less than 5%, ferric oxide less than 6% and combined water should total near 30%. Alkalis should be less than 0.7%. (Bracewell, 1962). For refractories, iron should not exceed 2.7%, and lime, magnesia, potash and soda content should not total more than 1%. (Bracewell, op. cit). In the manufacture of chemicals, the bauxite should be high in acid-soluble alumina and low in acid-soluble iron oxide. Ores with a silica content up to 10% are acceptable. (Bracewell, op. cit).

Copper

Copper is present in the Carson Volcanics, Elgee Siltstone and at the base of the middle Pentecost Sandstone. In the Carson Volcanics chalcopyrite is a common vesicle filling, but is not present in sufficient quantity to be considered economic.

The copper-bearing rock in the middle Pentecost Sandstone is located 3 miles south of the New York Jump-Ups and crops out for 50 yards beside the Wyndham-Karunjie road where grader cuts have removed soil overburden. The copper occurs as green malachite flakes up to a ¼ inch across which are scattered singly or in groups along the bedding planes of a poorly outcropping fissile micaceous siltstone. A section of the copper-bearing sequence is as follows:-

| Thickness feet | Lithology |
|---|---|
| | purple glauconitic sandstone |
| ? | soil cover |
| 4 | Micaceous siltstone, grey-green and slumped, copper-bearing, interbedded with flaggy laminated siltstone with pink to pale green laminations. |
| ½ | Grey-green micaceous siltstone, fissile and laminated, copper-bearing. |
| 20 | Feldspathic sandstone, purple-brown, fine- to medium-grained, flaggy to blocky, ferruginous. |
| | lower Pentecost Sandstone |

The total thickness of outcropping siltstone which contains malachite is approximately 3 feet. In the siltstone quartz (average grain size 0.05 mm), chlorite, green biotite and some feldspar are the dominant minerals. Tourmaline, zircon and epidote are common accessories, and the malachite appears apple-green and opaque to transmitted light. The mica is sub-parallel to the bedding, and the chlorite generally occurs in the interstices between quartz grains. Graphite has been identified in polished section by Pontifex (1966), whose report is contained in this Record as Appendix 6. The siltstone has assayed at 0.36% Cu.

The malachite in all respects is conformable with the bedding of the siltstone. No possible sources of copper, such as dolerite sills, are evident for at least 30 miles in all directions, and it is probable that the copper was originally deposited contemporaneously with the enclosing siltstone. Such copper, probably in the sulphide form, has since been altered and redistributed, though any redistribution by supergene processes has been confined to movement of material parallel to the bedding planes.

The stratigraphic sequence containing the copper can be traced throughout the Kimberley for over 400 miles, but examination of this sequence at two other localities in the Sheet area did not reveal the presence of any copper. However, comparatively little of the copper-bearing sequence has been prospected, and further investigation may be warranted, particularly in a small outlier of the sequence 16 miles north-east of the New York Jump-Ups. Further details of this copper occurrence and its relation to other copper deposits in the area are presented in a report by Roberts, Derrick & Ivanac ( 1966 ).

Fig. 14


Glauconitic quartz sandstone

a - apatite grains
g - glauconite grains
q - quartz
m - muscovite
f - feldspar
t - tourmaline

Ordinary light X80

Copper is present in the Elgee Siltstone approximately 8 miles north-north-east of the New York Jump-Ups, and the deposit crops out along a small fault zone beside the Wyndham-Karunjie road. The copper is present as malachite coatings on bedding planes of fissile red-brown siltstone and mudstone, and is associated with a gypsum gangue. Traces of copper are also present in a quartz-chlorite mudstone breccia, and it is probable that the introduction of copper and vein quartz was contemporaneous with the brecciation of the host rock.

## Iron

Many of the laterites on the Sheet area contain sufficient iron to be considered low-grade or marginal iron ore deposits. Analysis of two samples of laterite within the uppermost 30 feet of a profile in the Foster Range indicated an $Fe_2O_3$ content of between 56.2% and 66.9%.

Since iron ore reserves in Australia at present are enormous, it is unlikely that these low-grade ferruginous laterite deposits will prove economic for some considerable time. It is probable that they will prove of some use as a source of road construction material.

## Galena

Near the Carson River at a point 3 miles south-south-west of Moongiyarrie Falls a small quartz vein containing galena crops out. The galena occurs in a vugh containing three or four interlocking cubic crystals up to 4mm. square, set in a pale yellow and pink quartz gangue. Traces of malachite are present. The bulk of the rock is massive chloritic quartz which contains numerous small vughs, in which small but euhedral crystals of quartz are developed. The vein is associated with a zone of brecciation and faulting.

## Phosphate

The cupriferous glauconitic sandstone sequence near the base of the middle Pentecost Sandstone also contains phosphate. The phosphate is present as apatite, which occurs in small pellets similar in size and shape to the accompanying glauconitic grains (see Fig. 14). The glauconite grains form up to 15% of a fine-grained quartz sandstone which contains muscovite, potash feldspar, sericite and ferruginous material in grain-boundaries, and accessory tourmaline and rare graphite. The apatite-bearing pellets form only 3% to 5% of all the pellets in the rock, so phosphate grade in the rock is expected to be less than 1%.* The apatite grains are anhedral to subhedral and show high relief, a birefringence of 0.003, and an imperfect basal cleavage. Reaction to the ammonium molybdate test for phosphate was positive.

Glauconite and phosphate are generally deposited under very similar conditions of chemistry and sedimentation. Slight variation in these conditions could result in a concentration of either phosphate (apatite) or glauconite. It is possible, therefore, that greater concentrations of apatite may be present elsewhere in this sequence, which, as mentioned previously, extends continuously for 400 miles throughout the Kimberley.

## Ground water

Permanent water is abundant in the rivers and creeks of the Ashton Sheet area, (Figs 15, 16) and the construction of wells, bores, etc. is not essential at present for the raising of stock. Some of the better stock pastures which are present in the valleys of the Couchman and Foster Ranges are relatively poorly watered, and one or two artificial watering points in this area may be of advantage.

Parts of the King Edward River are situated within 4 to 5 miles of laterite and bauxite deposits, and could provide ample water for domestic and limited industrial purposes. For larger industry, weirs or small dams may be required.

* Chemical analysis shows 0.25% $P_2O_5$.

The following comments are extracts from a report by Allen (1966). The surface waters of the Sheet area have exceptionally low salinity. The salinity ranges between 25 and 250 ppm. T.D.S.*, with most values below 100 ppm. T.D.S. Water from catchments of volcanic rocks tends to have a higher salinity than those from sandstone. In general the surface waters have a lower pH than the ground waters. Some of the water contained in the King Leopold Sandstone is of very low salinity, and is similar in composition to rainwater. The ground water occurs in water-filled joints and fractures located in near-surface rocks, and except along master joints and faults probably does not occur below about 500 feet. Upland swamps, such as exist in the Crossland Creek area of the Ashton Sheet, are probably maintained by springs.

Construction materials

The majority of tracks in the Sheet area are confined to the sand and soil tracts which overlie much of the Carson Volcanics. Abundant road metal is available from the low basalt hills, and from the deposits of laterite found throughout the area. The latter deposits in particular would be simple to exploit.

There is also no shortage of sand and gravel deposits, which may be found in most watercourses.

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* Total dissolved solids.

Fig. 15. Permanent stream in north-west of Sheet area. Bedrock in jointed King Leopold Sandstone.

Fig. 16. Permanent pool on Drysdale River. Note marginal pools behind levee banks fed by ground water and seasonal floods.

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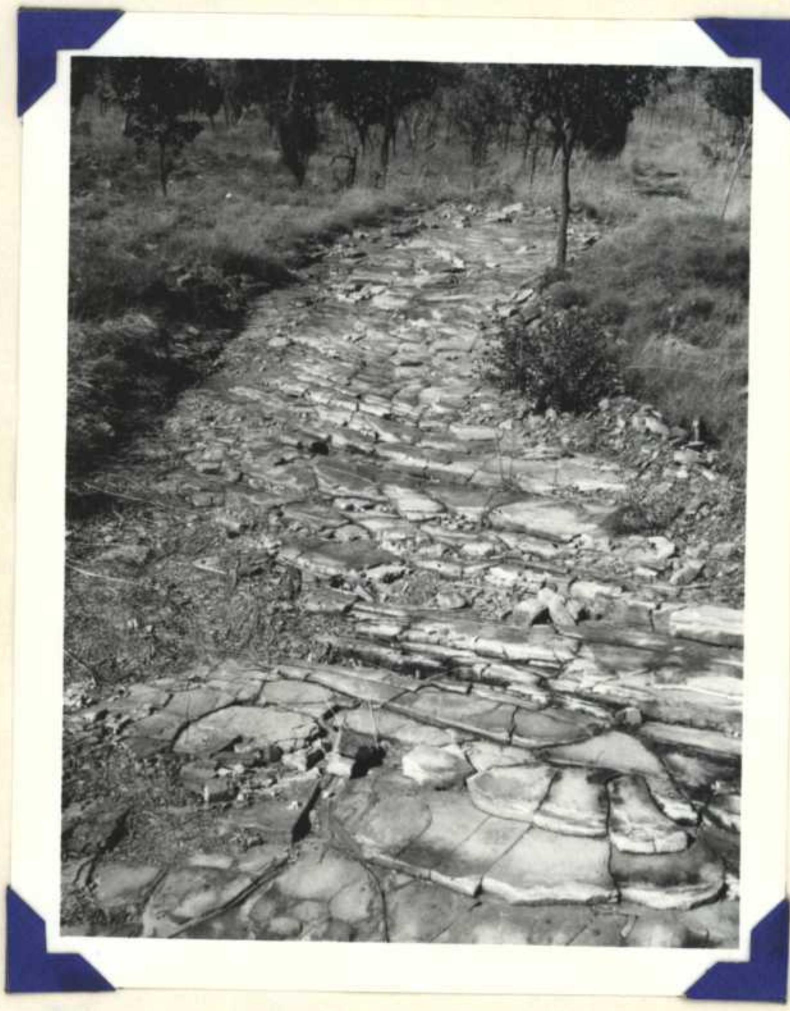


Fig. 17. Current bedding in Pentecost Sandstone showing shallow dip of curved foreset units.

STRATIGRAPHIC TABLE

TABLE 1

| Era | AGE | ROCK UNIT: Group | ROCK UNIT: Formation | ROCK UNIT: Symbol | THICKNESS (feet) | LITHOLOGY | STRATIGRAPHIC RELATIONSHIP | TOPOGRAPHY | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| C A I N O Z O I C | Quaternary | | | Qa | Up to 30' | Alluvium | | Water courses, river flood plains and levees. | |
| | Undifferentiated | | | Czs | Up to 25' | Sand, soil, eluvium | Overlies older rocks. | Flat mature land surface | Extensive tracts over Warton Sst. and Carson Volcanics |
| | | | | Czb | ? | Black soil | " " " | " " " " | Commonly developed on exposures of Hart Dolerite. |
| | | | | Czl | ? | Ferruginous pisolitic, sandy lateritic soil | " " " | " " " " | |
| | Tertiary | | | Tb | 10+ | Bauxite, aluminous laterite | Overlies Carson Volcanics with disconformity or slight unconformity. | Flat top remnants capping low hills. | Erratic distribution - well developed in N.W. of Sheet area. |
| | | | | Tp | 20 to 70' | Undifferentiated laterite. | Overlies Carson Volcanics and King Leopold Sandstone with disconformity or slight unconformity. | " " " | Some laterite transported and redeposited in valleys. (ferricrete?). |
| | | | | | | UNCONFORMITY | | | |
| P R O T E R O Z O I C | Adelaidean or Carpentarian | | Hart Dolerite | Bdh | Up to 240' | Dark grey-green, massive medium- to coarse-grained dolerite sills. | Intrudes Kimberley Group, but intrudes only King Leopold Sandstone on Sheet area. | Low boulder strewn hills and black soil plains in steep sided depressions in sandstone. | Mainly found exposed in cores of gentle domes in King Leopold Sandstone. Some zeolite, possible stilbite, present in some specimens. |
| | | BASTION GROUP | Mendena Formation | Btm | 100+ | Thick-bedded massive white feldspathic sandstone, fine-grained, cross-bedded, ripple marked; kaolinitic siltstone, mudstone conglomerate, blocky and laminated quartz sandstone and arkose, white to grey, fine grained. | Conformably overlies Pentecost Sandstone. | Small low mesas rising from broad sandy plains. | Top portion of Group not exposed. |
| | | KIMBERLEY GROUP | upper Pentecost Sandstone | Bkpu | ca 800 | Quartz sandstone, massive and thick bedded, med. gr. to c. gr., white to buff, cross-bedded; minor poorly sorted granule sandstone; clayey quartz sandstone, fine to medium grained, friable. | Conformably overlies middle Pentecost Sandstone. Overlain conformably by Bastion Group. | Wide sand-covered cuestas in north-east of Sheet area, elsewhere shallow dipping cuestas and rocky terraces separated by small scarps. | Sandstone generally white massive and well jointed, but upper and lower boundaries indistinct in parts of Sheet area. |
| | | | middle Pentecost Sandstone | Bkpm | ca 2100 | Alternation of white to buff massive to blocky m.g. quartz sandstone and friable buff to white m.g. feldspathic sandstone. Flaggy to blocky fine-grained glauconitic sandstone at base associated with thin Cu-bearing siltstone. | Conformably overlies lower Pentecost Sandstone. | Small irregularly developed cuestas, low scarps and narrow pediments. Ribbon-like sand deposits at base of scarps. | Glauconitic sandstone prominent marker bed. Copper deposit apparently of sedimentary type. |
| | | | lower Pentecost Sandstone | Bkpl | ca 550 | Massive to blocky quartz sandstone, m. to c.g., white to pale brown strongly cross-bedded. | Conformably overlies Elgee Siltstone. | Well-defined cuestas, separated by scarps up to 170' high. | Some overturned cross-beds present. |

| AGE | ROCK UNIT Group | Symbol | THICKNESS (Feet) | LITHOLOGY | STRATIGRAPHIC RELATIONSHIP | TOPOGRAPHY | REMARKS |
|---|---|---|---|---|---|---|---|
| PROTEROZOIC Carpentarian | Kimberley Gp. Elgee Siltstone | Bke | ca 300 | Red-brown to grey-green fine-grained quartz sandstone, calcareous red-brown siltstone and mudstone. Minor granule, sandstone and white cross-bedded medium-grained quartz sandstone. | Conformably overlies Warton Sandstone. | Forms prominent scarp up to 250' high below Pentecost Sandstone. Rest of formation valley forming, poorly out cropping. | Mud pellets, ripple marks and slump structures ubiquitous. Lower boundary with Warton Sst. generally obscured. |
| | Warton Sandstone | Bkw | ca 1270 | Quartz sandstone, white cream and pale purple-grey, c.g. to m.g., massive to blocky, thick bedded; large scale cross-bedding characteristic; minor feldspathic sandstone, fine grained sandstone and intraformational micaceous pebble conglomerate near base. | Conformably overlies Carson Volcanics. Minor disconformities at base. | Cliff-forming over most of Sheet area; upper parts of unit form soil covered plains with poor outcrop. | Lower boundary with Carson Volcanics arbitrary in some localities in Sheet area. Some cross-beds slumped and overturned. |
| | Carson Volcanics | Bkc | ca 1800 | Massive grey-green to black basalt, copper-bearing amygdaloidal basalt and ?spilite, epidote-calcite segregations and minor quartz-feldspar pegmatite; interbedded blocky feldspathic sandstone, m.g., white to light buff, cross-bedded and ripple marked; Micaceous siltstone and stromatolitic chert at top. | Conformably overlies King Leopold Sandstone. Boundary with Warton Sandstone often indistinct. | Poorly outcropping in south of Sheet area where low boulder strewn hills project from sandy plain. Subdued and undulating topography in north with laterite cappings prominent. | Bauxite and laterite mostly developed over massive basalt. |
| | King Leopold Sandstone | Bkl | Ca 2400 | Massive thick-bedded quartz sst, white, buff and purple-grey, m. to c.g., friable, cross-bedded, some ripple marks. Minor buff to brown, fine gr micaceous sst, flaggy and laminated. | Overlain conformably by Carson Volcanics. Base of formation not exposed. | Rugged and highly jointed sandstone plateau to south-west of Sheet area, forming undulating low plateau with soil cover eastwards and northwards. | Thin bands of pebble conglomerate present. Some laterite found on this unit - probably transported in part. |

# APPENDIX 1

## DISPERSAL, DEPOSITIONAL ENVIRONMENT AND PROVENANCE OF THE KIMBERLEY BASIN SEDIMENTS

### Dispersal

Grain size: The Kimberley Basin sediments include mudstone, siltstone and sandstone. Mudstone is relatively rare, and siltstone constitutes less than 5% of the sedimentary pile. The remainder is sandstone, and this is usually fine- to coarse-grained, with an average grain size of 0.7mm.

Sorting: Most of the sandstone is moderately to well-sorted, though some poor sorting is evident in hand specimen. However, sieve analysis of sandstone from the Drysdale Sheet area by Gellatly (1966) shows that the arenites are generally very well-sorted. Sorting coefficients for every arenite formation range from 1.3 to 1.4. The upper limit of the sorting coefficient for well-sorted sediments is 2.5. (Pettijohn, 1956).

Roundness and Sphericity: Most detrital grains of quartz and other minerals are well-rounded and highly spherical. Average values for the coefficients are 0.8 and 0.8 respectively. Both roundness and sphericity are lessened by the development of overgrowths and the suturing of concomitant grain boundaries.

Siltstone and mudstone generally show a subangular to subrounded quartz grain population. This is a reflection of the load capacity of the sedimentary currents, which carry the finer grades in suspension, thus limiting the amount of grain abrasion possible.

### Depositional Environment

Current bedding (Cross stratification): The current bedding observed in the Sheet area is of the trough and planar type, as defined by McKee and Weir (1953, p. 385), and scoop-shaped, as defined by Allen (1963). These terms describe the shape of the lower bounding surface of the current bedding set. The cross strata in the arenites are large-scale, and usually make an appreciable angle with the lower bounding surface. They are therefore termed discordant (Allen, op cit). The classification of McKee and Weir (op cit) has been modified and expanded by Allen, and using the latter's terminology, the current beds are of the Omikron or Pi type, the Pi type being the most abundant. (Fig. 17).

Measurements of the current direction were made along the central dip azimuth of the scoop-shaped foreset beds, which display dips of up to 30°. Where 25 or more readings were taken in any single area, a rosette diagram was constructed, while otherwise a single arrow was used to indicate the prevailing or average direction of the current. These are plotted on Fig. 18. The results show that paleocurrents from the north-west and west-north-west were very persistent, despite minor local reversals. These directions are consistent with those recorded from Drysdale, Mount Elizabeth and Lansdowne Sheet areas.

Overturned current beds are present in a number of localities on the Sheet area, and their form is shown in Roberts & Perry (1966). It is likely that the structure is produced by strong sediment-laden currents passing over wet and unconsolidated cross-strata and physically dragging the upper surface of the latter in the direction of the current movement.

The current directions do not necessarily indicate the direction of the source area. The currents, for instance, may be analogous to long-shore drift of many presents day shelf areas. The rosette diagrams (Fig. 18) show that although a current direction from the north-west is dominant, there are many other current directions present. Whether such variation could be expected in a uniform long-shore drift is not definitely known because of the lack of information in the Sheet area regarding paleoshorelines. The influence of rivers, deltas, coastline shape and physiography might be sufficient to give the variations observed, but on the Sheet area no real evidence for the presence of these influences has been found.

Generally massive quartz sandstone shows the best-developed large-scale current bedding. The intensity of current bedding apparently decreases with a. a decrease in the thickness of the bedding,

b. an increase in feldspar content

c. an increase in the numbers of small-scale asymmetric ripple marks.

These factors suggest that the current beds in quartz sandstone have developed away from areas of rapid erosion and at a depth well below the base of waves which produce small-scale ripples. The overturning of some of the current beds indicates that exceptionally strong and turbulent currents have also been present. This is supported by the highly deformed nature of the overturned structures when viewed in plan.

It is likely that the current-bedded quartz sandstone has been deposited in a roughly spoon-shaped basin trending in a south-easterly direction, open to the sea in most directions. The current bedding indicates a regional slope of the sea floor to the south and east. Variations in the topography of the sea floor have induced local variations in strength and direction of the bottom currents.

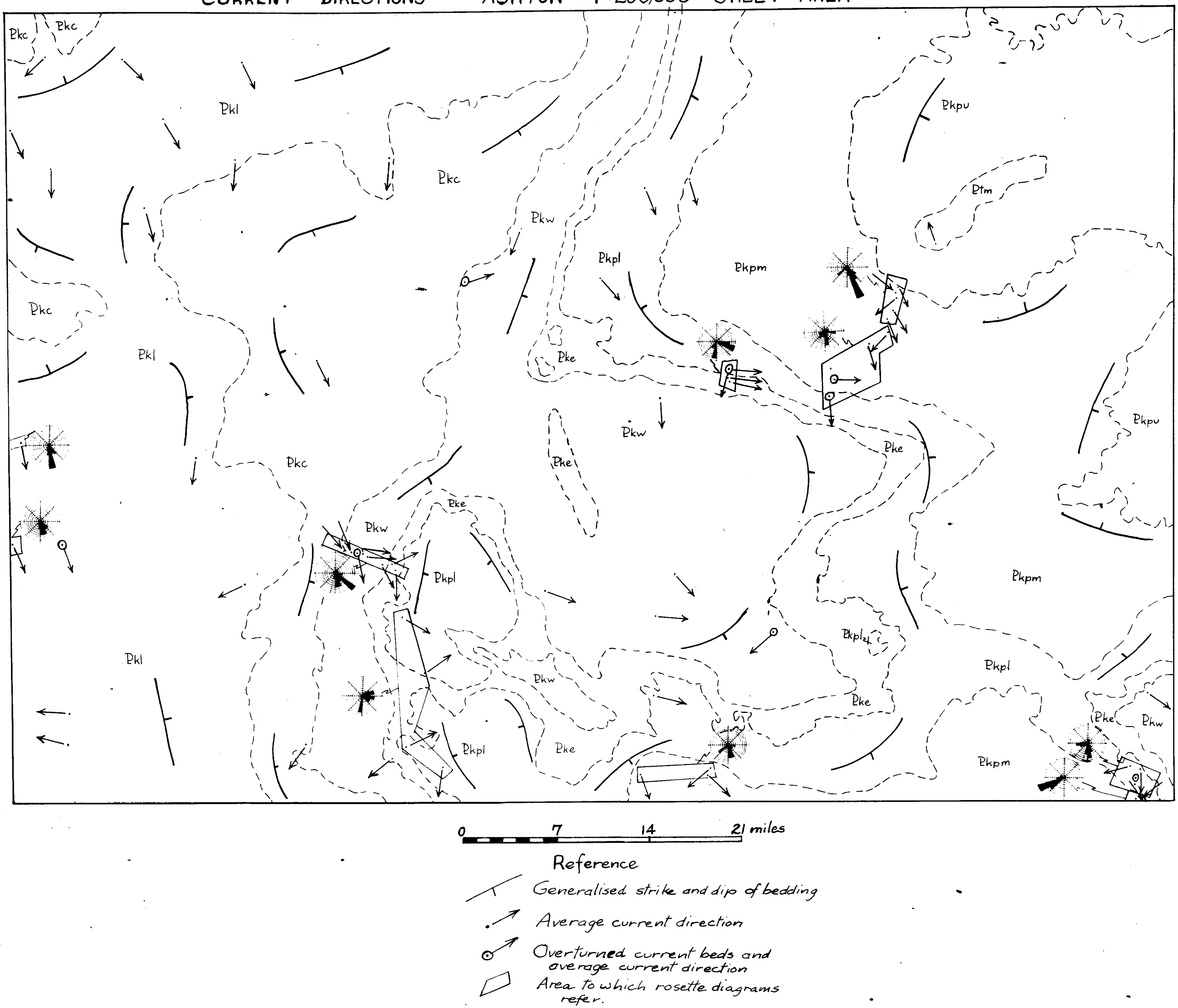
The development of the current beds is probably related to the migration of trains of lunate large-scale asymmetric ripples in depths many times the ripple height, though Allen (op cit) also suggests that current beds of the Omikron and Pi type can be produced by the migration of aeolian dunes.

Other features

Transgressive conditions within the basin are indicated by the occurrence of glauconite and phosphate in the rocks of the middle Pentecost Sandstone. These minerals are developed in depths of between 10 and 400 fathoms, in areas of impeded convection, restricted clastic influx and slow sedimentation. (Pettijohn, op cit.). Such conditions would be favourable also to the development of graphite and copper sulphide which may have given rise to the graphitic cupriferous siltstone associated with the glauconitic sandstone.

This postulated period of transgression has effectively matured the land surface and may also have assisted in the development of the Elgee Siltstone. This formation is a red-bed sequence of calcareous siltstone, mudstone and fine-grained sandstone. Interference ripple marks, small-scale current bedding and rare mud-cracks are present, and indicate a shallow shelf and inter-tidal zone of deposition. An off-shore reef has supplied calcareous material to the formation, and has restricted the influx of coarser clastic material. Despite the restricted circulation, oxidation of the shelf and intertidal deposits has been possible because of the prevailing shallow depths.

# CURRENT DIRECTIONS — ASHTON 1:250,000 SHEET AREA




To accompany Record No 1966/81

D52/A13/11

Provenance

In the sedimentary rocks of the Ashton Sheet area, quartz is the dominant detrital mineral, and the most stable. A majority of the grains show bubble and fine-grained mineral inclusions, some of which are apatite and ?sagenitic rutile. Such minerals and inclusions indicate an ultimate acid igneous source area. However, the extreme rounding of many of the grains and a marked absence of abundant matrix between the grains suggests that the immediate source has been sandstone which has been recycled.

The feldspar content is generally less than 5% in rocks from the Sheet area. There are some exceptions, notably in those rocks near the base of the Warton Sandstone, where thin bands of conglomerate are also present in the sequence. This suggests that the increase in feldspar content in this small thickness of section is related to increased diastrophism and consequently more rapid rates of erosion. The extremely low feldspar content overall, however, reflects the high maturity of the sandstone present in the Kimberley Basin succession.

The heavy mineral suite of mainly tourmaline and zircon is to be expected in mature sandstone. Zircon is subhedral to anhedral, and tourmaline, though well-rounded in most cases, does show a relict trigonal structure in some rocks. In most examples the tourmaline shows the pleochroic scheme O= dark green-grey to olive green, E= colourless to pale fawn, which is typical of the schorlite tourmaline group. Some grains show authigenic overgrowths, which in one case appeared abraded, suggestive of a recycled grain. From the colour and relative size of the tourmaline grains, it appears that they have been derived originally from a plutonic and pegmatitic terrain (Krynine, 1946). Monazite is rare, but it too is typical of sediments derived from an acid igneous source. Epidote is a relatively common heavy mineral, particularly in the fine-grained sediments. Many apparently detrital grains of epidote which occupy original pore spaces in the sandstone show ?authigenic overgrowths, and these grains are quite angular. Others are rounded, and all of the epidote appears to be altered to varying degrees. Epidote is a characteristic mineral of basic igneous rocks, and it is probable that it has been derived from a source other than that which gave rise to the tourmaline-zircon suite. Because of its relative instability epidote is usually considered to be a rare heavy mineral in mature sandstone, and its presence in these rocks suggests that it has not undergone recycling. It is more than coincidence also that rocks which are younger than the epidote-rich Carson Volcanics contain much more epidote than the King Leopold Sandstone, which underlies the volcanics. Rounded grains of fine-grained sandstone and siltstone in coarse- to medium-grained sandstone also confirm the presence of lithified sedimentary rocks in the source area.

To summarise the sediments of the Kimberley Basin have been derived from older sedimentary rocks which themselves have been derived from an acid igneous terrain. A basic igneous source area, possibly areas of outcrop of the Carson Volcanics, has provided small amounts of first-cycle detritus, notably epidote. Both first and second-cycle detritus have been distributed by currents which trend predominantly from the north-west.

Facies changes, provenance, dispersal and depositional environment of the whole of the Kimberley Basin will be treated in detail by Plumb (in prep.)

APPENDIX 2

ANALYSES OF LATERITE SEQUENCE
ASHTON SHEET AREA

Locality Lat. 15°20'S, Long. 126°26'E.

| Field No. | Registered No. | Distance from top (feet) | Avail. $Al_2O_3$ | Total $Al_2O_3$ | Total $SiO_2$ | Reactive $SiO_2$ | $Fe_2O_3$ | $TiO_2$ | $H_2O^+$ | FeO |
|---|---|---|---|---|---|---|---|---|---|---|
| A5/56/1a | 65162060 | 0 | - | 15.9 | 17.1 | 17.06 | 56.6 | 1.44 | 7.60 | 0.49 |
| A5/56/1b | 65162051 | 20 | 10.7 | 12.0 | 10.9 | 10.8 | 66.9 | 1.30 | 7.8 | 0.63 |
| | | 40 | Altered basalt | | | | | | | |
| | | 50 | Massive fresh basalt | | | | | | | |
| | | 70 | Valley deposits | | | | | | | |
| A5/561c | 65162050 | 70 | 31.43 | 37.0 | 4.75 | 4.64 | 36.5 | 3.20 | 17.7 | 0.32 |
| A5/56/1d | 65162061 | 70 | - | 41.6 | 3.55 | 3.46 | 29.7 | 4.55 | 19.0 | 0.41 |
| A5/56/1e | 65162062 | 70 | - | 18.8 | 5.20 | 5.11 | 59.2 | 1.61 | 13.4 | 0.34 |

APPENDIX 3

## EFFECT OF SCREENING AND WASHING ON BAUXITE SAMPLE MONTAGUE SOUND SHEET AREA

(by courtesy U.S. Metals Refining Coy.)

| | No. | Depth | Available $Al_2O_3$ | Total $Al_2O_3$ | Total $SiO_2$ | Reactive $SiO_2$ | $Fe_2O_3$ | $TiO_2$ | Ignition Loss |
|---|---|---|---|---|---|---|---|---|---|
| Head sample | 1 | 1.5-3.5' | 46.0 | 51.0 | 5.2 | 3.6 | 10.8 | 3.7 | 26.9 |
| | 2 | 3.5-5.5' | 53.2 | 54.7 | 3.5 | 3.1 | 6.7 | 3.5 | 30.3 |
| | 3 | 5.5-7.5' | 48.2 | 51.6 | 5.3 | 4.5 | 7.7 | 3.5 | 28.4 |
| | 4 | 7.5-9.5' | 39.2 | 49.1 | 7.9 | 7.2 | 9.7 | 3.1 | 27.0 |
| | 5 | 9.5-11.5' | 35.9 | 45.2 | 17.3 | 16.0 | 8.7 | 2.7 | 23.3 |
| $+\frac{1}{4}$" Dry screened | 1A | | 50.6 | 53.3 | 2.2 | 1.9 | 9.6 | 3.7 | 29.4 |
| | 2A | " | 56.6 | 58.6 | 1.0 | 1.0 | 3.8 | 3.7 | 31.2 |
| | 3A | | 54.1 | 56.7 | 2.2 | 2.0 | 4.7 | 3.5 | 30.5 |
| | 4A | | 50.9 | 54.9 | 3.0 | 2.9 | 8.3 | 3.4 | 29.0 |
| | 5A | | 47.5 | 52.7 | 5.6 | 5.2 | 8.1 | 3.1 | 27.3 |
| $-\frac{1}{4}$"+10 Dry screened | 1B | | 35.4 | 42.5 | 11.5 | 7.9 | 16.6 | 1.8 | 23.3 |
| | 2B | " | 45.7 | 48.4 | 6.7 | 6.6 | 8.9 | 3.4 | 27.2 |
| | 3B | | 41.4 | 47.2 | 7.0 | 6.5 | 11.8 | 3.7 | 25.9 |
| | 4B | | 41.8 | 46.4 | 8.8 | 8.0 | 12.0 | 3.4 | 25.4 |
| | 5B | | 37.1 | 46.3 | 16.1 | 15.3 | 8.4 | 2.8 | 23.6 |
| $+\frac{1}{4}$" washed | 1D | | 51.6 | 54.6 | 1.4 | 1.2 | 8.8 | 2.7 | 30.3 |
| | 2D | " | 58.3 | 58.7 | 1.0 | 1.0 | 4.2 | 3.6 | 31.6 |
| | 3D | | 54.7 | 57.3 | 1.6 | 1.5 | 5.4 | 3.4 | 29.9 |
| | 4D | | 54.4 | 54.9 | 1.8 | 1.8 | 7.0 | 3.4 | 29.2 |
| | 5D | | 51.8 | 56.0 | 2.1 | 1.1 | 5.0 | 2.9 | 30.6 |
| $-\frac{1}{4}$"+10 washed | 1E | | 36.4 | 39.8 | 10.3 | 9.6 | 19.6 | 3.7 | 23.1 |
| | 2E | | 49.4 | 50.6 | 5.3 | 4.6 | 8.2 | 3.5 | 27.5 |
| | 3E | " | 41.7 | 45.7 | 6.7 | 6.2 | 14.0 | 4.0 | 25.7 |
| | 4E | | 40.2 | 44.0 | 9.8 | 9.3 | 14.8 | 3.9 | 24.0 |
| | 5E | | 43.6 | 47.1 | 10.6 | 9.4 | 10.4 | 3.4 | 24.8 |

KIMBERLEY LATERITES AND BAUXITE
SEMI-QUANTITATIVE ANALYSIS BY
EMISSION SPECTROSCOPY
(in parts per million)

| Sample No. | Chromium | Vanadium | Gallium | Zirconium | |
|---|---|---|---|---|---|
| 75808 | 20 | 50 | 5 | 50 | By courtesy U.S. Metals Refining Coy. |
| 75809 | 25 | 150 | 20 | 50 | |
| 75810 | 30 | 50 | 20 | 50 | |
| 75811 | 20 | 50 | 10 | 50 | |
| 75818 | 25 | 40 | 30 | 50 | |
| 75819 | 15 | 30 | 4 | 50 | |
| 75820 | 25 | 25 | 8 | 50 | |
| 76119 | 40 | 200 | 15 | 50 | |
| 76120 | 25 | 20 | 12 | 50 | |
| 76121 | 60 | 200 | 25 | 50 | |
| 65.16.2050 | 10 | 250 | 6 | 50 | |
| 2051 | 8 | 150 | 8 | 50 | |
| 2052 | 50 | 250 | 12 | 50 | |
| 2054 | 250 | 400 | 5 | 50 | |
| 2060 | 6 | 10 | 4 | 50 | |
| 2061 | 10 | 120 | 5 | 50 | |
| 2062 | 8 | 70 | 8 | 50 | |
| 2063 | 150 | 1500 | 50 | 50 * | |
| 1049 | 5 | 40 | 3 | 50 | |
| 1050 | 12 | 150 | 10 | 50 | |
| 1051 | 12 | 250 | 8 | 50 | B.M.R. |
| 1052 | 40 | 600 | 15 | 50 | |
| 1054 | 6 | 80 | 2 | 50 | |
| 1055 | 3 | 10 | 4 | 50 | |
| 1057 | 50 | 25 | 1 | 50 | |
| 1058 | 200 | 500 | 8 | 50 | |
| 1059 | 150 | 300 | 30 | 50 | |
| 1060 | 150 | 20 | 3 | 50 | |
| 1061 | 30 | 151 | 3 | 70 | |

* Basalt, unaltered; contains 600 ppm Ni.

Oremineralogy report No. 1

File No. 65-7074
11.3.66

# An examination of seven bauxite samples from the Ashton 1:250,000 sheet, Kimberlies area W.A.

by

I.R. Pontifex

The samples were collected by G.M. Derrick. Some were sent to AMDL for partial silicate analysis. All the samples discussed in this report were analysed on the B.M.R. X-ray diffractometer to determine their mineralogical composition. This was done by Pontifex and Derrick under the supervision of J.M. Rhodes.

Locality. All of the samples were collected from the vicinity of the Couchman and Foster Ranges on the Ashton 1:250,000 sheet area. Their military grid coordinates are as follows:

| Sample No. | Coordinate | |
|---|---|---|
| 65.16.2050 | E 451800 | N 3064900 |
| 65.16.2052 | E 427800 | N 3067500 |
| 65.16.2053 | E 427800 | N 3067500 |
| 65.16.2054 | E 427800 | N 3067500 |
| 65.16.1051 | E 474500 | N 3159600 |
| 65.16.1052 | E 474500 | N 3159600 |

65.16.2050 (Field No. A5/56/IC)

Chemical analysis (AMDL)

| | | % |
|---|---|---|
| silica | $SiO_2$ | 4.75 |
| free silica (quartz) | $SiO_2$ | 0.11 |
| available silica (by diff.) | $SiO_2$ | 4.64 |
| ferric oxide | $Fe_2O_3$ | 36.5 |
| ferrous oxide | FeO | 0.32 |
| titanium oxide | $TiO_2$ | 3.20 |
| aluminium oxide | $Al_2O_3$ | 37.0 |
| water over 100°C | $H_2O^+$ | 17.7 |
| water at 100°C | $H_2O^-$ | 0.63 |

| V | Cr | Ga | Zr | |
|---|---|---|---|---|
| 250 | 10 | 6 | -50 | values in ppm. |

X-ray diffraction mineral identification

(i) Matrix. Gibbsite

(ii) Ferruginous pisolites. Hematite

Description of specimen.

This is a compact, red-brown concretionary laterite which consists of an aggregate of irregular shaped ferruginous nodules and of smaller amounts of ferruginous pisolites.

The nodules measure up to 3cm. across; the average size of the pisolites is 3mm.

Most of the nodules and pisolites consist of a mixture of aluminium hydroxide (probably gibbsite) and hydrated iron hydroxide.

Some of the pisolites consist entirely of extremely fine grained hematite which has a fine spongy texture. Poorly defined, concentric, colloform banding, and fine radial cracks are characteristic of most hematite-rich pisolites.

The matrix which fills between the nodules and pisolites is predominantly gibbsite which contains accessory amounts of admixed iron-hydroxide. This forms up to 25% of the rock.

In section, the matrix seen in hand specimen is found to consist of an aggregate of micro-pisolites which have an average diameter of 0.05mm; these are set in a fine matrix of what is presumably gibbsite.

65.16.2052 (Field No. A4/78/3a)

Chemical analysis (AMDL)

| | | % |
|---|---|---|
| silica | $SiO_2$ | 35.7 |
| free silica (quartz) | $SiO_2$ | 0.42 |
| available silica (by diff.) | $SiO_2$ | 35.3 |
| ferric oxide | $Fe_2O_3$ | 16.7 |
| ferrous oxide | FeO | 0.75 |
| titanium oxide | $TiO_2$ | 4.55 |
| aluminium oxide | $Al_2O_3$ | 29.8 |
| water over 100°C | $H_2O+$ | 11.3 |
| water at 100°C | $H_2O-$ | 1.10 |

| V | Cr | Ga | Zr | |
|---|---|---|---|---|
| 250 | 50 | 12 | 50 | values in ppm. |

X-ray diffraction mineral identification.

A sample of total rock was analysed; the essential component is kaolinite (aluminium silicate hydrate). The diffraction pattern indicates that small amounts of other materials are present but these were not identified.

Description of the specimen.

The rock consists of a compact aggregate of red-brown ferruginous, subspherical pisolites; they are close packed but generally not in contact. The pisolites appears to be leached and generally they show evidence of breaking down into a number of concentric shells which have a red-ochreous nature. The core of the pisolite is generally dark brown, the outer shell is usually white.

In section the pisolites are found to consist of loosely packed concentric bands of hydrated iron oxide.

The iron hydroxide is an amorphous variety since its presence is not detected in the x-ray diffraction pattern.

The mineral forming the outer shell (generally about 0.15mm. thick), has a grey-white birefringence, it seems to be isotropic but it has an anomalous translucent appearance. This mineral is common throughout the matrix where it forms the cores of micro pisolites. Considering its optical properties, its abundance, and the x-ray diffraction pattern of a whole rock sample, this mineral is most likely kaolinite.

Bands consisting of flaky kaolinite generally surround the pisolites in the matrix and mosaic like masses of kaolinite are scattered throughout the rock.

The kaolinite is generally stained by hydrated iron oxides and colloform bands of these line cavities in the rock.

65.16.2053. (Field No. A4/78/3b)

No chemical analysis available.

X-ray diffraction mineral identification.

An analysis of the pisolites indicates that their main constituent is gibbsite.

Description of the specimen

This is a light brown pisolitic laterite, it consists of a compact aggregate of pisolites which contains several irregular fragments of bauxite and irregular patches of matrix. The rock appears to have been silicified.

Most of the pisolites are cream-brown which indicates that they contain very little iron.

In section most of the pisolites consist of limonite stained gibbsite, concentric zoning is common and radial and irregular fractures are abundant. Many of the fractures are filled with limonite (including some hematite) and also with fine chalcedonic silica.

The core and concentric bands in some pisolites are replaced by secondary chalcedony and minor clay. Some irregular concretions of gibbsite have formed around a core consisting of fragments of small gibbsite pisolites and accessory detrital quartz grains.

Irregular fragments of gibbsite pisolites and accessory detrital rock fragments are scattered throughout the ferruginous matrix together with small sub-spherical pisolites. Chalcedony commonly partly fills intersticies within the matrix.

The relationships of the components in this rock indicate that it has undergone some reworking and secondary silicification. It appears that most of the pisolites were formed contemporaneously with the enclosing matrix by sedimentary accretionary and concretionary processes. The rock has subsequently been silicified; some of the original pisolites have been deformed; and part of the matrix has been reconstituted.

These events possibly took place during diagenesis or recent weathering.

65.16.2054 (Field No. A4/78/3c)

Chemical analysis (AMDL).

| | | % |
|---|---|---|
| silica | $SiO_2$ | 4.15 |
| free silica (quartz) | $SiO_2$ | 0.20 |
| available silica (by diff.) | $SiO_2$ | 3.95 |
| ferric oxide | $Fe_2O_3$ | 2.25 |
| ferrous oxide | FeO | 0.63 |
| titanium oxide | $TiO_2$ | 3.90 |
| aluminium oxide | $Al_2O_3$ | 58.8 |
| water over 100°C | $H_2O+$ | 29.8 |
| water at 100°C | $H_2O-$ | 0.69 |

| V | Cr | Ga | Zr | |
|---|---|---|---|---|
| 400 | 250 | 5 | 50 | values in ppm. |

X-ray diffraction mineral identification.

1. The cream coloured "pure" pisolites consist essentially of gibbsite.

2. The diffraction pattern of the red-brown ferruginous pisolites indicates that gibbsite is the main component.

3. The matrix consists essentially of gibbsite.

Description of the specimen

This is a compact, cream colored laterite consisting mainly of closely packed more-or-less equal size pisolites which have an average diameter of 4 mm. The pisolites commonly have a slightly ferruginous core but the bulk of most of them is cream or light-brown-cream which indicates that they contain very little iron.

In section the pisolites are seen to have an irregular concentric zoning. Radial and irregular cracks are abundant in most pisolites, presumably due to dehydration. The matrix consists of a loosely packed aggregate of gibbsite oolites which have an average diameter of 0.05 mm. Interstitial cavities are in some areas completely, and in other areas partly filled with secondary chalcedony. Fractures in the pisolites are also filled with secondary chalcedony and clays. The chalcedony forms between 3 and 5% of the rock.

Bands of colloform limonite line some cavities.

65.16. 1051 (Field No. DY8a/28/1a)

Chemical analysis. None available.

X-ray diffraction, mineral identification

The pisolites and oolitic aggregates in this rock consist essentially of gibbsite.

Gibbsite is also a major component of the matrix and massive parts of the specimen.

Description of the specimen

Most of this rock consists of extremely fine-grained indurated masses which contain porous aggregates of oolitic gibbsite and isolated pisolites. Several grains of detrital quartz are scattered through the oolitic aggregates.

The massive parts have a buff and light brown mottled appearance and they consist of closely packed aggregates of oolitic gibbsite which have been cemented by a cryptocrystalline siliceous matrix. Some areas have a porcellanous texture. The average diameter of the oolites in the massive and porous fractions is 0.3 mm.

The indurated masses grade imperceptibly into the relatively porous aggregates. Their relationships suggest that the entire rock was originally silicified and some parts have subsequently been leached with removal of silica,or alternatively, that the rock was originally porous and subsequently some parts were silicified.

Some pisolites are composed of several oolites which appear to have been welded together by some concretionary process, subsequent to the formation of most of the gibbsite oolites.

The relationships of the components in this specimen indicate (as in 65.16.2053) that some parts of the rock have been subject to secondary silicification and reconstitution of the matrix. This suggests that probably more than one period of lateritisation is responsible for the present form of these bauxites.

65.16.1052 (Field No. DY8a/28/1b)

Chemical analysis not available.

X-ray diffraction, mineral identification

An analysis of a whole rock sample revealed that gibbsite is the main component.

Description of the specimen. (No thin-section was cut).

This is a cream-light brown rock which consists of a compact aggregate of even-sized oolites of gibbsite. The average diameter of the oolites is 0.4 mm. Although the rock is generally porous the intersticies in some parts are filled with secondary opaline-like silica, and minor hematite.

DY8a/28/1d

Chemical analysis not available.

Description of the specimen

The matrix of this rock is essentially the same as described for DY8a/28/1b. This contains isolated pisolites up to 6 mm. in diameter and irregular fragments which measure about 5 mm. across; both were identified by X-ray diffraction as gibbsite. The fragments are scattered at random through the oolitic matrix and under the binocular microscope they are seen to have a colloform, secretionary internal structure.

Comment on X-ray diffraction mineral identification

With the exception of two specimens (or selected parts of specimens) in which kaolinite and hematite were the essential constituents, all the samples analysed on the X-ray diffractometer were found to consist predominantly of gibbsite. In each of these samples the diffraction pattern also indicated the presence of one (or more) other minerals.

The 'd' spacings of the most prominant peaks recorded on each chart in addition to the gibbsite peaks are tabulated below.

| SAMPLE NUMBER | 'd' SPACING Å | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65.16.2050 matrix | 7.98 | | 6.76 | 6.10 | 5.37 | 3.96 | 3.90 | | 3.52 | 2.66 | | | | |
| 65.16.2053 pisolites | | | | 6.13 | 5.39 | 4.17 | 3.91 | | 3.53 | | | | | |
| 65.16.2054a pisolites | | | | | 5.37 | | 3.90 | | 3.52 | | | | | |
| 65.16.2054b pisolites | | 7.13 | | | 5.36 | | 3.90 | 3.68 | 3.52 | 2.99 | 2.79 | 2.75 | 2.51 | |
| 65.16.2054c matrix | | 7.12 | | | 5.35 | | 3.89 | | 3.51 | | | 2.75 | | 2.62 |
| 8a/28/1b total rock | | | 6.75 | | 5.38 | | 3.88 | 3.66 | 3.51 | | | 2.75 | | 2.63 |
| 8a/28/1d fragments in matrix | | | | | 5.39 | 4.14 | 3.89 | | 3.53 | | | | | |
| 8a/28/1a oolitic fraction | | | | 6.15 | | | | | 3.52 | | | | | |
| 8a/28/1a massive fraction | | | 6.76 | 6.15 | 5.37 | | 3.88 | | 3.51 | | | | | 2.63 |

The order of intensity of the peaks is generally in the following order of 'd' spacing values, 5.37, 3.52, 3.90, and then, depending on whether they are present, 6.15, 2.75, 2.63.

These values were recorded using Cu radiation KV40, 24m.a., EMT1600, T.C.2, R.M. variable (8-32). Each sample was spanned from $10^\circ$ (2θ) to $50^\circ$ (2θ). The component responsible for these 'd' spacings could not be identified from the ASTMA Index to the Power Diffraction File (1963).

The following minerals are common associates of lateritic gibbsite but their 'd' spacings do not correspond to those tabulated. Goethite, lepidocrocite, diaspore, boemite, corundum, bayerite, kaolinite, illite, halloysite.

The presence of iron hydroxides which are obvious in the hand specimen of these rocks, and chalcedonic silica which was observed in the thin section of several samples, are not indicated on any of the charts.

It is assumed that these occur in a non-crystalline form. The iron hydroxides are probably amorphous; the silica is probably of colloidal origin and has not attained a crystalline structure.

## Genesis

These rocks are aluminous laterites which are generally considered to result from the weathering of aluminium silicate rocks yielding clays which are subsequently desilicated. This most commonly occurs under tropical conditions or under an alternating cycle of arid and humid-tropical conditions.

Gibbsite is most commonly derived from basic rocks, by the alteration of the more calcic plagioclase felspars, aluminous hornblende, epidote and biotite.

Gibbsite is itself changed to kaolinite if silica is available. This suggests that the rocks in the vicinity of sample no.65.16.2052 obtained a relatively greater amount of silica during their formation, than in other areas.

Most of the silica found in intersticies etc. within these rocks is secondary. This was most likely introduced by lateritisation processes subsequent to the accumulation of the bauxite.

The textures in some of the samples (notably 65.16.2053 and 65.16.1051) indicate that brecciation, and recementation by bauxitic material and secondary silica is common.

Ore mineralogy Report No.3 21st February, 1966

## AN EXAMINATION OF A CUPRIFEROUS SILTSTONE FROM THE KIMBERLEY PLATEAU, ASHTON 1:250,000 SHEET. W.A.

by

I.R. Pontifex

The sample was submitted by J.F. Ivanac for an examination of its copper content.

**Locality:** Kimberley Plateau, 30 miles N.E. of Kurinjie Station, E.568000 N.2982000.
**Field No:** Field No. 15/19/2. Registered No. 65030001

**Chemical analysis:**

Two representative samples from several pounds of the crushed rock were analysed on the atomic absorption spectrograph by N.J. Marshall for Cu, Pb, Co, Ni, and Zn. The results for both samples were essentially the same; they are given below in parts per million.

| Cu | Pb | Co | Ni | Zn |
|---|---|---|---|---|
| 3630 | -8 | 30 | 112 | 45 |

**Descritpion of the rock:**

This rock is essentially a grey, fissile, micaceous siltstone which is split easily along closely spaced cleavage planes. Small mica flakes and thin flakes of malachite (up to 2 mm. across) are scattered along the cleavage planes of the rock. Much of the malachite occurs along cleavage planes within chlorite and sericite.

The thin-section consists mainly of a homogeneous aggregate of equi-sized quartz grains (about 65% of the rock), and plagioclase and microcline grains (about 10% The average grain size is 0.05mm.

Intersticies within this aggregate are filled with chlorite ( about 20%) and minor amounts of malachite. The chlorite, particularly the longer flakes, have a generalised common orientation.

Accessory amounts of sericite opaque minerals, and tourmaline grains are scattered through the rock.

In polished section the opaque mineral grains were all seen to have a grey-pink colour and marked reflective pleochroism and anisotropism. Generally these were poorly polished because of an apparent parallel displacement of flaky structural components of the mineral. These opaque grains were identified as graphite.

No copper sulphides or oxides occur in the sections examined (at X500 magnification).

**Conclusions:**

The rock is a fissile micaceous siltstone. Small, but abundant flakes of malachite are localised along the rock cleavage planes. These are apparently entirely responsible for the anomalously high copper content of 0.36%, since no other copper minerals were recognised in thin sections or polished sections of the rock.

The malachite is undoubtedly a secondary mineral but its primary origin could not be determined. On a mineralogical basis it is suggested that the malachite may have derived from the secondary distribution of the alteration products of pre-existing copper minerals which were laid down within the enclosing siltstone.

Alternatively the malachite may have been deposited by supergene agencies which derived the copper from a source unrelated to the enclosing sediment.

The only opaque minerals identified in the rock is graphite.

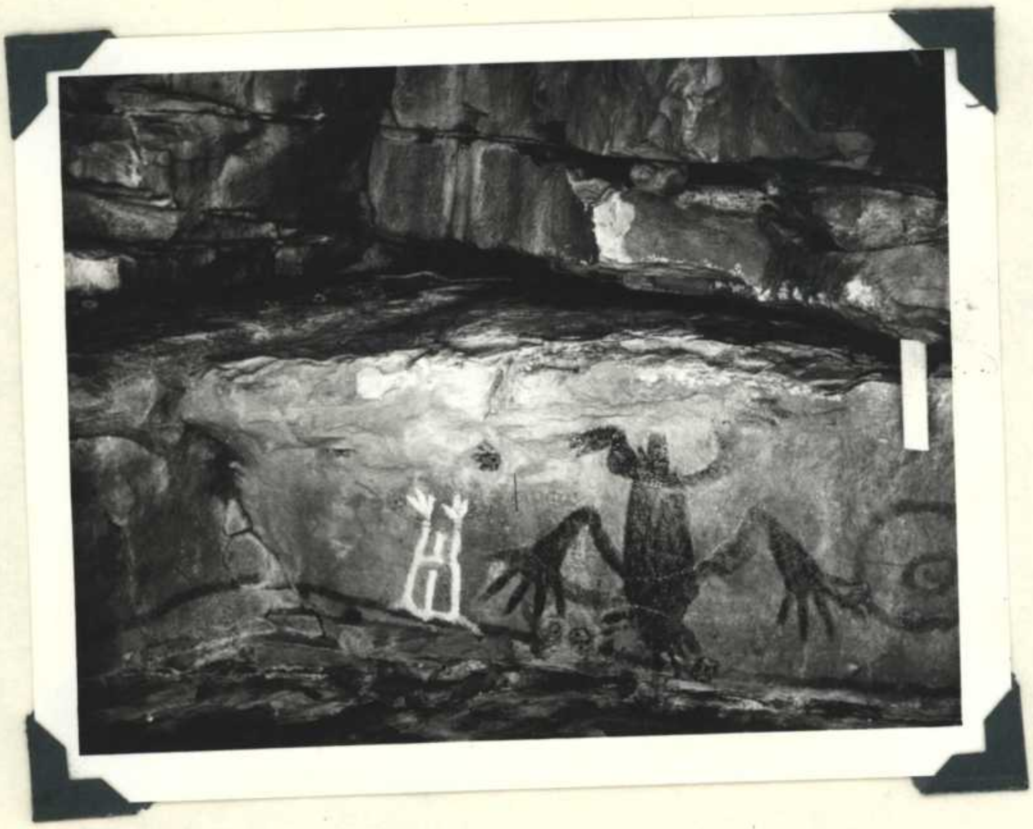


Fig. 19. Cave paintings
Lat. 15°47'S Long. 126°59'E

## APPENDIX 7

## ABORIGINAL CULTURE

In many parts of the Sheet area cave paintings, rock markings and ceremonial and burial grounds indicate the former widespread presence of an aboriginal society and culture independent of any white influence. Numerous references to the natives and their work were made by Morgan (op cit), and many of the localities cited by him have been placed on the 1:250,000 geological map of the Sheet area.

The native paintings are generally restricted to caves and sandstone overhangs which are located near permanent water e.g. the small gorge developed where the Drysdale River cuts through the Warton Sandstone. They are painted in white, red-brown and orange pigments, and show a variety of forms, some of which are shown in Fig. 19. Sets of concentric circles are very common, and in Fig. 19 a snake is apparently represented. The frog or kangaroo-like abstraction is composed of small charcoal pieces which have been stuck to the sandstone wall.

Ceremonial grounds appear to be confined to broad pavements of flat-lying sandstone. Morgan (op cit) noted that large blocks of sandstone were usually arranged in a circular manner, with some other blocks located at the centre of the circle. He also made reference to some bark canoes found beside the Drysdale River upstream from Drysdale Crossing.

Burial sites have been located beside the King Edward track approximately 30 miles north-west of Drysdale Crossing. These are usually small ledges or crevices in King Leopold Sandstone in which are numerous skeleton remains wrapped in rough coffin-like bark structures.

With the advance of civilization it appears that the aboriginals were increasingly confined to the central parts of the Kimberley Plateau, where the last of their numbers disappeared in the late nineteen-fifties.

AUSTRALIA 1:250,000 GEOLOGICAL SERIES

# ASHTON

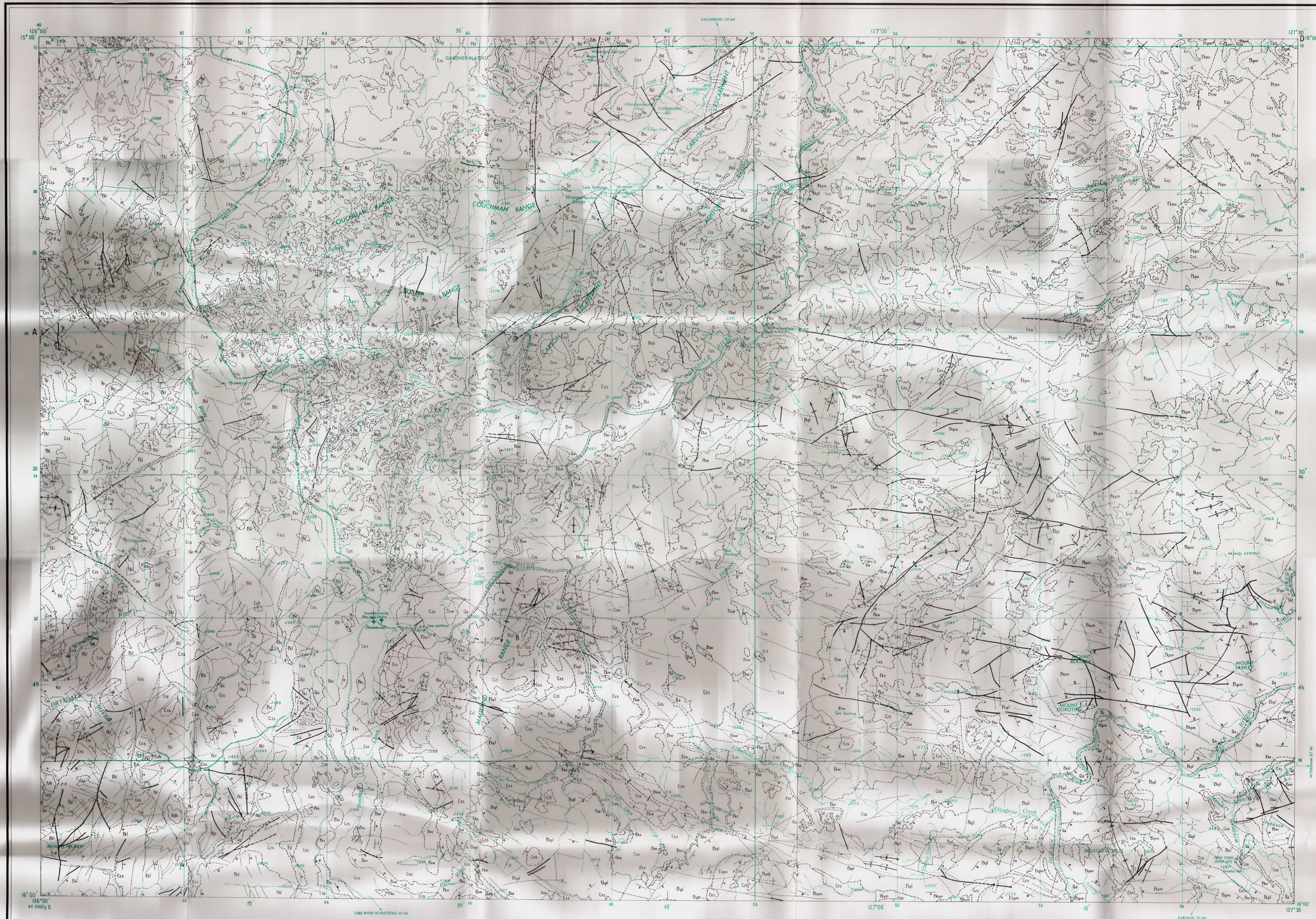
WESTERN AUSTRALIA

SHEET SD 52-13

PRELIMINARY EDITION, 1966

SUBJECT TO AMENDMENT






## Reference

| | | | | | | |
|---|---|---|---|---|---|---|
| CAINOZOIC | QUATERNARY | | | | Qa | Alluvium |
| | UNDIFFERENTIATED | | | | Czs | Soil, sandy soil, eluvium |
| | | | | | Czb | Black soil |
| | | | | | Czl | Ferruginous pisolitic, sandy lateritic soil |
| | TERTIARY | | | | Tb | Bauxite, aluminous laterite. |
| | | | | | Tp | Laterite, undifferentiated |
| PROTEROZOIC | ADELAIDEAN OR CARPENTARIAN | | Hart Dolerite | | Pdh | Dark grey-green medium-to coarse-grained dolerite |
| | CARPENTARIAN | Bastain Group | Mendena Formation | | Ptm | White fine-grained feldspathic sandstone, kaolinitic siltstone, mudstone conglomerate, minor quartz sandstone and arkose |
| | | Kimberley Group | Pentecost Sandstone | upper | Pkpu | White medium-to coarse-grained quartz sandstone; minor granule sandstone, fine-to medium-grained clayey quartz sandstone |
| | | | | middle | Pkpm | White to buff fine- to coarse-grained quartz sandstone and minor feldspathic sandstone; fine-grained glauconitic quartz sandstone and green grey micaceous siltstone at base |
| | | | | lower | Pkpl | White to pale brown medium-grained and minor coarse-grained quartz sandstone |
| | | | Elgee Siltstone | | Pke | Red-brown to grey-green fine-grained quartz sandstone, calcareous red-brown siltstone and mudstone; minor granule sandstone and white medium-grained quartz sandstone |
| | | | Warton Sandstone | | Pkw | White, cream and pale purple-grey coarse-to medium-grained quartz sandstone; minor feldspathic sandstone, fine-grained sandstone siltstone and micaceous pebble conglomerate near base |
| | | | Carson Volcanics | | Pkc | Grey-green to black massive and amygdaloidal basalt; grey-green amygdaloidal spilite; minor feldspathic sandstone, (stippled). stromatolitic chert and siltstone at top |
| | | | King Leopold Sandstone | | Pkl | White to buff, and purple-grey medium- to coarse-grained quartz sandstone, minor buff to brown fine-grained micaceous flaggy sandstone. |

Geological boundary

Anticline, showing plunge.

Syncline, showing plunge

Fault, showing relative horizontal movement

High-angle reverse fault

Shear zone

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)

Dip 15°-45° (air-photo interpretation)

Horizontal strata. (air-photo interpretation)

Trend lines (air-photo interpretation)

Joint pattern (air-photo interpretation)

Inclined platy flow

E1 Measured section

Dyke; b-basic, q-quartz

•Pb Minor mineral occurrence

Cu Copper

Pb Lead

Swamp, marsh

Vehicle track

"Doongan" Homestead

Landing ground

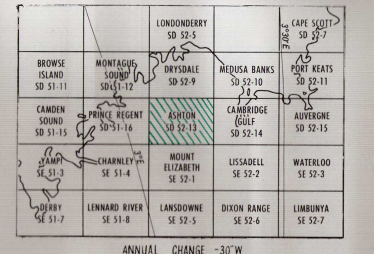
⊕ JMA4 Astronomical station

• 981' Height in feet, instrument levelled; datum: mean sea level

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 -30'W

Scale 1:250,000

5 0 5 10 15 MILES

5 0 5 10 15 20 25 KILOMETRES



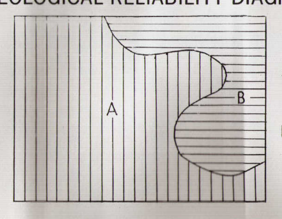
### Section

Attitude of faults not known

Cainozoic sediments, excepting Tertiary laterite, omitted from section.

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

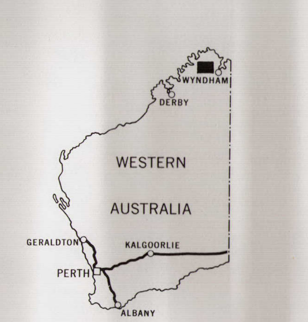
### GEOLOGICAL RELIABILITY DIAGRAM



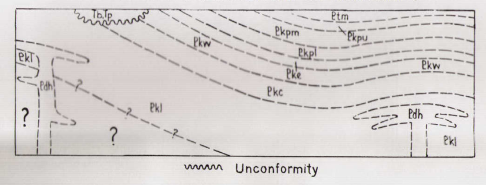

A Helicopter traverses and air-photo interpretation, minor ground traverses.

B Air-photo interpretation

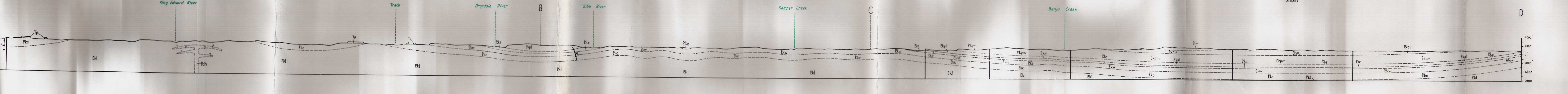
Geological Photo Interpretation by R.Richard (I.F.P 1964), G.M.Derrick (B.M.R 1965-66).
Geology, 1965 by: G.M.Derrick, D.C.Gellatly (B.M.R), I.R.Williams (G.S.W.A)
Compiled 1965 by: G.M.Derrick, J.L.McGovern (B.M.R)
Cartography by: Geological Branch B.M.R.




DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS




Unconformity

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