COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF SUPPLY AND DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN No. 16

A GEOLOGICAL RECONNAISSANCE OF THE KATHERINE-DARWIN REGION, NORTHERN TERRITORY

WITH NOTES ON THE MINERAL DEPOSITS

by L. C. NOAKES

Issued under the authority of Senator the Honourable John Armstrong, Minister for Supply and Development

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L. J. ROGERS, *Fuel Technologist*

This publication was prepared in the Geological Section

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Summary

This Bulletin presents the results of a geological reconnaissance of an area of approximately 27,000 square miles north and west of Katherine, in the Northern Territory. *The reconnaissance was made primarily to provide geological information required in connection with a land use survey which was made for the Northern Australia Development Committee under the direction of the Commonwealth Scientific and Industrial Research Organization.*

A geological map has been compiled and an account of the stratigraphy and a summary of the economic geology has been prepared.

An attempt has been made to reorganise the classification and nomenclature of rock units in the northern portion of the Territory in accordance with the Australian code of stratigraphic nomenclature (Glaessner, Thomas, Teichert and Raggatt, 1948).

The sedimentary rocks of the region consist largely of folded Lower Proterozoic sediments. These are overlain unconformably by arenaceous Upper Proterozoic sediments and these in turn are overlain by Lower Cambrian sandstones and limestones. Sedimentation took place during Palaeozoic time in the East Indies Geosyncline, but this, for the most part, lay to the north and west of the Northern Territory and in this region is represented only by a narrow belt of Upper Palaeozoic rocks along the western seaboard. The greater part of the region remained a land mass from Cambrian to late Jurassic or early Cretaceous time, when sediments were deposited in fresh water lakes. Marine sediments laid down in a shallow Lower Cretaceous sea were deposited upon these freshwater sediments. Since Cretaceous time the region has remained one of comparatively low relief. Extensive lateritisation occurred in Miocene (?) time and the "porcellanite," found overlying Lower Cretaceous sediments, is a remnant of this.

Uplift by warping and faulting took place late in Tertiary time and initiated the present cycle of erosion. Oscillations in sea level in Pleistocene and Recent time have led to the formation of coastal plains and of extensive alluvial deposits along the lower courses of the major streams.

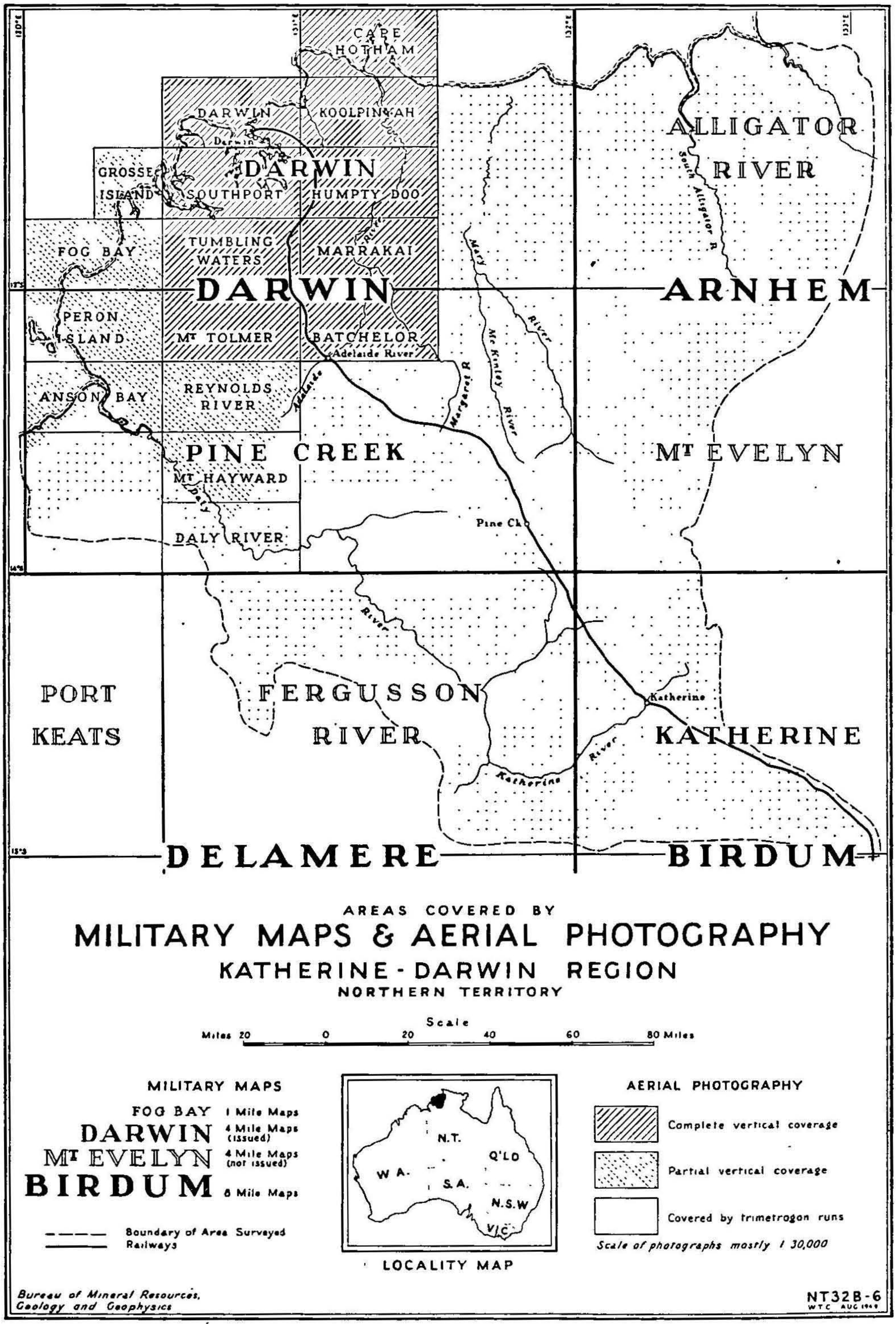
Igneous rocks include Lower Proterozoic amphibolites and granites which are associated with the Lower Proterozoic sediments, and of minor outcrops of volcanic rocks. Evidence for the age of the volcanics is not conclusive but they are believed to represent sporadic outbursts of volcanic activity in Lower Cambrian time prior to the deposition of the Lower Cambrian sediments.

Mineral production in the northern portion of the Territory reached a low level in 1946 when the value of minerals produced was approximately £3,228. This was due partly to the interruption of mining activity by World War II and partly to the fact that the established mineral fields offered few opportunities to miners and prospectors. Mineral production has increased in 1947/48 but it will remain small and largely dependent on syndicate mining for some time.

There are no areas within the region in which a search for petroleum could at present be justified.

The region has a comparatively high monsoonal rainfall (35-60 inches) and supplies of underground water are available in most places if they should be required.

PLATE 1.


CAPE HOTHAM
DARWIN
KOOLPINYAH
Darwin
DARWIN
GROSSE ISLAND
SOUTHPORT
HUMPTY DOO
ALLIGATOR RIVER
South Alligator R
FOG BAY
TUMBLING WATERS
MARRAKAI
DARWIN
ARNHEM
PERON ISLAND
Mt TOLMER
BATCHELOR
Adelaide River
Mary River
Mc Kinley River
Margaret R
ANSON BAY
REYNOLDS RIVER
Adelaide
PINE CREEK
Mt EVELYN
Mt HAYWARD
Daly
Pine Ck
DALY RIVER
River
PORT KEATS
FERGUSSON RIVER
Katherine
KATHERINE
Katherine River
DELAMERE
BIRDUM
AREAS COVERED BY
MILITARY MAPS & AERIAL PHOTOGRAPHY
KATHERINE - DARWIN REGION
NORTHERN TERRITORY
Scale
Miles 20 0 20 40 60 80 Miles
MILITARY MAPS
FOG BAY 1 Mile Maps
DARWIN 4 Mile Maps (issued)
Mt EVELYN 4 Mile Maps (not issued)
BIRDUM 8 Mile Maps
Boundary of Area Surveyed
Railways
N.T.
Q'LD
W.A.
S.A.
N.S.W
VIC
LOCALITY MAP
AERIAL PHOTOGRAPHY
Complete vertical coverage
Partial vertical coverage
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Bureau of Mineral Resources, Geology and Geophysics
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INTRODUCTION

General

The Northern Australia Development Committee (a Committee composed of representatives of the Commonwealth and the States of Queensland and Western Australia) has recommended that a series of regional surveys be made in Northern Australia with the object of providing data which will enable development of the region to be planned on a scientific basis. These surveys are being made under the direction of the Commonwealth Scientific and Industrial Research Organization.

From June to September 1946 the writer accompanied the C.S.I.R.O. party which was engaged in a reconnaissance survey of the Katherine-Darwin region. The other members of the party were Mr. C. S. Christian, ecologist and leader of the party; Mr. G. A. Stewart, soil surveyor; and Mr. S. T. Blake, botanist.

The area examined consists of 27,000 square miles in the north-western portion of the Northern Territory, west of longitude 133° east and between latitude 12° and 15° south. (See Plate 1 for locality map and reference to Australian map grid.)

The primary object of the survey was to determine pastoral and agricultural possibilities. A geologist was attached to the party mainly because the area to be surveyed had been very incompletely mapped and the existing geological records did not provide an adequate background for the soil and pastoral work to be undertaken. The primary function of the geologist was, therefore, to provide this background for soil interpretation, but it was also intended that he should gather as much information as possible on the stratigraphy and mineral possibilities of the area.

During the course of the investigation it was found that geological mapping provided the essential framework into which much of the other scientific data could be fitted, and a fairly complete investigation of the stratigraphy and geomorphology of the area became essential. An account of the stratigraphy and geomorphology are submitted in this report with a reconnaissance geological map of the region. This geological map is the result of the combined work of the party and could not have been completed without the full co-operation of the other members and particularly of Mr. G. A. Stewart.

An area of approximately 27,000 square miles had to be mapped by a series of traverses in a period of approximately four months, and the geology of the areas between these traverses had then to be filled in from available geological maps and records, and from aerial photographs which covered only parts of the region investigated. (See Plate 2.)

Subsequent field work will probably show inaccuracies due to incorrect interpolations or to faulty interpretation of aerial photography, but the map provides a fairly reliable picture of the regional geology and should form a useful basis for future geological work.

An attempt was also made to review the potentialities of the region in regard to mining, petroleum and underground water supplies; the results of this investigation are described in the economic section of the report.

Geological Mapping

The reconnaissance was carried out by a series of traverses made from a mobile base camp which was moved every three or four weeks to suit the requirements of the survey party. In general, the technical members of the party worked together as a team so that technical problems could be discussed in the field. This combination of ecologist, botanist, soil surveyor, and geologist proved highly successful as each member benefited from the technical knowledge of his colleagues.

The area is not well served by roads, but as the party travelled in jeeps it was possible to move about fairly freely. The total distance covered by the traverses was approximately 3,000 miles.

Army survey maps provided a basis for geological mapping, and these were supplemented, in some areas, by aerial photographs. The Army maps consisted of an eight mile to one inch series which covered the entire area, a four mile series which covered approximately 65 per cent. of the area, and a one mile series, compiled from aerial photographs, which covered approximately 20 per cent. of the area (see Plate 1).

The route of each traverse was plotted in the field on aerial photographs or on the largest scale map available. Spot heights were determined by barometer readings and corrected, as far as possible, by barographs based on barometer readings which were taken regularly at the base camp. Where the maps lacked adequate topographic detail to allow the traverse to be sketched, the route was plotted by compass traverses, using the speedometer and an aero compass mounted in one of the vehicles. Geological data were plotted on the maps or photographs as the traverse progressed and transferred to a reference plan on return to the base camp.

The topographical accuracy of both eight-mile and four-mile maps was generally poor, but few corrections or additions, beyond those of salient features, could be made during the reconnaissance.

The geology of the areas lying between the traverses had to be filled in from aerial photographs or from previous records and, where these were lacking, by interpolation. The greater part of this work was carried out jointly by the writer and G. A. Stewart at Canberra, where a master plan was assembled on a scale of four miles to one inch.

Geological boundaries established in the field or by stereoscopic examination of air photographs were marked on the vertical photographs and then transferred to the master plan by principal point plot. Geological boundaries were also plotted on some of the oblique photographs from trimetrogon runs and transferred to the plan. The photographic runs were oriented and the information transferred by means of the system of co-ordinates carried on the military plans. The completed geological plan and sections were then reduced by photography to a scale of 8 miles to 1 inch, which was adopted as the scale of the final plan.

Photographs covering every aspect of the reconnaissance were taken by C. S. Christian, and by arrangement with the Commonwealth Scientific and Industrial Research Organization, fifteen of them have been selected to illustrate this report. By arrangement with Department of Air, portions of two aerial photographs have also been reproduced to illustrate the report.

Previous Investigations

The first geological work of any consequence in the northern part of the Territory was carried out by the Rev. Tenison Woods, in the latter part of the nineteenth century, and results of his investigations were published in 1886.

After gold mining had been established in the Pine Creek area, about 1884, geological work was carried on by Inspectors of Mines, and toward the end of the century H. Y. L. Brown, then Government Geologist of South Australia, began periodical geological investigations in the Northern Territory.

In 1911 the Commonwealth Government became responsible for the administration of the Northern Territory, and geological work received new impetus. Dr. Woolnough made a reconnaissance of many of the accessible areas in the Northern Territory in 1912, and in the following years systematic geological surveys of mineral-bearing areas were carried out by the Director of Mines in the Territory, Dr. Jensen, assisted by G. J. Gray, and R. J. Winters. In 1924 Dr. Arthur Wade made a reconnaissance of the northern portion of the Territory to assess the prospects of finding petroleum, but he had little opportunity to carry out geological mapping.

Field parties of the Aerial, Geological and Geophysical Survey of Northern Australia commenced operations in the Northern Territory in 1935, and carried on until 1940, when field work was suspended. During these five years the Survey made detailed geological and geophysical examinations of many mines and mineral-bearing areas in the Katherine-Darwin region. Unfortunately, some of this work was not completed, and no regional geological map of the area was compiled.

The results of most of the investigations from 1886 to 1940 have been published. (See list of references at end of report.)

TOPOGRAPHY

The Katherine-Darwin region covers the north-western corner of the Northern Territory, west of longitude 133° east and between latitude 12° and 15° south.

The area lies within the zone of monsoonal climate, with a summer wet period of 3 to 5 months and a total annual rainfall of 35 to 60 inches. The topography of the area as a whole is mature, with a maximum relief of approximately 1,000 feet. It has been developed from an older, peneplaned surface which was warped and uplifted to initiate the present cycle of erosion. Remnants of the older land surface exist as lateritic plains, mesas and small tablelands in the Katherine-Darwin region, and extensive, although somewhat dissected, tablelands east and south of the region.

The Katherine-Darwin region may be divided into four broad physiographic units—The *Uplands*, the *Northern Plains*, the *Western Plains* and the *Daly River Basin.*

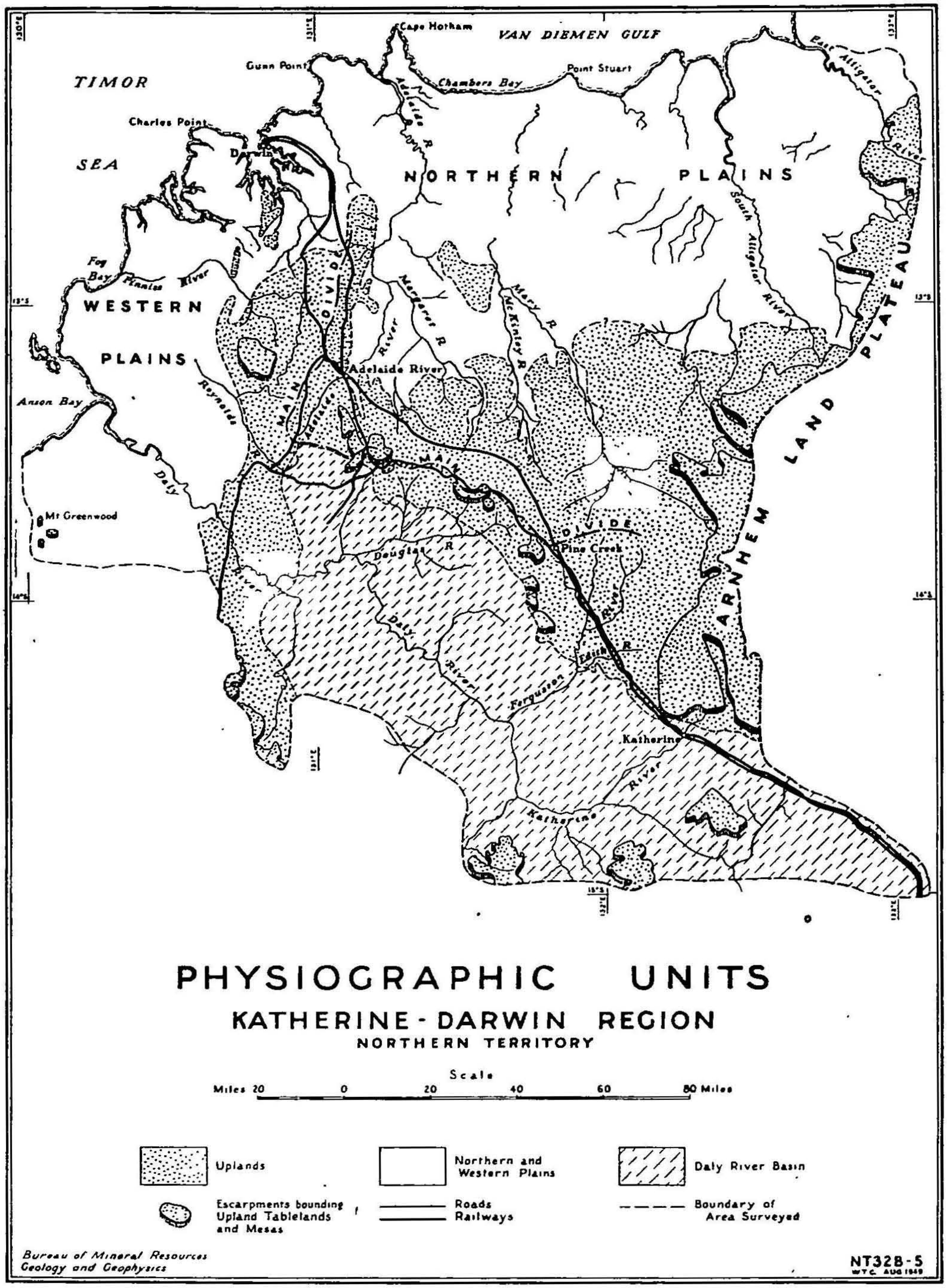
The *Uplands* occur in the central and eastern portions of the region in an irregular belt which runs from the south-western margin of the Arnhem Land Plateau in a west-north-westerly direction to the headwaters of the Adelaide and Finniss Rivers. From this locality a narrow belt of Uplands trends southward across the Daly Valley (see Plate 3).

The Uplands consist of ridges, mesas and small tablelands, and form the watersheds between the principal stream systems. A tenuous main divide, between streams flowing northward to Van Dieman Gulf and those flowing southward into the Daly River Basin, can be traced from the Arnhem Land Plateau in a west-north-westerly direction through Pine Creek to the headwaters of the Adelaide River, 20 miles south-south-west of Adelaide River township. From this locality, the main divide swings to the north and separates streams flowing west and north-west to the Timor Sea from the tributaries of the Adelaide River, which flows into Van Dieman Gulf. The main divide becomes progressively lower and less defined until it merges into gently dissected plain country about 20 miles north of Batchelor Siding.

In some places along the main divide the country is mature and represents undissected portions of the uplifted Tertiary peneplain. At other places dissection has commenced and the Tertiary land surface is represented by mesas or has been completely removed. On either side of the main divide, dissection is more pronounced in the ridges and foothills which lead down to the Northern Plains on one side and to the Daly River Basin or the Western Plains on the other.

From the headwaters of the Adelaide River, whence the main divide swings to the north, a spur of the Uplands, with mesas and small tablelands, trends southwards across the Daly Valley. The Daly River has cut through this spur, which forms the eastern limit of the Western Plains and the western boundary of the Daly River Basin.

The area lying between the Uplands and the northern coastline is designated the *Northern Plains.* The greater part of this area is flat or very gently undulating, but it does include, along its southern boundary, isolated low ridges and small areas in which some degree of dissection has taken place. Adelaide River township, which lies to the south-western margin of the Northern Plains, is approximately 70 miles from the northern coastline but



PHYSIOGRAPHIC UNITS

KATHERINE - DARWIN REGION

NORTHERN TERRITORY

at an elevation of only 170 ft. above sea level. Streams flowing northward from the Main Divide soon lose any semblance of youth and are mature or senile in their courses across the Northern Plains.

To the east, the Northern Plains are bounded by the Arnhem Land Plateau and, to the west, they merge into the Western Plains south and south-west of Darwin.

The *Western Plains* extend inland from the western coastline for distances up to 60 miles where they terminate abruptly against prominent north-south ridges. The Daly River traverses these plains for approximately 50 miles from the ridges to the sea, and its flow is subject to the tides over the whole of this distance. Large areas of the plains drain inward into swamps; and rivers, like the Reynolds, have no permanent channels connecting them with the sea. The southern limit of the plains is an irregular boundary formed by tablelands which constitute the divide between the Daly and the Fitzmaurice Rivers.

The *Daly River Basin* lies south of the main divide and has been formed in comparatively soft, horizontal strata. The broad shallow basin is about 180 miles long and 90 to 100 miles wide, and the topography here, though generally undulating, has not reached the same stage of maturity as is developed on the Northern and Western Plains. The Daly River and its tributaries are still actively eroding low horizontal bars of more resistant strata over which the rivers pass in rapids or falls. The Daly River Basin is bounded by the Main Divide on the north and on the south by an incised tableland, but to the east it merges gradually into the mature upland country south of Katherine.

GENERAL GEOLOGY

Introduction

GENERAL.—The Northern Territory forms part of the Australia Pre-Cambrian Shield and has been a comparatively stable area since Pre-Cambrian time. With the exception of the western seaboard, the country to the north and west of Katherine retains the record of only two periods of marine submergence since the Pre-Cambrian—one during Lower Cambrian and one during Lower Cretaceous time. There is no record of major diastrophism since the Proterozoic Era, and this long period of comparative stability and practically uninterrupted erosion has produced a region of low relief which consists, for the greater part, of Pre-Cambrian rocks.

The record of sedimentation includes Lower and Upper Proterozoic rocks, Lower Cambrian sediments and a veneer of Mesozoic deposits. A geosyncline developed to the west of this portion of the Territory during Palaeozoic time and the western coastal area consists mainly of Permian sediments deposited near the eastern margin of the trough.

The Lower Proterozoic sediments have been folded and metamorphosed, but there is little folding or metamorphism in the Upper Proterozoic rocks or in any of the later sedimentary deposits. The only known igneous intrusives are the Pre-Cambrian amphibolites and granites which intrude the Lower Proterozoic sediments. The absence of younger igneous intrusives is a further indication of the stability of the area since Pre-Cambrian time. Volcanic rocks occur in several places but all appear to belong to early Cambrian time when volcanic activity was widespread.

STRATIGRAPHIC NOMENCLATURE.—The nomenclature of rock units has presented a problem in preparing an outline of the geology of the region. Much of the existing nomenclature is confusing, partly because earlier workers have not followed a definite system in naming units, and partly because some units had not received formal names. An attempt has been made to review the nomenclature of the rocks that occur in the northern portion of the Territory in accordance with the principles of the draft Australian Stratigraphic Code (Glaessner, Raggatt, Teichert and Thomas, 1948).

In reviewing the nomenclature of rock units in the Northern Territory, all the formation names appearing in earlier records have been retained, although the status of the unit has, in some cases, been changed in accordance with the rules of the code adopted. Since geological information is still very incomplete, the suggested nomenclature is intended to form only a framework into which future workers can conveniently build. The suggested classification and nomenclature are set out in the accompanying stratigraphic table (Table 1) and the principal changes which have been made are discussed in the appropriate places in the text.

STRATIGRAPHY

LOWER PROTEROZOIC

Brock's Creek Group.—These metamorphics constitute the basement rock of the northern portion of the Northern Territory and outcrop over the greater part of the region lying north and west of Katherine.

A classification of these rocks was commenced by the Aerial, Geological and Geophysical Survey of Northern Australia in 1935. They divided the metamorphic rocks in the Pine Creek area into two groups—the Pine Creek Group and the Union Group (A.G.G.S.N.A., 1936b). The Survey recognised that the metamorphic rocks in the vicinity of the Daly River Police Post, on the northern side of the Daly River were very similar to the rocks of the Pine Creek and Union Groups, although no correlation could be definitely established. The metamorphic rocks north of the Daly River were referred to as the Daly River "stage" and those south of the Daly River in the Buldiva-Fletcher's Gully area, were referred to as the Muldiva "stage". (Hossfeld, 1937c, 4). It was recognised that the rocks of both of these "stages" were probably part of the same formation, and that the degree of regional metamorphism was higher in rocks of the Muldiva "stage."

Voisey (1939), a former officer of the Aerial, Geological and Geophysical Survey of Northern Australia, proposed a revised classification, based on that of the Aerial, Geological and Geophysical Survey of Northern Australia, in which he divided the Lower Proterozoic metamorphics into three units—the Golden Dyke "Series," the Pine Creek "Series" and the Muldiva "Series."

TABLE 1

STRATIGRAPHY OF THE KATHERINE-DARWIN AREA

	Name and Classification	Sub-Divisions	Description	Thickness	Correlation
Quaternary	—	—	River alluvia Marine coastal plains	—	—
Tertiary	—	—	Laterites No sediments identified	10′ +	—
Lower Cretaceous	Mullaman Group	Darwin Formation	Shales and sandy shales with Lower Cretaceous fossils	50′ + (up to 210′)	Portion of Winning "Series," Western Aust.; portion of Roma "Series," Queensland
		—	Poorly consolidated sandstones with some conglomerates and plant remains	(up to 210′)	Portion of Blythesdale "Series," Queensland
Permian	Port Keats Group	—	Sandstones, shales, and limestones with some freshwater sediments with traces of coal	1,500′ +	
Palaeozoic (relationship to Daly River and Pt. Keats Groups not established)	Elliott Creek Formation	—	Sandstone, shales, and limestone	Probably less than 500′	
Lower Cambrian	Daly River Group	—	Sandstone, limestone and shale	—	Mt. Elder "Series" and Negri "Series." Kimberley Division, W.A. Cambrian limestone and sandstone of Barkly Tableland and north-west Queensland
	Edith River Volcanics Maude Creek Volcanics Collia Creek Volcanics	—	Lavas and pyroclastics		Probably contemporaneous with Lower Cambrian volcanics of the Kimberley Division, W.A.
Upper Proterozoic	Buldiva Quartzite	—	Mainly quartzites, sandstones and grits with some shales—shallow water structures characteristically developed	1,000′ + (?)	Portion of Nullagine "Series," W.A.
Lower Proterozoic	Cullen and Litchfield Granites		Mainly biotite-hornblende granites	—	?
	Brock's Creek Group	Golden Dyke "Series"°	Sandstone, conglomerate, quartzite, slate and intrusive amphibolites	2,000′ + (15,000′ +)	Warramunga Group Tennant Creek, N.T. (?)
		Pine Creek "Series"° Pine Creek and Union Groups† Muldiva "Series"° Muldiva "stage"†	Slate, sandstone and tuff	? (15,000′ +)	
			Slate, phyllite and schist	? (15,000′ +)	

° Terms used by Voisey
† Terms used by A.G.G.S.N.A.
} but not recommended for immediate formal adoption.

These classifications provide a basis for the subdivision of the metamorphics, but before they can be used formally more field work is necessary. Until more geological mapping has been done it will not be possible to define the suggested rock units. It is suggested, therefore, that until this work has been done it is preferable to classify the metamorphic rocks to the north and west of Katherine as the Brock's Creek Group.

The Brock's Creek Group consists of folded and intruded geosynclinal deposits which originated as sandstones with, in places, conglomerates, tuffs, shales and unfossiliferous limestones. These have since been converted by regional metamorphism into silicified sandstones and tuffs, quartzites, slates and phyllites. In general, the grade of regional metamorphism is surprisingly low. Silicified contact metamorphic rocks, including hornfels and chiastolite slate, are found in proximity to the igneous intrusives. The Group is estimated by the Aerial, Geological and Geophysical Survey of Northern Australia (A.G.G.S.N.A., 1936b) to exceed 15,000 feet in thickness, and no unconformities have, so far, been noted anywhere in this considerable thickness of sediments.

The youngest rocks of the Group are believed to be the sandstones, conglomerates, quartzites and slates, with a total thickness of over 2,000 feet, between Adelaide River and Grove Hill, (Golden Dyke "Series" of Voisey). These rocks are intruded by thin sills of amphibolite. They may be traced for at least 15 miles north of the railway line at Brock's Creek and their outcrop extends south of the railway line for about 16 miles where they are overlain by Cambrian sediments. The slates, sandstones, and tuffs outcropping in the Pine Creek district (Pine Creek and Union Groups–A.G.G.S.N.A.–Pine Creek "Series"—Voisey) and west of the Adelaide River are believed to constitute the lower portion of the Brock's Greek Group. The quartzites, phyllites, and schists found along the Finniss River and near Fletcher's Gully, south of the Daly River (Muldiva "stage"—A.G.G.S.N.A.—Muldiva "Series"—Voisey) are similar to beds outcropping farther east, but have been subjected to a higher degree of regional metamorphism. There is strong evidence that regional metamorphism increases west of Adelaide River and the lower grade metamorphics grade into schists and schistose sandstones which occupy a meridional belt whose eastern margin runs roughly from Buldiva through the Daly River Police Station to Rum Jungle. Portion of this zone of intense regional metamorphism was subsequently granitised and the Litchfield Granite now forms the western boundary of the schistose rocks.

The Brock's Creek Group has been correlated, in the past, with the Warramunga Group at Tennant Creek (Sullivan 1946a) and with the Mosquito Creek "Series" in Western Australia (David, 1932), (Hossfeld 1937c, 4). There is some evidence to support these correlations; e.g., similarities in degree of metamorphism and structural history, type of sediments and kind of mineralisation.

It should be noted that some geologists in Western Australia place the Mosquito Creek "Series" in the Archaeozoic (Clarke, Prider and Teichert, 1944) whereas most geologists in Eastern Australia consider the Mosquito Creek

"Series" and its presumed eastern Australian equivalents as part of the Lower Proterozoic (David, 1932). Such differences of opinion are perhaps inevitable when an attempt is made to correlate groups of Pre-Cambrian rocks in widely separated localities. Geological work in the next few years, aided by age determinations on the basis of radio-activity, may provide a basis for re-classifying much of the Pre-Cambrian of Australia.

Granitic Rocks.—Granitic rocks are widely distributed throughout the region. They are associated with the Brock's Creek Group but are older than the Buldiva Quartzite and are therefore regarded as Lower Proterozoic. There are two major areas of granite—one in the east and one in the west—and many smaller outcrops. The major bodies have been named respectively the *Cullen Granite* and the *Litchfield Granite,** but no formal names are proposed for the smaller intrusives.†

The major bodies are essentially similar in mineral constitution and there appears to be no evidence to suggest that they belong to different epochs. The most common type is a medium-grained biotite-hornblende-granite in which hornblende constitutes only a small percentage of the ferromagnesian minerals. Marginal phases are commonly porphyritic in quartz, biotite or felspar, and more basic, dioritic phases are found in some places. Some marginal phases show directional structures, but in general there is little evidence of gneissic foliation.

The *Cullen Granite* is elongated in a north-south direction, but it does not conform closely to the structures of the Brock's Creek Group. The contact between the Cullen Granite and the Brock's Creek Group is fairly sharp. Contact metamorphic types such as hornfels are commonly found, but no granitisation was observed. Pegmatites and quartz veins carrying cassiterite and wolfram are found in some contact areas, but high temperature mineralisation does not appear to be as extensive as that associated with the Litchfield Granite.

The *Litchfield Granite* is the larger of the two major intrusive bodies, although a great part of it is now masked by Palaeozoic and Recent sediments. Its area of outcrop is elongated meridionally and conforms with the structural trends of the Brock's Creek Group. The eastern margin is well defined; the western boundary is exposed in the vicinity of Fog Bay but is masked farther south. The Litchfield Granite has been traced for 100 miles in a north-south direction and is at least 30 miles wide in the vicinity of the Daly River.

Although generally similar to the Cullen Granite, most of the Litchfield Granite appears to have been formed in place by processes of granitisation. The aureole of metamorphic rocks shows a higher degree of regional metamorphism than found elsewhere in the region, and the granite itself shows directional structures in some contact areas. The processes involved in the formation of granite are well shown by the granitised schists found on the

* Named by A.G.G.S.N.A. in 1936.

† Granite mapped in the Buldiva-Collia area by A.G.G.S.N.A. in 1936 was named Soldier's Creek Granite.

foreshores of Bynoe Harbour, and by the strongly metamorphosed remnants of the Brock's Creek Group, which occur on isolated ridges in the central portion of the granitic body. Murrenja Hill provides a good example of one of these remnants. High temperature mineralisation is common along the eastern margin of the Litchfield Granite where cassiterite- and tantalite-bearing pegmatites and greisen occur.

The smaller bodies of granite appear to be petrologically similar to the Cullen and Litchfield granites and are believed to be genetically associated with them.

UPPER PROTEROZOIC

Buldiva Quartzite.—The first formal name to be applied to the sandstones and quartzites of Upper Proterozoic age in this region was that of "Buldiva Quartzites."* This name was used by the Aerial, Geological and Geophysical Survey of Northern Australia for the quartzites mapped in the area between Buldiva and the Reynolds River (Hossfeld 1937c, 4). The name has therefore been retained, though in some places the formation consists of sandstone rather than quartzite. These beds are approximately 200 feet thick in the Buldiva area, but in other places they are probably more than a thousand feet thick. Because of similarity in age, structure and lithology they are, tentatively, correlated with the Nullagine "Series" of Western Australia or part thereof (Hossfeld, 1937c, 7).

During the reconnaissance, the Mount Tolmer Plateau was found to consist of Buldiva Quartzite, and a considerable extension of these beds, north of Blackfellows' Creek, has been traced on aerial photographs. The outcrop of the formation is very distinctive in aerial photographs, particularly where the dips are low (see Plates 5 and 6), and there seems little doubt that the greater part of the Arnhem Land Plateau which stretches from Katherine to the coast, east of the Alligator River, is composed of gently dipping Buldiva Quartzite. Outliers of this formation, faulted into the Brock's Creek Group, have also been identified on air photogaphs between Burrundie and the Arnhem Land Plateau. Another faulted outlier of the formation occurs along Hayes Creek, approximately one mile south of the Stuart Highway. Part of this outlier was mapped by the Aerial, Geological and Geophysical Survey of Northern Australia in 1939, but the map has not been published. It was recognised that the quartzite rested unconformably on the underlying Brock's Creek Group and the quartzite outlier was mapped as "Nullagine." This quartzite shows a higher degree of silicification than is usual in the Buldiva, but the outcrop abuts against a major fault and may have been silicified by solutions from that channel.

In the outcrops exposed on Mount Tolmer and at Blackfellows' Creek the Buldiva Quartzite consists mainly of sandstone and quartzite with some beds of grit and shale. The sandstone and quartzite, in most places, show abundant evidence of shallow water deposition in the form of beautifully preserved ripple

* Buldiva "Series" was first proposed embracing the Buldiva Quartzite and the overlying Cambrian limestone which was thought to be conformable with the quartzite.

marks, rain prints, sun cracks and some indeterminable markings like worm tracks (Plate 7, Figs. 1 and 2). The sandstone and quartzite are strongly jointed and, where the dips are low, provide a distinctive, tessellated pattern on air photographs. The two dominant joint planes are close to vertical and commonly trend north-west and north-east respectively. Furthermore, sub-horizontal bedding in conjunction with close vertical jointing produces characteristically rugged outcrops.

This distinctive joint pattern and the structures within the formation constitute some of the evidence for correlating the beds of the Arnhem Land Plateau with the Buldiva Quartzite (Plates 5 and 6). Outcrops of the Buldiva Quartzite were inspected by G. A. Stewart at Cannon Hill, near the north-western edge of the Arnhem Land Plateau, and these are described as hardened sandstone with some quartzite, grit and conglomerate (Plate 8, Fig. 1). Stewart also examined outcrops of the formation in the Katherine Gorge, 16 miles north-west of Katherine, and found quartzite and hard conglomerate, with well-worn boulders, lying sub-horizontally or dipping to the north-east at angles up to 25° (Plate 8, Fig. 2). The edge of the Arnhem Land Plateau was examined by the Aerial, Geological and Geophysical Survey of Northern Australia, approximately 28 miles north of Katherine, in 1939. The similarity of these rocks to those of the Buldiva Quartzite was recognised and the outcrops were mapped as Cambrian on the plan reproduced in the Annual Report of the Survey for 1939. The writer visited the north-western edge of the plateau, 10 miles north-west of Katherine, in 1947, and has no doubt that the outcrops in this locality are part of the Buldiva Quartzite.

The Buldiva Quartzite, although sub-horizontal in most places, shows some steep dips, probably due to monoclinal folding, and sharp folds have been observed adjacent to major faults such as those bounding the Rock Candy Range in the Daly River Valley. The beds exposed in the Arnhem Land Plateau commonly show dips which range from sub-horizontal to 30° in a north-easterly direction. These are in marked contrast to the sharp buckles developed against major faults. One such fault is clearly shown in aerial photographs in the cliffs on the west bank of the Katherine River about 12 miles upstream from the town. In this locality, strata with a low north-easterly dip have been buckled against the fault and turned into a vertical position. Identical structures, adjacent to faults, were observed in aerial photographs along the edge of the tableland north of this locality.

The maximum thickness of the formation is not known and the thickness observed varies considerably with the structure of the beds in relation to old surfaces of erosion. Sections which must aggregate more than a thousand feet can be seen in the aerial photographs in places where the formation has been folded, but no actual measurements have been made.

Age of Buldiva Quartzite.—The Buldiva Quartzite was previously considered to be Upper Proterozoic or Lower Cambrian in age (Voisey, 1939). Evidence gathered on the recent reconnaissance confirms this opinion, in that the deposition of the formation probably began in the Upper Proterozoic but may have continued into Lower Cambrian time. In the past, Buldiva Quartzite was considered conformable with the overlying Cambrian limestone because both units showed comparable dips in the sections examined in the Buldiva area (Voisey, 1939, 149), but it is now evident that either the Cambrian beds definitely overlap the Buldiva Quartzite or, more probably, that there was an interval of erosion before the Cambrian sediments were laid down.

No sections were found during the recent reconnaissance in which the relationship between the two formations could be clearly seen. The road from Tipperary to the Daly River Police Station passes from Cambrian limestone on to the Buldiva Quartzite 12 miles north-west of Tipperary Station, but here the observer passes from gently dipping limestones on to gently dipping quartzite across a wide zone in which an actual contact so far has not been found.

The real evidence of what may be termed a regional unconformity between the two units lies in the fact that the Cambrian limestones are found in many places along the northern edge of the Cambrian basin to rest directly on Lower Proterozoic metamorphic or granitic rocks. If the two groups are conformable, then the Cambrian limestones must have overlapped the Buldiva Quartzite, but this supposition appears untenable when the wide distribution of the Buldiva Quartzite in this region is taken into account. To the writer, the evidence suggests that the Buldiva Quartzite was deposited, possibly gently folded, and partly eroded before the deposition of Cambrian sediments commenced towards the end of Lower Cambrian time.

A point of considerable interest is that the Buldiva Quartzite appears comparable to some of the strata mapped by Wade as Lower Cambrian in the Kimberley Division of Western Australia and the northern portion of the Northern Territory (Wade, 1924). Wade describes quartzites, indurated shales, and siliceous flags with some calcareous horizons from the Osmond Range in the Kimberley Division. These sediments underlie the volcanics which Matheson and Teichert (1946, 78) have identified as lying at the base of the Cambrian sediments. Wade describes well preserved ripple marks in the quartzites as well as worm burrows and a variety of unidentified fossil markings.

Wade found quartzites with similar markings in the Victoria River and along the Arnhem Land coast of the Northern Territory and mapped them as Lower Cambrian. The conglomerates, quartzites, grits and shales which Wade describes as Lower Cambrian from Elcho Island, Cape Wilberforce and from other places along the Arnhem Land coast appear referable to the Buldiva Quartzite which forms the eastern and southern edge of the Arnhem Land Plateau. Wade mapped this plateau as sandstone of "unknown age," but he does not mention visiting the area and presumably based his conclusions on an older map by Woolnough (1912).

The work of Matheson and Teichert (1946) in the Kimberley Division indicates that the deposition of Cambrian sediments in that area probably commenced toward the end of Lower Cambrian time, so that the underlying basalts may be regarded as Lower Cambrian in age. The quartzites of the Mount Osmond Range described by Wade as underlying the basalts may therefore be regarded as Upper Proterozoic (although deposition may have extended into Lower Cambrian time), and, if his correlations are correct, the beds along the Arnhem Land coast are approximately of the same age.

However, it is apparent that the geological history of the Katherine-Darwin region differs from that of the Kimberleys in Western Australia and from that of the MacDonnell Ranges in Central Australia – two regions in which the relationship between Cambrian and Upper Palaeozoic sediments has been studied. In the MacDonnell Ranges, sedimentation persisted from Nullagine to at least Ordovician time (Madigan, 1932). In the Kimberleys, the oldest Cambrian sediments are probably upper Lower Cambrian, but beneath these sediments lie volcanics, approximately 3,000 feet in thickness, which in themselves represent a time break between the Nullagine sediments and the Lower Cambrian limestones. Farther north, in the Katherine-Darwin region, these Lower Cambrian volcanics are represented only by isolated outcrops of lavas and small intrusives so that the Upper Proterozoic sediments were not afforded a protecting cover of volcanic rocks. It is therefore concluded that the Buldiva Quartzite may be correlated with some part of the Nullagine "Series" of Western Australia and that, in the Katherine-Darwin region, a period of erosion may be recognised in Lower Cambrian time before the deposition of the Lower Cambrian sediments.

PALAEOZOIC

Lower Cambrian: Volcanic Rocks.—Volcanic rocks have previously been recorded from three localities within the region—on the Edith River and on Maude Creek, in the Katherine area, and at Collia Creek, south of the Daly River. With the exception of portion of the Edith River, none of these areas was investigated during the recent reconnaissance, but two small additional outcrops were found. The volcanic rocks include lavas and pyroclastics and may be appropriately termed "volcanics" (Glaessner *et al.*, 1948). They are therefore referred to as the Edith River Volcanics, the Maude Creek Volcanics and the Collia Creek Volcanics. Although they are probably contemporaneous, separate names have been retained until more convincing proof is obtained.

Woolnough (1912, 17) describes the Edith Creek Volcanics as basaltic rocks, ranging from dacites to basalts, accompanied by tuff, agglomerate and tuffaceous sandstone. These are folded into small anticlines and synclines but the predominant dip is towards the east. Woolnough considered that the volcanics underlie the Cambrian strata in the vicinity of Katherine, but Jensen (1915, 21) disagreed with this conclusion and thought that the volcanics were Permo-Carboniferous. The writer examined exposures along the main road north of Katherine and found Cambrian limestones overlying a ferruginous tuffaceous sandstone. In the aerial photographs this sandstone can be traced to the north into the volcanics with which it appears to be intercalated. Hence the writer believes that Woolnough offered the correct interpretation and that the Edith River Volcanics underlie the Daly River Group. Aerial photographs indicate that on their western boundary the volcanics are faulted into Lower Proterozoic metamorphics and, on their eastern boundary, are faulted against the Upper Proterozoic Buldiva Quartzite which also dips gently to the east. The topographical relief and the structure of the Buldiva Quartzite in area led Woolnough to consider them as younger rocks overlying the volcanics.

Less information is available concerning the Maude Creek Volcanics, but Woolnough (1912, 20) states that volcanic rocks can be traced at intervals from Edith River to a point three miles south of Maude Creek where amygdaloidal basaltic rocks occur. Purple tuffaceous rocks dipping south-east at 45° are recorded by Woolnough (1912, 21) along the Katherine River, about 4 miles north of Katherine, but these may belong to the Brock's Creek Group.

The Collia Creek Volcanics which outcrop in the headwaters of the Fish River near Buldiva are described as gritty felspathic quartzites passing upwards into tuff and overlain by porphyritic lavas (Voisey, 1939, 147). These volcanics rest on the Buldiva Quartzite and are overlain by Mesozoic sediments of the Mullaman Group.

Two very small outcrops of volcanic or hypabyssal rocks were mapped recently—an outcrop of basalt which forms a bar across the Daly River at the southern end of the Rock Candy Range (see Plate 9, Fig. 1), and an outcrop of dolerite 18 miles north-west of Tipperary Station, near the track to the Daly River Police Post. In both these outcrops, the igneous rocks rested on or intruded the Buldiva Quartzite, but their relationships to Cambrian sediments could not be determined.

Age of Volcanic Rocks.—The age of the volcanic rocks has been a source of contention for many years, and the field evidence is still not sufficient to establish their age beyond doubt. However, it is suggested that the volcanics are of Lower Cambrian age and that they overlie the Buldiva Quartzite and underlie the Daly River Group.

The evidence for this may be summarised as follows:—

In the first place, all the volcanics rest on Pre-Cambrian rocks—either Brock's Creek Group or Buldiva Quartzite – and have not been found overlying Cambrian limestone or any younger deposits.

In the second place, the volcanic rocks appear to be genetically associated with the extensive volcanics found to the south and south-east of the Katherine-Darwin region. Jensen recognised this and suggested a correlation in 1915 (Jensen, 1915, 21). However, he placed the volcanics in the Permo-Carboniferous, partly from his own observations of the outcrops of volcanic rocks between the Upper Daly River and Tanami to the south, and partly from old reports, including one by Hardman (1885) in which the age of the volcanics in the Kimberley area was considered to be Devonian or post Devonian. Since 1915 it has been established that the volcanics in the Kimberleys underlie the Cambrian limestones, and Matheson and Teichert (1946, 78) place them in the Lower Cambrian – between the Cambrian limestone and the quartzites of the Mount Osmond Range, which are regarded as Nullagine. A perusal of Jensen's report in which he considered the volcanics as younger than the Cambrian limestone shows that the outcrops he described in 1915 from south of the Daly River are very similar to those found in the Kimberleys, and he may have been misled by the fact that the volcanics are, in places, topographically higher than the limestones which occupy basins within the older volcanic rocks. It seems therefore that the Lower Cambrian volcanics of the Kimberley region can be traced to the north almost to the Daly River itself, and hence, very substantial evidence will be required before the volcanics of the Katherine and Daly River areas can be reasonably considered as younger than the extensive volcanics of the Kimberley region.

However, vulcanism was apparently much less extensive in the Katherine-Darwin region, and the available evidence suggests that similar conditions applied south-east of Katherine, since Lower Cambrian volcanics are not represented at the base of the Cambrian sediments in north-western Queensland (Bryan and Jones, 1945, 16).

Daly River Group.—Sediments—of Cambrian age—lie entirely within the Daly River watershed, in the southern part of the region. The only formal name given to these sediments is "Daly River Limestones," which Voisey (1939, 149), applied to limestone, shale and sandstone beds in the Daly River area.

Details of the sequence have not been established, but subsequent work will undoubtedly lead to recognition of lithological units of the rank of formation, hence it is suggested that the appropriate designation is "Daly River Group." The word "limestone" has been dropped from the name of the Group because recent field evidence suggests that the greater part of the unit may consist of beds of sandstone and shale. The Cambrian sediments in this region lie in a structural basin to which the name Daly River Basin may be applied. Coarse basal phases are apparently lacking, which suggests that the sediments were deposited in a quiet, transgressive sea.

The Group consists of sandstone, ferruginous sandstone, limestone and shale. The basal beds appear to be unfossiliferous, but a *Girvanella* horizon has been found in the higher beds. These sediments dip at very low angles and in some places have been gently folded. There are not many good outcrops of these rocks, so that an estimate of thickness cannot be made without more detailed structural and stratigraphical work.

Sediments near the base of the Group are well exposed in a section at the foot of a mesa on the road to Tipperary Station, 4 miles south of the Stuart Highway. At this point about 150 feet of alternating flaggy silicified limestone and sandstone are exposed. The sandstones are soft and unaltered and are composed largely of fine angular quartz grains—a characteristic of the sandstones of this Group. These beds rest on rocks of the Brock's Creek Group, although the actual contact was not observed. A close search failed to reveal any fossils, and the lower portion of the Group, here and in other areas, such as Katherine, appears to be unfossiliferous. Farther south, along the Tipperary road, 9 feet of marls are exposed in the bank of Station Creek, 3 miles north-east of Tipperary Station. These are higher in the sequence than the limestone and sandstone referred to above and may contain fossils although none was found during the present investigation.

The only fossils found in the Group came from a limestone which outcrops 5 miles south-west of Tipperary Station, where the rock was almost entirely composed of *Girvanella** (see Plate 9, Fig. 2). A similar occurrence has been described by Voisey (1939, 150) from near the head of the Fish River, south of the Daly River, and if this proves to be the same horizon it will be a useful key bed in the Daly River Group. It probably lies in the middle of the Group and appears to be several hundred feet stratigraphically above the base.

The strike of these sediments varies but is generally north-west in the Tipperary area and, although gentle folds are apparent, the general dip appears to be to the south-west at angles which range from 2-10°.

Although individual beds are thin—a few inches to two feet thick in most places — the limestones and sandstones of this Group provide good aquifers, and the apparent basin structure suggests that artesian water may be obtained from the central portion of the Daly River Basin. The Buldiva Quartzite underlies much of the basin, and the sandstones of this formation should also contain water.

Toward the middle of the Daly River Basin, between the Douglas and Katherine Rivers, beds of sandstone with some shale outcrop over a wide area, and may form the upper portion of the Daly River Group. The shales of Gypsy Creek may lie toward the base of these sandstones (see Plate 10, Figs. 1 and 2). North-west of the Ferguson River, and between the Ferguson and Katherine Rivers, the sandstones outcrop in mesas with, in some places, a capping of lateritised sediments of the Mullaman Group. Some of these outcrops appear as Carboniferous sandstone in Woolnough's map (Woolnough, 1912) and as sandstones of unknown age, probably dune deposits, on Wade's map (Wade, 1924). Limestone, stratigraphically lower than the sandstone, outcrops along the upper reaches of the Daly River and in some of its tributaries (see Plate 11, Fig. 1). It was not possible to map these sandstones during the recent reconnaissance, and their relationship to the Lower Cambrian sediments in the south-west and north-west needs more investigation.

Comparison of Daly River Group with Cambrian Sediments in Western Australia and Queensland.—The Cambrian sequence in the Kimberley Division of Western Australia has been worked out in some detail by Matheson and Teichert (1946, 80). They divide the Cambrian sediments into two conformable series—the Negri "Series," overlain by the Mount Elder "Series." The Negri "Series" consists of limestone and shale, some of which is fossiliferous,

* Identified by Miss Crespin, Bureau of Mineral Resources, Geology and Geophysics.

and the Mount Elder "Series" is composed largely of sandstone. Teichert has reviewed the palaeontological evidence for the age of these sediments and places the Negri "Series" in the upper part of the Lower Cambrian.

The sediments of the Daly River Group appear comparable with the Negri "Series" and are, therefore, regarded as upper Lower Cambrian. It is possible that the sandstones which appear to form the upper portion of the Daly River Group may be equivalents of the Mount Elder "Series" of Matheson and Teichert.

The oldest Cambrian sediments known in north-western Queensland consist of sandstones, siltstones, cherts, and limestones (Bryan and Jones, 1945, 16). The oldest of these sediments are referred to the uppermost part of the Lower Cambrian. It is therefore likely that the Daly River Group can be correlated with at least the lower beds of the Cambrian sequence in the Barkly Tablelands and in north-western Queensland.

Elliott Creek Formation.—Sediments here designated Elliott Creek Formation occupy a gently undulating terrain to the north of Mount Litchfield. The Formation includes a succession of apparently thin beds of sandstone, shale and limestone which lie horizontally in most of the outcrops examined. Outcrops are not plentiful, and geological information was based on auger hole samples over the greater part of the traverse made across the Formation.

The Formation takes its name from Elliott Creek, which drains much of the area in which the sediments outcrop. Cambrian sediments are shown in this area on Wade's map (Wade ,1924), but there is no record of a formal name for the sediments.

The basal beds are hardened sandstone overlain by brown, somewhat flaggy rocks which are very similar in appearance and grain-size to sandstones of the Daly River Group. Shale, sandstone and limestone appear higher in the sequence and these appear to alternate and provide many changes in soil across the gently undulating terrain. Only one bed of flaggy limestone was found in outcrop and this appeared to be 2 to 3 feet thick. The bed lay horizontally but had been extensively weathered and did not form continuous outcrops (Plate 11, Fig. 2).

The thickness of the Elliott Creek Formation cannot be estimated, but most of the outcrops appear to be approximately horizontal, and if this is so a thickness of less than 500 feet is indicated.

The age of the Elliott Creek Formation cannot be established, because no fossils were found in it. In lithology and degree of metamorphism it resembles both the Daly River Group (Cambrian) and the Port Keats Group (Permian), but it differs from the Pre-Cambrian and Mesozoic. There seems little doubt therefore that its age is Palaeozoic.

Permian: Port Keats Group.—Sediments of the Port Keats Group outcrop in a belt along the western seaboard of the area south of Port Blaze. In the latitude of Mount Greenwood the belt extends inland for about 40 miles;

farther south, beyond the limits of the area mapped, it appears to be wider. In some places these sediments are masked by recent alluvium and by mesas formed in Mesozoic sediments, but they outcrop in the headlands south of the mouth of the Daly River.

The writer has named these sediments the Port Keats Group, as no formal name or classification has been suggested in the past. Port Keats was one of the localities where the sediments were first studied and was the site of early boring operations. The beds warrant classification as a group because they comprise a considerable thickness of both marine and freshwater sediments which will undoubtedly be subdivided in future geological work.

Permian fossils were first found in these rocks by Commander Stokes near the mouth of the Victoria River in 1886, and the outcrops there and at Port Keats were subsequently described by Brown in 1906. Brown states that the rocks at Fossil Head consist of sandstone, shale and sandrock and provide the most typical section of the beds. These lie almost horizontally with a very gentle dip to the west.

Bores, in search of coal, were drilled between 1904 and 1908 at Port Keats, about 70 miles south-west from the mouth of the Daly River, and at Cape Ford, which lies midway between the Daly and Port Keats. The logs of bores drilled at both localities appear in reports by Brown (1906, 1908). One of the four bores drilled at Port Keats reached a depth below the surface of 1,505 feet and was entirely in Permian sediments (Brown, 1908, 9). The drill foreman's log of this bore (No. 4) showed alternations of sandstone and shale, some of them carbonaceous, but Brown notes that, in many instances, rocks recorded as shale and sandstone were highly calcareous and included limestone. The logs of earlier bores at the same locality (Brown, 1906, 38) recorded plant remains in carbonaceous shale, and there is no doubt that the Permian sequence in this area includes both marine and freshwater beds.

At Cape Ford, the second of two bores reached the limit of the drill at 1,506 feet below the surface and also was entirely in Permian sediments (Brown, 1908, 10). The Cape Ford section, judging by the foreman's log, appears essentially similar to that established at Port Keats. The fossils discovered in the Port Keats Group, including those found in the bores, were described by Etheridge (1907).

During the recent reconnaissance an attempt was made to reach the coast at Redcliff, which lies south of the Daly River, but the coastal plains proved too wet and the party was obliged to turn back when eight miles from the coastline. The Port Keats Group in this area occupies low-lying, very gently undulating country. Very few outcrops could be found, but the composition of the soils indicated that sandstone was the predominant rock type.

The only good exposure of the Group was found at the base of Mount Greenwood, under a capping of Mesozoic strata (Plate 12, Fig. 1). The section showed approximately 130 feet of sandstone with intercalations of sandy shale, but a careful search failed to reveal any identifiable fossils. Most of the sandstone, and particularly that exposed at the base of the section, was noticeably friable and appears comparable with the "friable, sugary, sand-rock" which Brown (1906, 16), described from Fossil Head. The beds at Mount Greenwood strike north-west and dip south-west at low angles which average approximately 5°.

On the geological map (Plate 2) an outcrop of the Port Keats Group is shown between Anson and Fog Bays, north of the Daly River. One traverse was made across this area, but most of the outcrops consist of laterite and the geology is based on soil interpretation. The underlying rocks are apparently shale, sandy shale and sandstone. Argillaceous rocks appear to be predominant and some of the shales are calcareous, particularly in the western part of the area. Fragments of shale and sandstone were found under laterite in one locality near the eastern edge of the area, but these gave no clue to structure and contained no palaeontological evidence beyond occasional worm tracks. The age of the sediments in this area is, therefore, in doubt, but they have been provisionally mapped as part of the Port Keats Group because of their lithology and geographical position.

MESOZOIC (LOWER CRETACEOUS)

Mullaman Group.—The occurrence of Mesozoic marine shales in the Darwin area has been known since 1895 (Brown, 1895), but the Mesozoic freshwater sandstones and conglomerates in the higher country south-east of Darwin were first recognised by the Aerial, Geological and Geophysical Survey of Northern Australia in 1936. In the recent field work, the marine shales have been traced from Darwin to the south-east and appear to overlie, conformably, the freshwater beds.

The Mesozoic sediments were not given formal names by past workers. However, they warrant classification as a group because they include at least two formations—an upper marine formation, for which the name of Darwin Formation is appropriate, and a lower formation of freshwater sediments. All of these beds have been mapped as one unit—the Mullaman Group—because the freshwater beds have not been adequately defined and could not be formally named or mapped as a separate unit. The Group is named after the Mullaman Tablelands, 5 miles west of Pine Creek, where fairly typical sections of these beds were described by Rev. Tenison Woods in 1886. The name "Darwin" could not be applied to the Group as only the upper portion of the unit is represented in that area.

The Aerial, Geological and Geophysical Survey of Northern Australia (Hossfeld, 1937c, 5) found plant fossils in basal beds of the Mullaman Group in the Buldiva area and there is little doubt that they are represented to the south-east of the Katherine-Darwin region, as the writer found plant remains low in lower Mullaman (?) sandstones in the Roper Valley in 1947. Also D. M. Traves subsequently found plant fossils (? *Otozamites*) near Newcastle Waters and near Cresswell in the Barkly Tablelands. Whitehouse (1940) records a fragment of quartzite containing *Otozamites* from the Barkly Tablelands, and this may have come from the vicinity of Creswell.

There is little evidence of the freshwater beds under the marine shales in the vicinity of Darwin, and it is doubtful whether they are represented at Mount Greenwood in the south-western corner of the region. This suggests that a westerly or north-westerly limit of the lacustrine sediments lies between Adelaide River and Darwin.

No plant fossils were found in other localities during the limited time which could be devoted to the search for them. However, there is evidence that sandstone and conglomerates occur at the base of the Mullaman Group over a very wide area, in the central, southern and south-eastern parts of the region.

Specimens collected from the Buldiva area by the Aerial, Geological and Geophysical Survey of Northern Australia were recently re-examined in the Bureau of Mineral Resources, Geology and Geophysics. Miss Crespin found radiolaria in specimens of shales, similar to those of the Darwin area, which represent beds stratigraphically higher than those in which the plant fossils were found, and thus proved that the Buldiva section contains both freshwater sediments and marine shales.

The sediments of the Darwin Formation were originally fine shale and sandy shale, with, in some places, beds of grit or fine conglomerate at the base.

Much of the original, shaly sediment, which contains radiolaria, has been converted into a tough, fine-grained rock to which the name "porcellanite" has been applied (Jensen, Gray and Winters, 1916, 16), ("magnesite" of Tenison Woods, 1864). The rock is a silicified clay-shale, usually white, yellow-brown or mottled, according to the distribution of limonitic staining. This "porcellanite" is of pedological origin and represents the mottled and pallid zones of a mature laterite* which was formed on the peneplaned Tertiary land surface.

During lateritisation, lower pedological horizons were formed in shales by severe leaching and most of the iron and portion of the silica were removed. Leaching of silica is shown by the corroded skeletons of radiolaria which, under the microscope, can be seen in all stages of disintegration. However, silica was re-deposited more or less irregularly within the mottled and pallid zones and produced a tough, fine-grained rock in which the original shaly bedding is generally obscured.

In many places, the surface soil and the massive ferruginous zone of the laterite have been removed by erosion and the silicified mottled and pallid zones exposed. These zones are, therefore, not stratigraphical horizons, although they behave as such, in most places, because the strata are commonly flat-lying. The extent to which the laterite transgresses bedding planes will not be known until details of the Mullaman Group can be worked out.

The source of the soluble silica is not known, but there seems to be a close connection between radiolarian shale and the silicified pallid zone, and it appears likely that the radiolaria have themselves provided much of the silica.

* In this report, the term "laterite" includes all or any of the zones of the lateritic profile (ferruginous, mottled, pallid, and siliceous zones) and is not used in its restricted sense where it is applied only to a portion of the ferruginous zone.

The silicified pallid zone is very widespread and radiolaria have been found in specimens of the rock in widely different localities. It seems significant that the only outcrops of Mullaman rocks upon which a cap rock of "porcellanite" was not found were those in the vicinity of Fog Bay, where the sediments were more arenaceous than those in the vicinity of Darwin and where radiolarian shales have not been identified.

G. A. Stewart believes that the texture of the parent material was an important factor in the formation of strongly silicified mottled and pallid zones, and he suggests that it was formed in shales which were intermediate in texture between coarse sandy phases and fine clay. The pedological processes involved in the formation of these zones are discussed by G. A. Stewart in his report on the soils of the area. This report will be published by the Commonwealth Scientific and Industrial Research Organization.

At Point Charles, 16 miles west of Darwin, the Darwin Formation is only 40 to 50 feet thick, and has been completely lateritised. The section at the lighthouse consists of 5 to 15 feet of massive laterite underlain by as much as 40 feet of leached shales forming the mottled and pallid zones of the profile (see Plate 13, Figs. 1 and 2). Secondary silicification in these zones is irregular and not so pronounced as in other areas where the strongly silicified "porcellanite" has been produced. At one place, the unconformity between the Darwin Formation and the underlying metamorphics of the Brock's Creek Group was observed. The contact lay within the pallid zone of the laterite, but relics of structure and bedding could be discerned on both sides of the contact.

The Darwin Formation is found occupying flat-topped hills south and east of Darwin. These mesas owe their characteristic sharp profile to the "porcellanite" which forms a tough cap rock over the underlying shales and sandstones (see Plate 12, Fig. 2). There is little doubt that the silicified pallid zone was formed only in shales of the Darwin Formation. Radiolaria have been identified by Miss Crespin in this zone from Darwin, Buldiva, and from mesas between Pine Creek and Adelaide River.

The thickness of the outliers of the Mullaman Group, mapped from aerial photographs of the Arnhem Tableland, is probably less than 100 feet. The lateritic cap has been completely eroded in some places but is present in others, and hence the Darwin Formation is almost certainly represented in this area (see Plate 5). The characteristic outcrop of the cap rock was the principal criterion used in identifying rocks of the Mullaman Group on aerial photographs, and some outcrops of this Group have probably been missed in areas where the cap rock has been eroded away.

The maximum observed thickness of the Mullaman Group is approximately 210 feet. This thickness was measured in mesas along the Stuart Highway, 12 miles north-east of Brock's Creek. In this section the Group consists of sandy sediments with at least one conglomerate bed towards the base. The upper 20 feet consists of white or buff-coloured silicified pallid zone overlying two feet of conglomerate. The silicified pallid zone shows a tendency to develop vertical cracks like columnar jointing, but traces of approximately horizontal bedding can be seen. The lower portion of the section is covered by detrital material and the detailed sequence cannot be established. The upper portion of this section, at least 20 to 30 feet thick, consists of Lower Cretaceous marine sediments, as radiolaria were identified in the cap rock by Miss Crespin; but no plant remains were found in the lower portion of the section, in which the freshwater sediments are most probably present.

At Mount Greenwood, south of the Daly River (Plate 12, Fig. 1), the upper 90 to 100 feet of sediments probably belong to the Mullaman Group and consist of 70 to 80 feet of shales and sandy beds overlain by 16 feet of "porcellanitic" material which includes a thin bed of ferruginous sandstone. The sandstone bed is horizontal and shows little alteration by pedological processes. A cast of *Dimitobelus* was found in the cap rock, but no plant fossils could be detected in the lower portion of the section.

Age of Mullaman Group.—The earliest note on the palaeontology of sediments of the Mullaman Group is contained in a paper by Hinde (1893) who found radiolaria in a specimen of silicified shale from Darwin. The specimen was collected at Darwin by Captain Moore, of H.M.S. *Penguin,* about 1891, and was subsequently forwarded to the Director of the Geological Survey in Great Britain. Hinde listed a number of species of radiolaria, but he concluded that it was not practicable to determine the age of the sediments from which they came.

The age of the shales in the Darwin area was determined in 1895, when H. Y. L. Brown collected, from Point Charles, ammonites and other fossils which Etheridge, Junior, identified as Cretaceous forms (Brown, 1895, 6).

Brown made a further collection of fossils in the Darwin area in 1905, and these were described by Etheridge (1907, 15). Etheridge concluded that the beds at Point Charles represented a distinct horizon in the Lower Cretaceous but he ventured no correlations with Cretaceous formations in other parts of the continent. He particularly noted "the plenitude of the fossils, their fragmentary condition in general, the absence of large or even medium-sized individuals, the abundance of the remains of cephalopods, and the number of small coprolites and slightly phosphatic nodules."

The exact age of the Darwin Formation has not been established. Whitehouse (1926) has suggested that the beds at Point Charles are of Upper Albian age and represent a horizon above that of the Tambo Series of Queensland. Miss Crespin* believes that the age of the Darwin Formation is Albian, but that there is insufficient evidence at present to correlate these radiolarian beds with subdivisions of the Lower Cretaceous sediments in Queensland.

Marine fossils of probable Lower Cretaceous age have also been found at Yeuralba, north-east of Katherine, by the Aerial, Geological and Geophysical Survey of Northern Australia. Unfortunately, these fossils were poorly preserved and no determinations were possible.

Also, as noted above, radiolaria have been identified by Miss Crespin in material collected by A.G.G.S.N.A. from the Buldiva area.

* Personal communication.

The plant fossils found by A.G.G.S.N.A. in basal beds of the Mullaman Group in the Buldiva area have been identified as *Otozamites bengalensis* by Dr. Walkom (Hossfeld, 1937c, 5). In Australia this plant has been found only in sediments considered to be of Jurassic age. However, in other countries *Otozamites bengalensis* occurs fairly abundantly in both Triassic and Lower Cretaceous formations (Walkom, 1921).

The freshwater beds apparently lie conformably below the Lower Cretaceous marine shales, which are not older than Aptian; hence the writer considers that these beds should be regarded as Lower Cretaceous rather than Upper Jurassic, and suggests a possible correlation with portion of the Blythesdale "Series" of Queensland (Bryan and Jones, 1946, 55).

It appears to the writer that the plant-bearing beds were deposited in a series of freshwater lakes which developed at the beginning of Cretaceous, or possibly towards the close of Jurassic, time and which gradually became submerged beneath the deposits of a Lower Cretaceous epeiric sea.

TERTIARY LATERITES

Areas of laterite have been delineated on the geological plan wherever possible because of their importance in the interpretation of soils and geomorphology, but the underlying parent rock is indicated in all laterite areas. Laterite masks all outcrops in some areas, but the character of the underlying rocks can be deduced from examination of lateritised material obtained from auger holes.

The most extensive areas of laterite lie in the northern and north-western parts of the region, where the late Tertiary land surface suffered comparatively little uplift, and where, in consequence, dissection of the laterites has been slow. Comparatively small areas of Tertiary laterite, mainly capping mesas, are found in the higher country to the south and south-east of Darwin. The lateritic profiles are almost completely preserved in many of the northern areas in which erosion has been restricted, but in the higher country to the south and south-east of Darwin, where the old land surface has undergone more uplift and erosion, the lateritic profile has been dissected. In many places the ferruginous zone has been removed and portion of the mottled and pallid zones exposed, particularly where these lower zones have been partially silicified and converted into quartzite (billy) or silicified clay-shales ("porcellanite").

All of these mature laterites are regarded as contemporaneous, and in this region, at least, there is a record of only one period, toward the close of the Tertiary cycle of erosion (in Upper Miocene time(?)) when the process of base-levelling was sufficiently far advanced to produce a very mature land surface over a wide area. As a result of greatly restricted erosion, deep soil cover formed over much of the region. The stability of the soil over a comparatively long interval and the persistence of tropical and sub-tropical climatic conditions enabled mature laterites to be developed.

In the present cycle of erosion, in which most of the Tertiary laterite has been removed, the climate of the region has remained, for the most part, conducive to lateritisation and lateritic podsols and immature lateritic soils are still forming at various levels within the region wherever geological and topographical conditions are suitable. However, these Quaternary lateritic soils can be distinguished by geomorphological differences from the mature laterite of the Tertiary landsurface.

PLEISTOCENE AND RECENT DEPOSITS

Pleistocene and Recent deposits consist mainly of river and coastal plain alluvia which constitute large areas of the Northern and Western Plains. The alluvium of the coastal plains is the more extensive of the two. These deposits extend inland for many miles along the valleys of the principal streams; they consist of mud and fine sand deposited in drowned river valleys, this drowning resulted from the last significant submergence of the coastline which Browne (1945) considers took place toward the close of Pleistocene time. Well preserved skeletons of crayfish* have been found by local inhabitants in the estuarine deposits at several places around the coast.

The rise in base level consequent on this submergence caused extensive alluviation along the river channels inland from the estuaries. Some of these deposits—e.g., on the Northern Plains—are sufficiently extensive to be shown on the geological map. This alluvium consists largely of fine sand and silt with some gravels at the base of the deposits. The thickness and size of the gravel probably increase upstream toward the head waters where erosion is still active.

In Mid-Recent time, the final eustatic movement took place and sea level fell about 20 feet to expose the estuarine deposits and slightly rejuvenate the lower courses of the streams. The exposed estuarine deposits became the coastal plains, and these carry raised beaches and shell remains for some miles inland from the present coastline.

Eustatic movement in Pleistocene and Recent time produced a series of coastline oscillations (Browne, 1945) and the deposition and subsequent exposure of the alluvia of the coastal plains have been referred to the latest of these movements—a submergence which Browne places at the end of the Pleistocene followed by an emergence in Mid-Recent time. More detailed mapping in the region may provide evidence of some of the earlier Pleistocene oscillations which could not be satisfactorily traced during the present investigation.

Some small lakes were formed by valley constriction during the present cycle of erosion. Conglomerates and sandy sediments were deposited in these and eventually removed partly or wholly by stream erosion. Remnants of Recent conglomerate were noted at the head of the Margaret River five miles south of Grove Hill, and in the banks of a small stream between the Douglas River and Gypsy Creek.

* One specimen from the mouth of the Daly River has been identified by Miss Crespin, Bureau of Mineral Resources, Geology and Geophysics, as *Thalassina anomala*.

STRUCTURAL GEOLOGY

Folding

The only sediments which have been closely folded in the area are those of the Brock's Creek Group. The recent reconnaissance provided no opportunity to trace the structural history of this Group, but some details of structure, in certain areas, have been published in reports of the Aerial, Geological and Geophysical Survey of Northern Australia, which are listed in the bibliography of this Bulletin.

The Buldiva Quartzite and the Daly River Group have been subjected to rather similar, broad folding movements, although the pronounced jointing and monoclinal folding observed in the Buldiva Quartzite appear to represent stronger forces than those responsible for the jointing and folding of the Cambrian beds.

The structure and distribution of the Buldiva Quartzite suggest a pattern of very broad domes and basins. Basin structures are apparent in the Daly River area where dips are to the east or south, and on the Arnhem Land Plateau where the beds dip consistently to the north-east. The sediments were apparently arched up between these areas, and remnants of the domal structure are preserved near Hayes Creek and south of Adelaide River. The distribution of Upper Proterozoic and Cambrian sediments in the vicinity of Hayes Creek suggests that folding and some erosion of the Buldiva Quartzite took place before Cambrian sediments were laid down.

The age of the gentle folding observed in some sections of the Daly River Group cannot, as yet, be determined. In the Kimberleys, to the south-west of the Katherine-Darwin region, the Cambrian sediments have been more strongly folded and it is likely that both groups of Cambrian rocks were folded at the same time.

It seems, then, that the history of earth movements in the Katherine-Darwin region, particularly during the Palaeozoic Era, is obscure because of the comparative stability of the area, and that much of this history must be sought in areas to the south and south-west where a more decipherable record is available.

Faulting

Prominent faults found in the field or identified on aerial photographs are shown on the geological map. There are probably at least three groups of faults represented in the area.

The oldest faults and shears are found in the Brock's Creek Group, associated with folding and ore emplacement. However, no attempt could be made to map these structures in the time available.

A second group of faults is represented by strong movements which displaced the Buldiva Quartzite and against which the formation is considerably buckled. The fault which forms the western side of the Katherine River valley, upstream from Katherine, belongs to this group, which may have been associated with gentle folding of the Buldiva Quartzite early in Palaeozoic time.

The third group of faults is associated with the Tertiary uplift. The most prominent faults observed in the area belong to this group and are marked by strong topographical expression and, in places, by hot springs (see Geological Map, Plate 2). The most prominent of these faults bounds the western edge of the Mount Tolmer Plateau and trends a little west of north for at least 50 miles. Palaeozoic beds of the Elliott Creek Formation and overlying Mesozoic sediments are down-faulted against the Pre-Cambrian rocks of the Tolmer Tableland. Other Tertiary faults appear in the Rock Candy Range and elsewhere in the Daly River Basin. Hot springs occur at Berry Spring (near Darwin), at Katherine, and on the Douglas River, and are probably all related to Tertiary faults, although this relationship could be definitely established only at the hot springs on the Douglas River.

GEOLOGICAL HISTORY

Archaeozoic rocks have not been found in the northern portion of the Territory. The geological history of the region opens with the deposition of the Brock's Creek Group in Lower Proterozoic time. These marine sediments were deposited in a great geosyncline whose southerly extension is difficult to trace. They were subsequently folded and metamorphosed by granitic intrusives.

The structure and metamorphism of the Brock's Creek Group provide the only evidence of major diastrophism in the area which has maintained a remarkable degree of stability since Lower Proterozoic time.

Uplift occurred and a considerable period of erosion ensued before the area was again submerged under an Upper Proterozoic or Nullagine sea. The sediments of the Buldiva Quartzite were then deposited, originally as sandstone and conglomerate in a shallow geosyncline or transgressive sea.

The deposition of the Buldiva Quartzite was followed by isolated outbursts of vulcanism in early Cambrian times, and this, in turn, by the deposition of limestones and sandstones in a quiet, transgressive, Lower Cambrian sea. The relationships between these transgressions is obscure, but there is a strong suggestion that a period of uplift and erosion may have intervened between the deposition of the Buldiva Quartzite and the deposition of the Lower Cambrian sediments.

The uplift which followed Cambrian sedimentation was accompanied by little deformation, and the Lower Cambrian sediments show little alteration and very gentle folding. In the northern portion of the Territory this uplift ushered in a period of remarkable stability which has extended, with only minor interruptions, from Cambrian to Recent time.

As a result of this stability, the area has remained one of comparatively low relief over the greater part of this time. The fact that the Cambrian sediments were not entirely removed during the remainder of the Palaeozoic Era, despite the apparent lack of protective covering, implies that the relief of the area was never high for any considerable period of time. The Lower Cretaceous land surface, represented by the surface on which the sediments of the Mullaman Group now rest, included large areas of comparatively soft

Lower Cambrian sediments in the Daly River Basin which were not to be extensively eroded until late in the Tertiary period.

However, active sedimentation took place during the Palaeozoic in the East Indies geosyncline to the immediate west of this area and the fringe of Upper Palaeozoic sediments along the western coast suggests that, during much of Palaeozoic time, the northern portion of the Territory remained a low-lying stable block which formed the eastern margin of the East Indies trough.

The Upper Palaeozoic sea probably reached its greatest eastern extension during Permian time when sediments of the Port Keats Group were deposited. The margin of the geosyncline moved westward after the deposition of the Permian sediments and by the end of the Jurassic the area was apparently a mature land surface cut in Pre-Cambrian, Lower Cambrian and, on the west, in Permian rocks.

The sandy beds at the base of the Mullaman Group suggest that freshwater lakes developed in the central and southern parts of the area at the end of the Jurassic or at the beginning of the Cretaceous period, but the north-western portion of the region was not affected until an epeiric sea submerged the entire area in Lower Cretaceous time. Fine-grained sediments including radiolarian shales were deposited in this sea, which can be traced eastward of Katherine and may have been continuous with the great Lower Cretaceous sea which covered much of Queensland and north-western New South Wales.

The Mullaman Group includes the latest marine sediments of any consequence in the northern portion of the Territory. The Group was probably never very thick, and the maximum thickness of the present exposures beneath the Tertiary land surface is little more than 200 feet. The fact that this Miocene (?) peneplain, in the northern part of the Territory, was cut largely in sediments of the Mullaman Group clearly suggests that the uplift in Mesozoic time must have been slight and comparatively even.

Thus the cycle of erosion which was initiated in Cretaceous time and continued until the late Middle Tertiary, probably began with a fairly low-lying land surface which presented little scope for erosion. By Miocene time the mantle of Lower Cretaceous sediments in the Katherine-Darwin region was very thin, and the peneplaned surface transgressed on to metamorphics of the Brock's Creek Group in the area now occupied by the Northern Plains. An outcrop of lateritised granite, which must have been an inlier at the time of lateritisation, was observed on the old land surface, about ten miles north-west from Pine Creek, and provides further indication of the thinning of Cretaceous sediments by erosion in Tertiary time.

Under conditions of high rainfall and with, in most places, a sub-stratum of soft sandy shales, conditions for lateritisation were ideal and a very deep lateritic profile was developed, probably in Middle or Upper Miocene time.*

* Dr. Teichert has observed laterite on Miocene sediments in the North-West Basin, Western Australia (personal communication), and this probably represents soils on the same Tertiary land surface which the writer has traced throughout the Northern Territory. Teichert refers to these Miocene sediments in "The Genus *Aturia* in the Tertiary of Australia," *Jour. Pal.*, Vol. 18, No. 1, 1944, and he found overlying laterite in the course of more recent investigations.

The so-called "porcellanite" of the Darwin Formation was formed as a soil horizon below this Tertiary land surface. The toughness of this material played an important part in the ensuing cycle of erosion, and little would remain of the Mullaman Group if it were not for the protection afforded by this fossil soil horizon.

The final movements which initiated the present cycle of erosion cannot be accurately placed but probably occurred in late Miocene time and were most likely synchronous with late Miocene folding in New Guinea and with uplifts in other parts of Australia. The present position of the Tertiary laterite, representing the older land surface, provides a useful clue to the nature of the late Tertiary uplift. The movement probably took place gradually over a considerable period of time, and the principal structure was a broad warp, made somewhat irregular by normal faulting, by which the old surface was warped upwards differentially—the amount of vertical movement tending to increase from north to south (see geological sections, Plate 2). The maximum elevation appears to have been attained in the vicinity of Pine Creek, as the lateritic cappings are lower to the south, across the Daly, and to the south-east, near Katherine.

It is interesting to note that the configuration of the northern coastline—in the Northern Territory and in the adjoining portions of Queensland and Western Australia—was largely determined by the pattern of warps and faults which resulted from these Tertiary movements.

GEOMORPHOLOGY

At the commencement of the present cycle of erosion, the Katherine-Darwin area had a low but definite relief, and it is possible to trace the development of the four main physiographical divisions—the Uplands, the Northern Plains, the Western Plains, and the Daly River Basin (see Plate 3).

All the stream erosion below the level of the Tertiary laterite has occurred since late Miocene (?) time and some idea of the amount of erosion can be obtained from sections accompanying the geological map (Plate 2).

The geomorphology of the region is discussed in detail in the revised general report of the Northern Australia Regional Survey which will be published as a bulletin by the Commonwealth Scientific and Industrial Research Organization, and only the salient points of the geomorphology are given here.

The Uplands

The major factors which determined the situation of the Uplands and of the main divide were the attitude and elevation of the warped and faulted Tertiary land surface. Remnants of the Tertiary land surface, in this region, are therefore found as mesas and tablelands in the higher portions of the Uplands, particularly along the main divide where little dissection has taken place, and as lateritic plains along the northern and north-western seaboard, where lack of relief has protected them from erosion.

The Tolmer Tableland and the long spur of elevated country which runs south from the head of the Adelaide River toward the Daly River owe their prominence to the resistant Buldiva Quartzite. South of the central divide, across the Daly Valley, and to the east in the Arnhem Land Plateau, erosion has made comparatively little progress in dissecting the uplifted Tertiary land surface—largely because of the resistant character of the gently-dipping Buldiva Quartzite which underlies much of this surface, particularly in the Arnhem Land Plateau.

Northern Plains

The development of the Northern Plains is easy to trace. Consequent streams, developed down northerly slopes of the warped Tertiary surface, cut slowly through the laterite into Lower Proterozoic rocks below.

The dominant north-south structure of the Brock's Creek Group then determined the drainage pattern and fixed the northerly flowing river system. This structural control is still evident in the upper portion of the north-flowing rivers. With the advancing cycle the outcrops of the Mullaman Group became an incised tableland, and eventually this was converted into isolated mesas by headward erosion of the streams.

The principal features which allowed maturity to be reached so quickly are: the northerly slope of the terrain before erosion commenced; the fact that the veneer of Lower Cretaceous sediments, with their tough lateritic capping, was restricted to the southern portion of the area; the high monsoonal rainfall; and the fact that the rivers could follow the northerly structural trends of the Brock's Creek Group with few barriers to resist erosion. With the exception of one or two infaulted blocks, which now form outliers towards the western edge of the plains, the Buldiva Quartzite had apparently been removed from this area before Cretaceous time.

The final stages of development of the Northern Plains were brought about by eustatic movements which affected all the Australian continent in Pleistocene and Recent time. A considerable rise in sea level submerged the fringe of the mature northern plain and drowned the valleys of the principal rivers. Sand and mud were deposited in these broad, shallow estuaries, and the rise in base level caused alluviation of stream channels for many miles upstream. Sea level then fell about 20 feet during Recent time and this exposed the wide, silted estuaries which form the coastal black soil plains. The streams were slightly rejuvenated and carved new channels through their alluvial deposits and through the new estuarine plains to the sea. Raised shallow beaches, sand dunes and marine beaches were found everywhere along the Northern Territory coastline and provide abundant evidence of this latest marine recession.

Western Plains

The development of the Western Plains followed much the same pattern as that of the Northern Plains. Maturity was reached quickly in this area because of the down-faulting of the western block, the original slope of the terrain and the softness of much of the rock beneath the Mullaman Group. In addition, over considerable areas of the Tertiary land surface, the lower horizons of the lateritic profile may not have been silicified.

The rise in sea level in Pleistocene time flooded great areas now occupied by coastal plains (see geological map, Plate 2), causing alluviation farther inland and the dumping of great quantities of sand along the foot of the Tolmer fault-scarp. The subsequent fall in sea level created great areas of black soil plain and swamp, and rivers such as the Reynolds have not had sufficient fall to cut channels through to the sea.

Daly River Basin

South of the main divide, consequent streams penetrated the Mullaman Group into the Lower Cambrian sediments. These rocks in themselves did not offer great resistance to erosion, but their sub-horizontal attitude prevented the streams from maintaining their channels in the most favourable strata, as they could in areas of folded Lower Proterozoic rocks. Thus, erosion within the Daly River Basin has been retarded in many places by horizontal bars which have imposed temporary base levels on the streams eroding them. Several low bars formed by tough limestone, and in one place by basalt, are still evident in the channel of the Daly River and its tributaries (Plate 11, Fig. 1).

Perhaps the principal reason why the Daly River Basin has not been more extensively eroded is that a barrier of tough Pre-Cambrian rocks lies normal to the course of the river for many miles downstream from the Rock Candy Range. Both Buldiva Quartzite and the metamorphics of the Brock's Creek Group strike approximately north and south, and they present a formidable barrier. The Daly River swings sharply to the north and north-west against the Buldiva Quartzites and has been forced to follow bedding and joint planes in cutting a series of gorges on its way to the Western Plains.

The Daly River Basin is still being actively eroded and has not reached the same degree of maturity as is found on the Northern and Western Plains.

ECONOMIC GEOLOGY

Introduction

As an introduction to this section of the report, it must be emphasised that the primary objective of the Northern Australian Regional Survey was an investigation of the pastoral and agricultural possibilities of Northern Australia. At the same time, the survey was concerned with providing a summary, in each region surveyed, of the natural resources and of the progress made by industries developing these resources.

The geological reconnaissance of the Katherine-Darwin region, supplemented by geological reports of previous workers, has provided information to form a summary of the mining industry in this region and for comments on the future prospects of mineral development; suggestions are made for assisting the mining industry and for future geological work. Notes on underground water and on petroleum prospects are included in this section of the report.

It was not possible to carry out detailed examinations of individual mines or of mining fields during the reconnaissance, but an attempt was made to visit all of the working mines in the region, and brief inspections were made of mining activities in the Pine Creek-Adelaide River area (Agicondi and Woggaman Goldfields), at Batchelor, at the Finniss River (Woggaman Goldfield), and at Fletcher's Gully, in the Daly River Goldfield. It was intended to visit mining centres at Wolfram Hill and Maranboy, but these visits had to be abandoned because of sickness.

The mineral deposits are discussed under "Goldfields," which are administrative districts in which minerals other than gold occur (see map, Plate 4). Table 2 gives the mineral production from the northern portion of the Territory from 1869 to 1948. The production figures from the individual mining areas are not available.

The information provided in geological and mining reports (particularly in those of the Aerial, Geological and Geophysical Survey of Northern Australia) has been used in compiling the following summary, and a list of these reports appears in the bibliography.

It is pointed out that the following notes on mining activity summarise the position at the end of 1946. Production figures for 1947 and 1947/48, from the Annual Reports of the Director of Mines in the Northern Territory, have been added to the Production Table, and notes on the changes in production since 1946 have been incorporated in the text.

However, the outlook for mineral production in this area has not significantly changed since 1946, and the increase in the number of mining claims and leases and the increase in mineral production in 1947 and 1948 were expected. No new mines or mineral areas have contributed to this increased production, which mainly consists of gold and tin concentrates won from mines or claims which were either in production or being prepared for production in 1946.

Mineral Deposits

GENERAL

Mineral deposits of commercial significance have been found only in Lower Proterozoic rocks of the Brock's Creek Group and are genetically associated with granitic intrusives. The deposits include those of gold, copper, silver-lead, tin, molybdenum, tantalum and tungsten.*

A broad zoning of the deposits in relation to the major granitic intrusives is apparent in the regional distribution of the deposits. The widest distribution of the high temperature minerals tantalite and cassiterite occurs along the eastern margin of the Litchfield Granite in metamorphics which show a higher grade of regional and thermal metamorphism than found elsewhere in the northern portion of the Territory. Deposits of copper, silver-lead and gold are found some distance from this contact in the Daly River Goldfield.

* Uranium minerals have been discovered recently near Rum Jungle.

The same broad zonal arrangement is found associated with granite contacts in the more easterly mineral fields. Deposits of tin, molybdenum and tungsten are found close to granite, as at Mount Shoobridge, Mount Wells, Wolfram Hill, etc., and silver-lead and gold deposits are found some distance from the contact of the granite and metamorphic rocks.

The metalliferous deposits occupy fracture systems in the Brock's Creek metamorphics, or, in rare cases, occur as replacement bodies. In general, the deposits are comparatively small.

The total value of mineral production from this area from 1869 to 1948 is £3,286,279, of which approximately two-thirds has been derived from gold. The value of annual production attained a maximum of £126,077 in 1906, but declined to approximately £43,000 in 1919/20 and to £3,228 in 1946. However, production in 1947 showed a slight increase, and in 1947/48 the value of mineral production reached £14,081. No gold production was recorded between 1939/1940 and 1947/1948, but some tin and wolfram concentrates were produced during World War II. Wolfram was produced in 1943, 1944, 1945 and in 1947/1948, and small parcels of tantalite in 1943, 1944, and in 1947/1948.

The number and total areas of gold mining leases and mineral leases increased from 84 leases, covering 1,923 acres, in 1946, to 134 leases, covering 3,269 acres, in 1947/1948.

THE AGICONDI GOLDFIELD (gold, tinstone, wolfram, silver-lead, copper)

The Agicondi Goldfield includes mining centres in the neighbourhood of Pine Creek and extends approximately from Burrundie eastwards to Mount Todd. Mining commenced in 1872 on this field and the maximum annual production was attained in 1894. Mining activity became intermittent during the present century and virtually ceased in 1935.

Deposits of gold, tin, wolfram, silver-lead and copper have been found—mainly in zones marginal to the granitic intrusives—and alluvial tin has been worked within the areas occupied by the granite. Most of the production, particularly in the earlier days of the field, has come from rich ore-shoots in the oxidised zone. Very little mining has been done below water level and few individual mine records have been kept. Thousands of Chinese were employed in the early days of mining (6,200 in 1889), and many of these eventually worked alluvial and lode deposits as tributers, but their mining practices lacked method and co-ordination.

In consequence, most of the easily accessible payable ore has been removed from the many old mines and workings in the Agicondi Goldfield and, for most of these mines, no adequate records appear to exist of the grade and tonnage of ore which was extracted or which was exposed in developmental workings.

It is interesting to note that gold production reached a maximum in this and in neighbouring districts when the greatest number of Chinese were engaged in the industry. The explanations are that, with cheap coolie labour, it was possible to mine and treat a grade of ore which would have been unpayable with white labour, and that many of the Chinese labourers, who worked underground or alluvial deposits as tributers, were content with small returns and a low standard of living.

The only mines still held under lease on the Agicondi Goldfield in 1946 were the Hercules (Sullivan, 1940), the Eleanor and the Enterprise (Hossfeld, 1936c).* These gold mines may warrant further investigation or development, but as none of them has a treatment plant or adequate proved reserves of ore, there is no assurance that production can be resumed. It is probable that patches of alluvium will be sluiced for gold or tin during wet seasons, but production from alluvial mining in the immediate future is likely to be small.

WOGGAMAN GOLDFIELD (gold, tinstone, tantalite, copper, iron)

The Woggaman Goldfield includes several mining localities between Burrundie and the Western Coast, of which the most important are the Burrundie-Adelaide River district, the Batchelor district, the Finniss River district and the Daly River district.

Burrundie-Adelaide River District (gold, tinstone, copper).—This district includes some of the oldest mining localities, and the general remarks made in regard to mining and future possibilities on the Agicondi Goldfield apply equally well to this district. Gold, tin and copper deposits have been mined in the past, but present production is limited to gold and tin and is very small. In 1948 twenty gold-mining leases were held in the district; one mineral lease was held at Mount Shoobridge and three at Mount Wells.

The only producing centre in 1946 was a syndicate mine (the Black and White) near Grove Hill, where a quartz stringer only one inch in width was sufficiently rich in gold to repay mining. Since 1946 a one-head stamp battery has been erected at the mine and gold was produced from a small crushing of 13 tons in 1947/1948.

The Fountain Head mine has a battery and should be producing in the near future. However, the mine is small and only partly developed and is not likely to become a major producer. Production of gold was expected from alluvial deposits in the Shackle Creek locality, and of tin from deposits at Mount Shoobridge, but only a very small quantity of gold was produced in these localities in 1947/1948.

Although there are no major mines from which production can be confidently anticipated, there are several gold mines which may warrant further investigation, particularly the Golden Dyke, the Iron Blow and the Cosmopolitan Howley. Details of these mines are contained in reports by Hossfeld (1936a, 1937b), Sullivan (1947) and in the annual report of the Aerial, Geological and Geophysical Survey of Northern Australia for 1939.

The extensive alluvial flats along the Mary, McKinley and Margaret Rivers have received some attention as potential dredging areas. Some of these flats

* In 1947/1948, seven tons of silver-lead concentrates were produced from the Evelyn Mine.

on the Upper McKinley were inspected during the recent reconnaissance and it is considered unlikely that the gravels underlying this alluvium have been sufficiently enriched to warrant dredging. Flats on the McKinley River were drilled in 1946 by a syndicate or company, but reliable information on the results of this testing is not available.

Batchelor District (gold, iron).—A gold-bearing quartz-tourmaline vein was discovered in the Batchelor area in 1943, and many leases were subsequently pegged in 1946. Twelve leases were still held in the area in 1948, but geological examination and further prospecting have shown that the area is unlikely to contain significant mineral deposits. Small high temperature vein deposits, similar to the original discovery, may occur in the locality. In 1947/1948 a small parcel of ore from this district was crushed at the Black and White Mine, at Fountain Head, and produced over 5 oz. of gold per ton.

Deposits of iron ore occur on the western side of the railway line, four miles north-north-west from Rum Jungle Siding, but the quantity and grade of ore available has not yet been established.

Finniss River District (tinstone, tantalite).—The Finniss River district lies in the meridional zone of pegmatite and greisen dykes which occurs along the eastern margin of the Litchfield Granite. Many of these dykes contain deposits of tin and tantalite. Tin has been produced from this area at intervals from about 1882, but tantalite was not produced until 1906.

The district is divided into a northern and southern portion by the Finniss River. The northern area, between the Finniss River and Bynoe Harbour, has been the more extensively worked in the past. The terrain consists of well-defined meridional ridges interspersed with wide flats which comprise at least one-third of the total area. Outcrops are found only along the ridges, and in consequence the area has been well prospected in the past.

It is probable that few new outcrops of pegmatite will be found in this area, but prospecting in the vicinity of abandoned workings is worthwhile. This applies particularly to eluvial material which consists of soil and detritus covering the slopes below the outcrops of pegmatite dykes and which, in many places, contain payable quantities of tin or tantalite. Only the most primitive methods have been used in working these deposits. Some of them might be worked profitably by methods such as ground sluicing by nozzle and pump.

The lode deposits are typical of those found in pegmatite dykes in that the mineralisation is erratic and ore irregularly distributed. For this reason they are not likely to justify development on a large scale, but some may be suitable for working by syndicates or parties who could extract small bodies of payable ore.

There were no batteries or sluicing plants operating in the northern area in 1946, but twelve mineral leases were held. Some prospecting was being carried out and a small company intended to sluice the tin and tantalite-bearing eluvial material at Mount Finniss. Approximately 1½ tons of tin concentrates were produced from the West Arm locality in 1947/1948, when the number of mineral leases held had increased to 22.

The southern portion of the area has good prospects and has not been intensively prospected. The Bamboo Creek tin mine at Bamboo Creek is producing tin concentrates from a pegmatite dyke, and at least two other parties at Bamboo Creek and at Walker's Creek were preparing to ground sluice eluvial tin deposits in 1946. Removal of the eluvial cover will allow prospecting in the bedrock for lode deposits.

At the Bamboo Creek Mine, tin ore, extracted by following erratic shoots within a pegmatite dyke or pipe, is treated in a small battery. The area may contain other similar lode deposits, and future development may prove sufficient small deposits to warrant the erection of a central treatment plant. Since 1946, production from Bamboo Creek has increased, and Northern Territory Tin and Tantalite N.L. have commenced the erection of a treatment plant at Walker's Creek. Twelve mineral leases were held in the southern portion of the Finniss River district in 1947/1948.

Some of the long, narrow flats in this area should contain old creek channels under the alluvium. Such channels may contain tin-bearing gravels, and it is suggested that a selected flat be drilled as a test.

The major factors hindering mineral development in the Finniss River district at present are transport and communication during the wet season, when the mining camps are completely isolated by floodwaters for several months. Families cannot be established in the area with any degree of safety while these conditions pertain, and it will be necessary to improve them if it is desired to establish a mining community in the area. Consideration might be given to methods of development of an aerial service and a teleradio installation which would provide essential transport and communication throughout the year.

Daly River District.—The Daly River district lies north of the Daly River in a narrow, meridional belt of Lower Proterozoic rocks, which extends from the Reynolds River south across the Daly River to Fletcher's Gully and Buldiva in the Daly River Goldfield.

Copper and tin have been produced from the Daly River district and deposits of silver-lead are known to occur, but there is little possibility that mining will be re-established.

One prospector hopes to recover alluvial tantalite in the vicinity of Noltenius Billabong, but the prospects of any significant production appear slight.

Copper was discovered between Noltenius Billabong and the Daly River in 1882, and 2,500 tons of copper ore (from the oxidized zone) averaging 28 per cent. metallic copper were produced from 1886 to 1891. The South Australian Government erected a reverberatory furnace in the vicinity of the mines in 1905, but the venture proved a financial failure and the smelter soon closed down.

DALY RIVER GOLDFIELD (gold, tinstone, copper)

Fletcher's Gully and Buldiva are the principal mining centres in the Daly River Goldfield. Gold and tin ore have been produced in the past, but these localities are very isolated and one mineral lease at Fletcher's Gully was the only tenement held in 1948. One gold mine was being worked at Fletcher's Gully in 1946, but only a small production of higher-grade ore from narrow veins seemed likely to result.

Both alluvial and lode tin have been produced from the Buldiva and Muldiva areas, and a little alluvial tin has been produced from Collia. Reports of the Aerial, Geological and Geophysical Survey of Northern Australia suggest that large deposits are not likely to be found in these areas, but that small deposits of alluvial and lode tin may be found, suitable for syndicate or small party operations.

The Daly River Goldfield includes a small area of Lower Proterozoic rocks about 20 miles south from Pine Creek, where the Daly River, Agicondi and Maranboy Goldfields adjoin. Deposits of gold and copper have been found in this corner of the goldfield, but no mining tenements are held in the area at present and resumption of mining activity seems very unlikely.

In general, prospects in the Daly River Goldfield appear uninviting, but tin deposits in the Buldiva-Collia area warrant further investigation. The major factors hindering mineral development in the Buldiva-Collia area is that of access and communication during the wet season, and if miners are willing to return to this area the possibility of establishing an aerodrome and teleradio service should be considered, as this would ensure that transport and communications were available throughout the year.

MARANBOY GOLDFIELD (gold, wolfram, tinstone, copper)

The Maranboy Goldfield includes the Maranboy and Yeuralba localities and extends westward to the vicinity of Mount Todd and Yenberrie Hill. Gold, wolfram, tinstone and copper have been mined from this field, but the production of these minerals in the immediate future will be small.

In the Maranboy area, 40 miles east of Katherine, small deposits of lode tin have been worked at intervals since 1913. Nineteen mineral leases were held in the area in 1948, and a Government battery is still operating. This battery can treat parcels of gold or tin ore railed from other areas, as well as tin ore mined from the Maranboy deposits. In 1948 four mineral leases were held at Yeuralba, approximately 25 miles north of Maranboy, and wolfram mining was revived in 1947/1948. Small deposits of both tin and wolfram have been worked sporadically in the past, and a survey of the Yeuralba and Maranboy areas is required to assess the future prospects of these areas. Small quantities of copper concentrates were produced from Yeuralba and Maranboy in 1947/1948.

The western portion of the Maranboy Goldfield embraces the Mount Todd and Driffield areas, but the only immediate prospects appear to lie in the

Mount Todd gold mine (Cottle, 1937b; Hossfeld and Nye, 1941). Sufficient capital has been raised recently to enable this mine to be opened up, and preparations are in hand to commence production in 1949.

DEPOSITS OF NON-METALLIC MINERALS

Barite has been reported from the Fletcher's Gully area; *ochre* from near Burrundie; *magnesite* from Stapleton Siding; and *amblygonite* has been mined in the Finniss River district. *Bauxite* may also occur in the region.

Speciments of the *barite* have been examined and are of good quality, but the size of the deposit is not known. The deposit lies south of the Daly River, where access is difficult, and this would add considerably to cost of production. Opening up of the deposit could only be regarded seriously at the present time if a large production of high-grade barite could be maintained at low cost. Hossfeld (1937c) records a reef, consisting largely of barite, about five miles north-west from Collia Waterhole, in the Buldiva-Collia area, and this may be the deposit reported to the writer as occurring in the Fletcher's Gully area. The dimensions of the reef are not given, but a sample of the material was examined by the Government Assayer at Darwin and an analysis of hand-picked crystals of barite showed a barium sulphate content of 95.90 per cent. (Hossfeld, 1937c, 10).

No information is available on the quality or size of the *ochre* deposits near Burrundie, and further investigation is suggested. A ready market exists in Australia for high-grade ochre.

The *magnesite* deposits near Stapleton Siding were not investigated, but the specimens examined are of good quality, and Mr. Sargeant, of Stapleton Siding, stated that analyses have proved the material to be satisfactory for refractory purposes. The mineral has been found in wells and post holes over a considerable area, and the deposit would be worth investigating if a profitable market could be found. The highest grade of magnesite realises approximately £2/10/- per ton at Australian ports, and hence, unless some special back-loading arrangements could be made, the cost of mining, carting (by rail or road 70 miles to Darwin), and shipping, would be prohibitive.

In brief, the present prospects of working deposits of barite and magnesite at a profit under the present marketing conditions are poor, but the type, size and grade of the ochre deposits should be investigated. These deposits would be valuable if local industries should be established, such as paint and refractory works, which would provide a local market for barite, ochres, magnesite and other non-metals. However, such development is most unlikely while the population of the Northern Territory remains small.

Amblygonite, a fluo-phosphate of aluminium and lithium, valued for its lithium content, occurs in pegmatite dykes about four miles west of Lucey Mine, in the Finniss River district. A total of 64 tons of amblygonite was mined from this locality between 1905 and 1925. The ore was hand-picked, transported by road to Darwin, and shipped to Germany. Production ceased when the content of lithium oxide in the ore declined below the minimum allowable grade of seven per cent. Amblygonite has also been reported at Mt. Litchfield.

There is some chance that deposits of *bauxite* (aluminous laterite) may exist in the Tertiary laterites of the Katherine-Darwin region. Tertiary laterites are widespread in their occurrence but to date none has been sampled and analysed for silica, iron and alumina content. The rock types most likely to give rise to aluminous laterite in this area are the Lower Cambrian volcanics, but unfortunately all of the known outcrops of these rocks lie well below the level of the old lateritised surface and consequently any laterite from this source has been removed by erosion. Most of the laterites in the Katherine-Darwin area have been formed from Lower Cretaceous shales, and there is a possibility that some aluminous laterite may have been formed although the shales appear siliceous in many places, and, in general, the lower horizons of the laterite profiles show varying degrees of secondary silicification.

SUMMARY AND CONCLUSIONS

Gold, wolfram, tin, tantalite, silver-lead and copper have been produced in the past from the northern portion of the Territory, and a small production of tin, tantalite, wolfram and gold can be expected in the immediate future.

Deposits of magnesite, barite and ochre have been noted. The present cost of mining and transport is too high to allow magnesite or barite to be exploited, although a sufficiently high grade of ochre might be profitably mined.

In 1946 a total of only 39 gold mining leases and 45 mineral leases was held in the northern portion of the Territory and production was at a very low level. However, this was not a true indication of the potentialities of the mineral fields, where mining was seriously interrupted during the latter half of the Second World War, and the small upward trend of production since 1946 may be expected to continue.

The principal reasons for the present lack of mining activity are believed to be:—

> There are few operating mines to offer employment; equipment for individual ventures is hard to obtain and, owing to the high general demand for labour in Australia, men can find work entailing less hardship and uncertainty than does mining or prospecting.
>
> In the less remote mineral fields the easily accessible oxidised ore has been extracted from the known deposits. Most of these lode deposits are too small to warrant further exploration by mining companies and, without records of the grade of ore below water level, such exploration is beyond the means of small syndicates or individuals.

Future prospects of metalliferous mining may be summarised as follows:—

Major Mines.—Only one major gold mine (at Mount Todd) has established ore reserves and the plant with which to produce. Two mines at Fountain Head have plant but the mines are small and only partly developed. There are no other mines with plant or with established ore reserves from which production can be expected in the immediate future.

Syndicate Mining—The present production of tin, tantalite and gold, both lode and alluvial, is the result of syndicate mining, which will remain the principal source of production for some time. Tin and tantalite are produced from a promising field in the Finniss River area where at least five parties are operating. Small tin deposits are being worked at Maranboy, and wolfram mining will be revived at Yeuralba and possibly at Wolfram Hill. The deposits of alluvial tin at Buldiva would probably attract attention if the localities were less isolated.

Prospects of New Discoveries.—In previous sections of the report, some comments have been made on the immediate future of mining in each of the recognised goldfields, based on known mineral deposits and on present mining activity. However, it is possible that additional ore bodies or new mineral fields may be discovered by surface prospecting or by scientific investigation.

Additional ore bodies may be discovered by surface prospecting in the established goldfields, but the prospects for discoveries are brighter in geologically favourable, but more remote, areas, where little prospecting has been done in the past. Geologically favourable areas are those in which outcrops of the Brock's Creek Group are associated with granite. One locality in which these conditions are fulfilled lies approximately 40 miles north of Grove Hill, another is approximately 65 miles north-east of Burrundie (see geological map, Plate 2). In addition, areas marginal to the Cullen Granite have probably not been exhaustively prospected, particularly towards the northern end, and mineral-bearing areas may also be exposed in the valley and gorges of streams which dissect the Arnhem Land Plateau.

In the west, the Bamboo Creek area, and the eastern margin of the Litchfield Granite, south of the Daly River, have not been exhaustively prospected, but no new prospecting areas can be indicated.

Apart from surface prospecting, new ore bodies may be found in the established goldfields by the application of geological and geophysical methods, followed or accompanied by diamond drilling. The Brock's Creek Group has been strongly folded in most of the mineral-bearing areas, and insufficient work has been done on the control of ore deposition, particularly in the Brock's Creek area. Detailed structural work was carried out in this area by the Aerial, Geological and Geophysical Survey of Northern Australia in 1939, but the detailed geological plans of the area have not yet been published, and the work of attempting to find new ore bodies in this area by structural methods was not completed. However, C. J. Sullivan, a former officer of the Aerial, Geological and Geophysical Survey of Northern Australia, has recently published some of his work on the Brock's Creek area and has suggested a new approach to the problem of finding new ore bodies (Sullivan, 1947). It is hoped that opportunity will be taken to complete this work by drilling, as the best chances of discovering additional ore bodies in the Katherine-Darwin region appear to lie in the application of scientific methods of prospecting.

RECOMMENDATIONS

It is suggested that development of the mineral deposits can best be assisted in the following ways:—

Technical Assistance.—A commendable policy of financial assistance to miners is in force in the Northern Territory and should be continued. Most of the men at present engaged in mining in the Darwin district require technical assistance in prospecting, or in sampling and developing mineral deposits or in selecting and operating mining and treatment plants. Such assistance could best be supplied by a geologist and an Inspector of Mines stationed in the northern portion of the Territory. An agreement has been made between the Departments of Interior and Supply and Development whereby the Bureau of Mineral Resources, Geology and Geophysics will provide resident geologists for the Northern Territory Administration. These officers will be available to give advice to the Administrator and the local community on all geological matters.

Geological Summaries.—The reports of the Aerial Geological and Geophysical Survey of Northern Australia and some of the older records provide detailed geological accounts of many of the mines and of some of the mining localities in this region. However, there is no report in which all the relevant information and recommendations are compiled to provide a complete summary of the mining prospects in each of the recognised districts. It is suggested that such summary reports should be compiled as the first step toward assessing the present potentialities of the mineral fields. In these reports, it should be possible to delineate those areas in which further prospecting or field work is warranted, and to indicate those mines and leases on which recommendations, made by geologists who have worked in the area previously, have not been carried out.

Geological and Geophysical Surveys.—Geological and, where necessary, geophysical surveys should be made of the known and potential mineral-bearing areas on the lines suggested under the heading "Prospects of New Discoveries," on page 46.

Government Treatment Plants.—A Government battery is operating at Maranboy, and there are no other mineral fields on which the erection of a central treatment plant can be recommended at present. Future development may warrant the re-installation of a Government battery in the Pine Creek-Adelaide River area, but until sufficient tribute ore is in sight, small parcels of high-grade ore can be treated at Maranboy, under the cartage-subsidy scheme or, by private arrangement, at Fountain Head.

A central treatment plant cannot yet be recommended in the Finniss River district, but future development may disclose sufficient tribute ore to justify this being done.

Communications.—Consideration should be given to improvement of facilities for transport and communication with the outlying mining fields, to encourage the growth of stable mining communities. As mentioned earlier in this report, the major factor hindering development of the Finniss River and Daly River areas is lack of access and communication in the wet season. It is suggested that this state of affairs might be remedied by the construction of aerodromes and by inauguration of subsidised aerial and teleradio services in those areas which are isolated during the wet season.

Petroleum Prospects

Dr. Wade, after his reconnaissance in 1924, reported that there was no prospect of petroleum occurring in that portion of the Northern Territory described in this Bulletin (Wade 1924, 38), and subsequent geological work has produced no new evidence on which a more optimistic opinion could be based.

The Palaeozoic sediments of the East Indies Geosyncline offer the best prospects for the occurrence of petroleum, and these, for the most part, are submerged beneath the Timor Sea to the west of the Territory coastline. However, they outcrop in the Burt Range Basin of Western Australia and in the adjacent portion of the Northern Territory, and these areas therefore warrant investigation. The Bonaparte Gulf Company Pty. Ltd., in which Zinc Corporation Limited, Vacuum Oil Company Pty. Ltd., and D'Arcy Exploration Company Ltd., are represented, carried out a preliminary survey of the Burt Range Basin in 1947, with a view to examining its oil possibilities.

Upper Palaeozoic sediments are also exposed (as a narrow belt) along the western coastline of the Territory south of the Daly River, but no evidence has been found as yet to suggest that they might contain oil.

There appears little possibility of oil deposits occurring in the Cambrian sediments of the Daly River Basin, but no bores have been put down in the central portion of the basin, and little is known about the stratigraphic succession, or the thickness and structure of the Daly River Group. The sediments have suffered little metamorphism but are intersected by major Tertiary faults. Hot springs were observed along at least one of these faults, but there is no record of the presence of oil or gas in the Daly River Basin.

Underground Water

Underground water resources in the northern portion of the Territory have not been closely investigated in the past because the area receives a comparativly high summer rainfall—35 to 60 inches per annum—and, in consequence, most of the areas occupied by miners or graziers are adequately supplied with water from waterholes and streams, or from shallow wells. However, the existing watering facilities were inadequate for Service requirements during World War II, and many bores were put down—principally along the north-south road and railway line. The Department of the Army has provided a complete record of these bores, and much of the following information is based on bore logs supplied by that Department.

From these bore logs and from the evidence provided by mines and wells, it is apparent that supplies of potable ground water are available over the greater part of the area and can be tapped by comparatively shallow bores. With the exception of sites which are topographically unsuitable, such as the crests of ridges and the tops of some of the mesas, supplies of water can probably be obtained at most places at depths of less than 300 feet. However, the depths at which significant supplies are found depends largely on geological factors, and consequently geological advice is advisable in selecting sites for bores, particularly in areas occupied by Pre-Cambrian or granitic rocks.

Many Army bores were put down in metamorphics of the Brock's Creek Group, and very few of these failed to produce water. Quantities of potable water ranging from 500 to 2,000 gallons per hour were pumped from depths which ranged from 25 to 300 feet below ground level. In most places major supplies were drawn from depths of 100 to 200 feet. There appears to be no difficulty in obtaining supplies of about 1,200 gallons per hour by pumping from this depth. The static water level in old mine workings, and in wells, in areas occupied by the Brock's Creek Group along the railway line commonly lies between 20 to 50 feet below the surface, and similar static water levels were noted in the Army bores. Underground water in the Brock's Creek Group is contained in fractures and joints in the rock rather than in porous strata, and in many places bores could be so sited that they would penetrate the most favourable, shattered beds.

Cambrian rocks consist largely of limestone and sandstone with varying degrees of silicification, and underground water is contained in porous limestone and sandstone aquifers as well as in fractures in the more silicified rock types. Between the Stuart Highway and the Daly River, and to the south-east of Katherine, quantities up to 1,800 gallons of water per hour have been obtained by pumping from depths which range from 70 to 170 feet.

It is probable that artesian water can be obtained in some Cambrian areas, particularly along the Daly River, but more information will be required on the structure of the Cambrian sediments before artesian basins can be delineated. At least one bore in the vicinity of Manbaloo encountered artesian water in limestone at a depth of 91 feet below the surface. The bore flowed at the rate of 800 gallons per hour, but 4,000 gallons per hour were produced by pumping. This artesian basin may only be small, but similar basins could probably be found in other areas occupied by Cambrian rocks.

In general, supplies of underground water should be readily obtainable throughout areas occupied by Cambrian sediments, and the quantities available should be comparable with those obtained from the Pre-Cambrian rocks.

According to the Army bore logs, supplies of underground water are not as readily obtainable in areas of granitic rocks as in the areas of Cambrian and Pre-Cambrian sediments discussed above. In areas underlain by granitic rocks, underground water is generally stored in joints and fractures and in weathered sections of the rocks. The yield at any bore site will, therefore, depend largely on the extent to which such fractures are developed in the underlying rock and in some places on the shape of the surface between the weathered and fresh rock. Supplies of underground water comparable with those encountered in areas occupied by the Brock's Creek Group should be obtainable from areas underlain by granite if the bore sites are located in strongly jointed rocks.

Areas which are occupied by sediments of the Mullaman Group include the low-lying country fringing the north-west coastline and the table-topped hills which are found farther inland. Supplies of underground water up to 1,500 gallons per hour have been obtained from bores in the vicinity of Darwin; however, this water is not drawn from the outcropping Mullaman (Cretaceous) sediments but from the Pre-Cambrian metamorphics which underlie the Mullaman Group.

Supplies of ground water should be readily available at shallow depths—in many places less than 100 feet—in the Western Plains, north and south of the Daly River, and it is noted that supplies of potable artesian water were tapped at 1,050 feet below the surface by a bore drilled in Permian sediments at Cape Ford, south-west from the mouth of the Daly River, in 1907. At a depth of 1,374 feet the flow of artesian water increased to 1,600 gallons per hour.

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With the exception of Plates 5 and 6, all the photographs reproduced in this bulletin were taken by C. S. Christian, Officer-in-Charge of the Northern Australia Regional Survey, and appear by courtesy of the photographer and of the Commonwealth Scientific and Industrial Research Organization.

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Canberra. August, 1949.

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PLATE 2

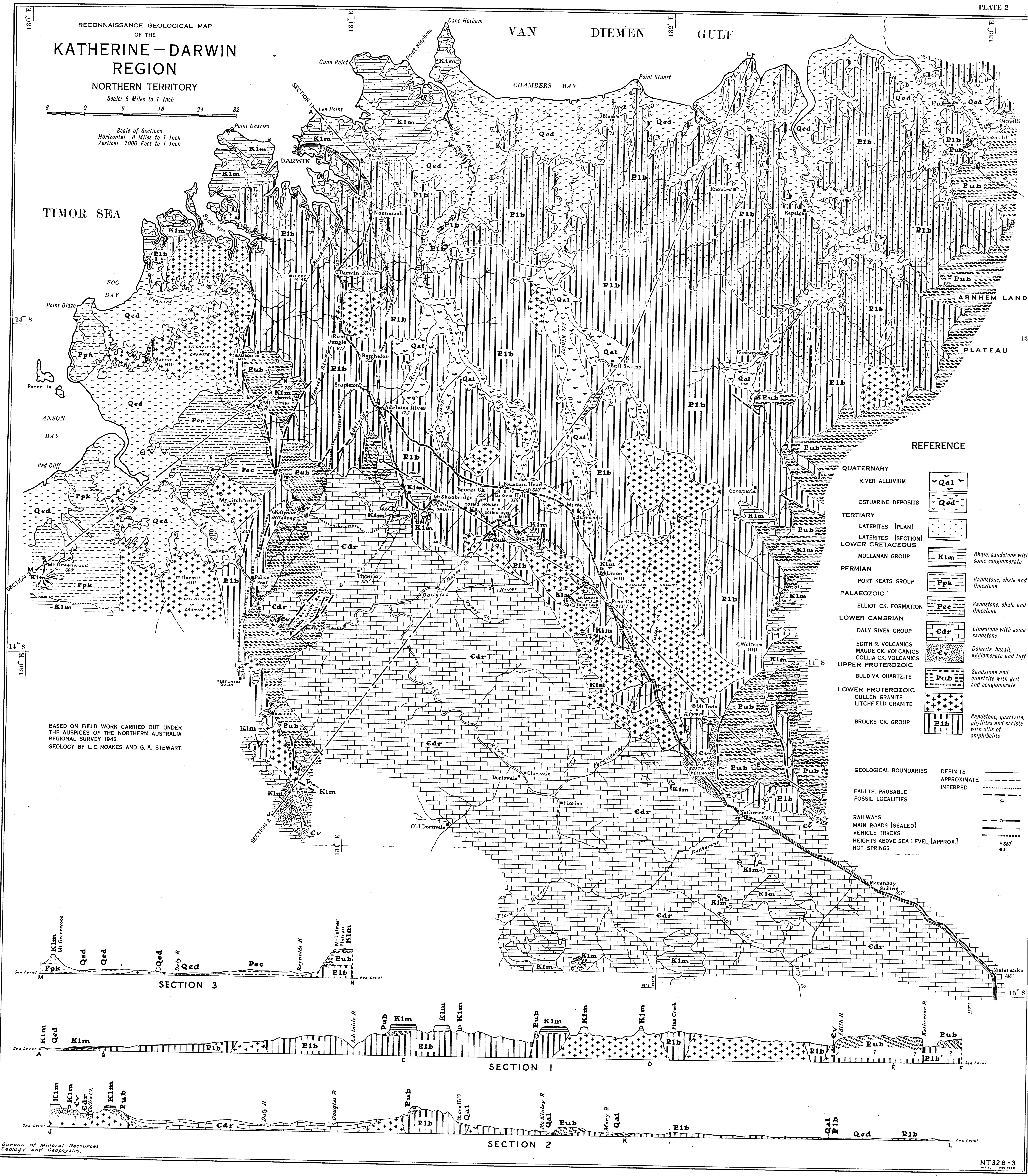
RECONNAISSANCE GEOLOGICAL MAP
OF THE
KATHERINE—DARWIN
REGION
NORTHERN TERRITORY
Scale: 8 Miles to 1 Inch
Scale of Sections
Horizontal 8 Miles to 1 Inch
Vertical 1000 Feet to 1 Inch
VAN DIEMEN GULF
TIMOR SEA
CHAMBERS BAY
ANSON BAY
FOG BAY
ARNHEM LAND PLATEAU
DARWIN
Katherine
Mataranka
REFERENCE
QUATERNARY
RIVER ALLUVIUM
ESTUARINE DEPOSITS
TERTIARY
LATERITES [PLAN]
LATERITES [SECTION]
LOWER CRETACEOUS
MULLAMAN GROUP
Shale, sandstone with some conglomerate
PERMIAN
PORT KEATS GROUP
Sandstone, shale and limestone
PALAEOZOIC
ELLIOT CK. FORMATION
Sandstone, shale and limestone
LOWER CAMBRIAN
DALY RIVER GROUP
Limestone with some sandstone
EDITH R. VOLCANICS
MAUDE CK. VOLCANICS
COLLIA CK. VOLCANICS
Dolerite, basalt, agglomerate and tuff
UPPER PROTEROZOIC
BULDIVA QUARTZITE
Sandstone and quartzite with grit and conglomerate
LOWER PROTEROZOIC
CULLEN GRANITE
LITCHFIELD GRANITE
BROCKS CK. GROUP
Sandstone, quartzite, phyllites and schists with sills of amphibolite
GEOLOGICAL BOUNDARIES
DEFINITE
APPROXIMATE
INFERRED
FAULTS, PROBABLE
FOSSIL LOCALITIES
RAILWAYS
MAIN ROADS [SEALED]
VEHICLE TRACKS
HEIGHTS ABOVE SEA LEVEL [APPROX.]
HOT SPRINGS
BASED ON FIELD WORK CARRIED OUT UNDER THE AUSPICES OF THE NORTHERN AUSTRALIA REGIONAL SURVEY 1946.
GEOLOGY BY L. C. NOAKES AND G. A. STEWART.
SECTION 3
SECTION 1
SECTION 2
Bureau of Mineral Resources
Geology and Geophysics.
NT32B-3

TABLE 2

MINERAL PRODUCTION, NORTHERN (DARWIN) DISTRICT, NORTHERN TERRITORY

(Partly adapted from table given as supplement to Aerial, Geological and Geophysical Survey of Northern Australia Report for period ended 30th June, 1940).

	Gold Bullion		Tin Concentrates		Wolfram Concentrates		Copper Concentrates		Silver-Lead		Tantalite Concentrates		Silver Ore		Total Value
	ozs.	£	tons	£	tons	£	tons	£	tons	£	tons	£	tons	£	£
1869 to August 17, 1880	15,000*	52,500	—	—	—	—	—	—	—	—	—	—	—	—	52,500
1880		680	—	—	—	—	—	—	—	—	—	—	—	—	680
1881		111,945	—	—	—	—	—	—	—	—	—	—	—	—	111,945
1882		80,720		1,650	—	—		206	—	—	—	—	—	—	82,576
1883		77,195		871	—	—		—	—	—	—	—	—	—	78,066
1884		77,935	113	814	—	—		—	—	—	—	—	—	—	78,749
1885		70,414		135	—	—	1,411	13,775	—	—	—	—	—	—	84,324
1886		63,139		78	—	—		9,492	—	—	—	—		303	73,012
1887		68,774		1,322	—	—		5,888	295	13,675	—	—		—	89,659
1888		34,802		3,159	—	—		1,360		15,463	—	—		1,491	56,275
1889		47,339		4,360	—	—		11,565	369	2,310	—	—		3,849	69,423
1890		80,524		6,140	—	—		4,600		647	—	—		3,720	95,631
1891		98,149		1,870	—	—	3,135	3,619		4,120	—	—		20	107,778
1892		109,228	546	2,433	—	—		2,155	—	—	—	—		1,640	115,456
1893		108,110		1,595	—	—		1,190	—	—	—	—	710	150	111,179
1894		109,621		1,251	—	—		1,204	—	—	—	—		115	116,999
1895	605,954	102782		1,815	—	—		410	—	—	—	—		—	107,645
1896		81,200		530	—	—	—	—	—	—	—	—		1,230	83,692
1897		81,024		—	—	—	—	—	—	—	—	—		—	81.024
1898		84,744		100	—	—	—	—	—	—	—	—		—	84,844
1899		60.648	5	180	—	—	—	—	—	—	—	—		—	60,828
1900		61,089	17	774	—	—	438	14,095	—	—	—	—		523	76,480
1901		61,187	80	2,105	2	175	429	2,345	—	—	—	—	—	20	65,832
1902		61,379	120	5,985	—	—	142	1,813	—	—	—	—	—	—	69,177
1903		41,629	171	10,773	—	—	3	55	—	—	—	—	—	—	52,457
1904		40,926	366	27,360	28	2,500	346	27,029	167	1,386	—	—	—	—	99,201
1905		47,246	288	25,877	25	2,573	—†	16,336	130	1,303	—	—	—	—	93,335
1906		33,637	398	33,837	108	7,144	955	48,760	232	2,355	2.10	140	—	—	126,077
1907		18,279	436	41,365	91	11,451	832	15,031	297	2,093	—	—	—	—	88,219
1908		21,095	441	35,876	35	1,925	525	7,968	2	30	—	—	—	—	67,194
1909		24,148	220	32,741	32	4,105	—†	3,742	—	—	—	—	—	—	64,736
1910	7,138	21,711	364	31,113	70	6,686	97	1,196	—	—	—	—	—	—	60,706
1911	8,839	26,702	239	22,900	50	4,048	164	1,470	—	—	—	—	—	—	55,145
1912	7,414	20,150	271	27,001	39	3,330	377	3,998	107	820	—	—	—	—	55,299
1913		13,250	258	25,526	11	3,140	41	482	308	2,228	—	—	—	—	44,626
1914/15	6,357	14,538	160	20,745	20	5,601	1,677	11,860	90	550	—	—	—	—	53,734
1915/16		3,861	140	14,700	79	6,083*		8,162	178	1,068	—	—	—	—	30,013
1916/17		3,677	270	27,120			48	5,517		275	—	—	—	—	27,395
1917/18	525	2,229	245	41,432	100	17,600*	619	9,648	26	200	—	—	—	—	61,461
1918/19	900	3,521	162	30,021	70	12,110*	159	2,349	12	132	—	—	—	—	45,784
1919/20	939	3,192	179	27,610	72	11,597	67	780	17	299	—	—	—	—	42,798
1920/21	304	1,042	83	7,793	—	—	—	—	—	—	—	—	—	—	8,800
1921/22	145	488	79	5,891	—	—	—	—	—	—	—	—	—	—	6,050
1922/23	207	714	136	13,887	—	—	—	—	—	—	—	—	—	—	14,468
1923/24	816	2,988	97	12,855	—	—	—	—	—	—	—	—	—	—	15,124
1924/25	519	1,939	110	15,966	—	—	—	—	191	617	—	—	—	—	18,897
1925/26	142	537	98	15,852	—	—	—	—	61	594	—	—	—	—	16,897
1926/27	123	468	109	18,755	—	—	—	—	31	379	0.07	8	—	—	19,609
1927/28	114	431	79	10,828	—	—	—	—	2	22	0.33	66	—	—	11,346
1928/29	143	553	59	6,958	—	—	—	—	12	79	0.97	207	—	—	7,796
1929/30	16	57	31	3,345	1	—	—	—	7	37	2.70	1,013	—	—	5,131
1930/31	593	2,445	33	2,331	—	—	—	—	8	160	1.42	450	—	—	5,386
1931/32	763	3,465	26	2,322	—	—	—	—	—	—	0.76	240	—	—	6,027
1932/33	712	4,488	25	2,519	—	—	—	—	24	411	—	—	—	—	7,418
1933/34	232*	1,642*	66	9,566	1	76	—	—	8	11	0.38	65	—	—	11,360
1934/35	863 fine	5,954*	38	6,036	1	175	—	—	—	—	1.07	264	—	—	12,429
1935/36	633	4,091	30	4,176	—	—	—	—	—	—	—	—	—	—	8,267
1936/37	364	2,632	46	7,696	3	511	—	—	—	—	—	—	—	—	10,839
1937/38	284	2,088	18	2,972	14	3,252	—	—	26	328	0.28	180	—	—	8,820
1938/39	258	1,903	26	4,220	11	1,728	—	—	—	—	—	—	—	—	7,851
1939/40	448	3,903	26	4,208	9	1,739	—	—	—	—	—	—	—	—	9,850
1940/41	—	—	20	3,416	4	660*	—	—	—	—	—	—	—	—	4,076
1941	—	—	22	4,041	—	—	—	—	—	—	—	—	—	—	4,041
1942	—	—	32	6,627	—	—	—	—	—	—	—	—	—	—	6,627
1943	—	—	26	5,594	5	1,695*	—	—	—	—	0.58	—	—	—	7,289
1944	—	—	11	2,086	6	2,034*	—	—	—	—	0.12	—	—	—	4,120
1945	—	—	23	5,026	—	122*	—	—	—	—	—	—	—	—	5,148
1946	—	—	15	3,228	—	—	—	—	—	—	—	—	—	—	3,228
1947 (to June 30)	—	—	16	3,340	—	—	—	—	—	—	—	—	—	—	3,340
1947/48	97	1,040	25	8,932	6	2,810	4	129	7	456	0.71	714	—	—	14,081
Total	660,842	2,166,787	6,894	713,630	891	114,870	11,469	238,229	2,607	52,048	11.49	3,347	710	13,061	3,286,279

* Estimated. † Not recorded.

In addition to the above, the following minerals have been produced:

Amblygonite

Year	Tons	£
1905	20	204
1924	4.65	42.2
1925	39.25	343.1

Bismuth

Year	Ore tons	Est. Bi tons	£
1908	2	1.20	300
1911	0.075	0.05	25
1917/18	0.075	0.05	24

Graphite

Year	Tons	£
1924	2.65	13

Molybdenite (approx. 90% MoS_2)

Year	Tons	£
1914	0.02	10
1916	0.10	45
1917	0.125	58
1918	0.012	6
1922	0.06	8

These tables give, as completely as records permit, production from the Northern (Darwin) District of the Northern Territory. Production from Tanami and Arltunga is known to be included in figures for early years, but exact quantities and values are not available.

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EXPLANATION OF PHOTOGRAPHIC PLATES

PLATE 5

Oblique aerial photograph looking north across Katherine Gorge (in middle distance). Metamorphics of Brock's Creek Group (Plb) on left are overlain by Buldiva Quartzite (Pub) which forms a tableland and dips gently to the north-east. Lower Cretaceous sediments of Mullaman Group (Klm) overlie Buldiva Quartzite in lower right corner of photograph.

PLATE 6

Vertical aerial photograph of western edge of Arnhem Land Plateau east of Burrundie. Northerly trending metamorphics of Brock's Creek Group (Plb) on left are overlain by beds of Buldiva Quartzite (Pub) which dip gently to the east and form the Arnhem Land Plateau.

PLATE 7

Fig. 1.—Differential weathering in thinly bedded sub-horizontal beds of the Buldiva Quartzite on Mt. Tolmer Plateau. The prominent bed half way up the face is approximately five inches in thickness.

Fig. 2.—Wind (?) ripple marks in flaggy beds of Buldiva Quartzite on Mt. Tolmer Plateau. Average wave length of ripples is about three inches.

PLATE 8

Fig. 1.—Isolated hill adjacent to Arnhem Land Plateau near Cannon Hill on East Alligator River, with part of sub-coastal plain in foreground. Sub-horizontal quartzite, sandstone and conglomerate of the Buldiva Quartzite are exposed in cliff face, which is about 50 feet high.

Fig. 2.—Katherine Gorge, showing strongly jointed Buldiva Quartzite dipping gently to the north-east. Cliff on right is approximately 25 feet high.

PLATE 9

Fig. 1.—Outcrop of Lower Cambrian (?) basalt on Daly River, ten miles south-east of Daly River Police Station. Handle of the hammer, in centre of photograph, is 12 inches long.

Fig. 2.—Outcrop of *Girvanella* limestone, Daly River Group, four miles south-west of Tipperary Station.

PLATE 10

Fig. 1.—Shale and sandstone of Daly River Group (Cambrian) exposed on Gypsy Creek, 16 miles east of junction of Daly and Douglas Rivers.

Fig. 2.—Ripple marks on sandstone at base of Gypsy Creek section shown in Fig. 1 of this plate.

PLATE 11

Fig. 1.—Sub-horizontal limestone of Daly River Group (Cambrian) at Florina Falls, on the Flora River.

Fig. 2.—Limestone of Elliott Creek Formation (Palaeozoic?), ten miles north of Mt. Litchfield.

PLATE 12

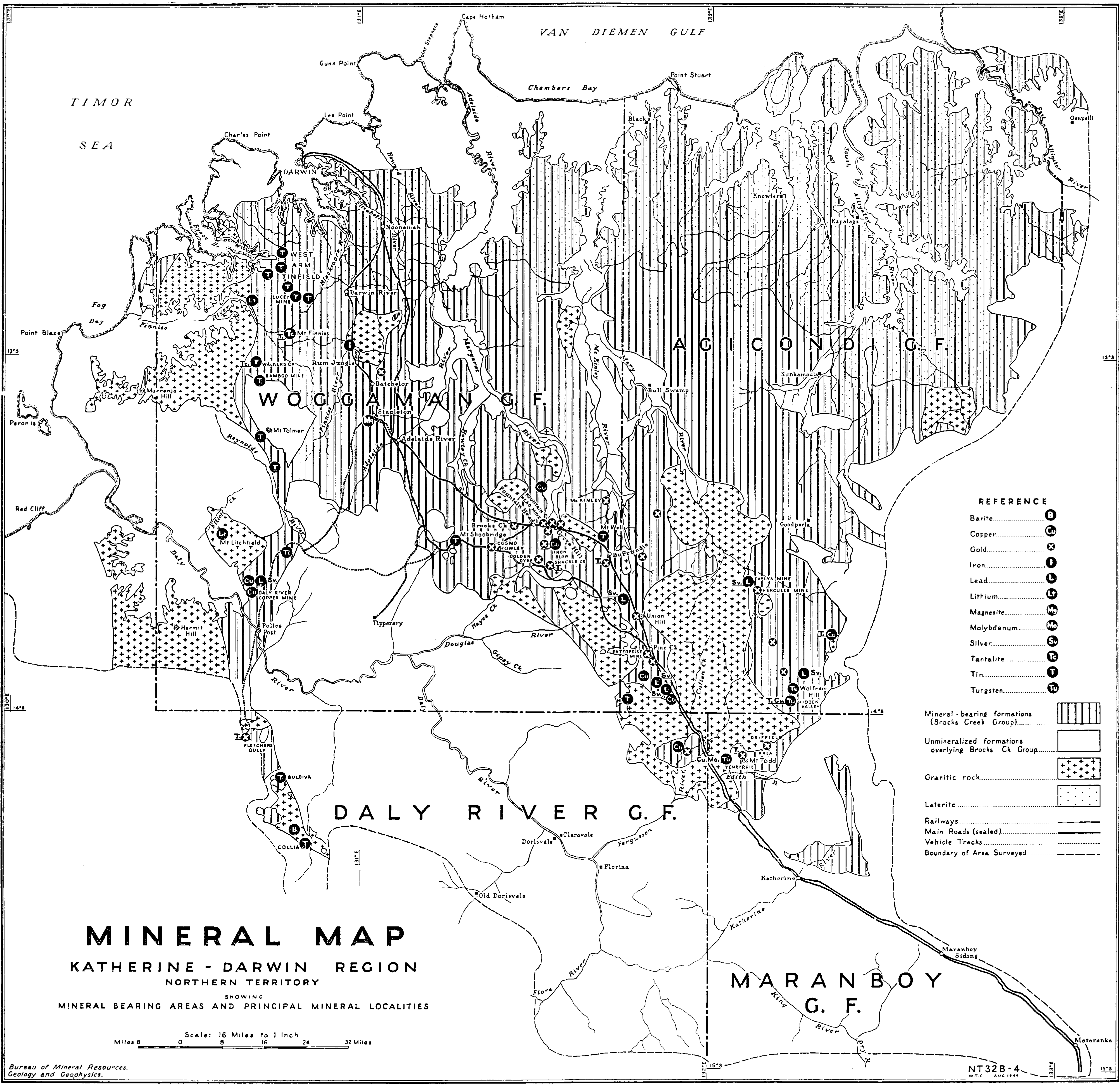
Fig. 1.—View looking southward from Mt. Greenwood. Beds of Port Keats Group (Permian) occupy low-lying, gently undulating country and outcrop at base of mesas, which are capped with sediments of Mullaman Group (Lower Cretaceous).

Fig. 2.—Mesas capped with sediments of Mullaman Group, eight miles south-east from Adelaide River. Protective lateritic cap rock (silicified pallid zone) can be clearly seen.

PLATE 13

Fig. 1.—Cliff at Charles Point showing an almost complete laterite profile: shallow surface soil, massive ferruginous zone, mottled and pallid zone.

Fig. 2.—Blocks of massive laterite (ferruginous zone) breaking away from scarp at Charles Point. Surface soil seen on the right has been eroded from foreground, leaving a pavement of massive laterite. Height of scarp is about 25 feet.


MINERAL MAP
KATHERINE - DARWIN REGION
NORTHERN TERRITORY
SHOWING
MINERAL BEARING AREAS AND PRINCIPAL MINERAL LOCALITIES
Scale: 16 Miles to 1 Inch
Miles 8 0 8 16 24 32 Miles
Bureau of Mineral Resources, Geology and Geophysics.
NT32B-4
W.T.C. AUG 1949
REFERENCE
Barite
Copper
Gold
Iron
Lead
Lithium
Magnesite
Molybdenum
Silver
Tantalite
Tin
Tungsten
Mineral-bearing formations (Brocks Creek Group)
Unmineralized formations overlying Brocks Ck Group
Granitic rock
Laterite
Railways
Main Roads (sealed)
Vehicle Tracks
Boundary of Area Surveyed
TIMOR SEA
VAN DIEMEN GULF
Chambers Bay
Cape Hotham
Point Stephens
Gunn Point
Point Stuart
Lee Point
Charles Point
DARWIN
Fog Bay
Point Blaze
Peron Is
Red Cliff
AGICONDI G.F.
WOGGAMAN G.F.
DALY RIVER G.F.
MARANBOY G.F.
WEST ARM TINFIELD
LUCEY MINE
Mt Finniss
WALKERS CK
BAMBOO MINE
Rum Jungle
Batchelor
Stapleton
Adelaide River
Mt Tolmer
Murrenja Hill
Mt Litchfield
DALY RIVER COPPER MINE
Hermit Hill
Police Post
Tipperary
Noonamah
Darwin River
Brocks Ck
Mt Shoobridge
Mt Wells
Mc KINLEY
Bull Swamp
Union Hill
Pine Ck
ENTERPRISE MINE
Burrundie
EVELYN MINE
HERCULES MINE
Wolfram Hill
HIDDEN VALLEY
DRIFFIELD AREA
Mt Todd
YENBERRIE
Goodparla
Kunkamoula
Knowles
Kapalaga
Oenpelli
Blacks
FLETCHERS GULLY
BULDIVA
COLLIA
Claravale
Dorisvale
Florina
Old Dorisvale
Katherine
Maranboy Siding
Mataranka
Douglas River
Hayes Ck
Gipsy Ck
Daly River
Reynolds River
Finniss River
Adelaide River
Howard River
Elizabeth River
Blackmore R.
Margaret River
Mc Kinley River
Mary River
South Alligator River
East Alligator River
Cullen Ck
Edith R.
Fergusson
Katherine
King River
Flora River
Dry R.
130°E
131°E
132°E
133°E
13°S
14°S
15°S


Klm
Pub
Plb


Plb
Pub

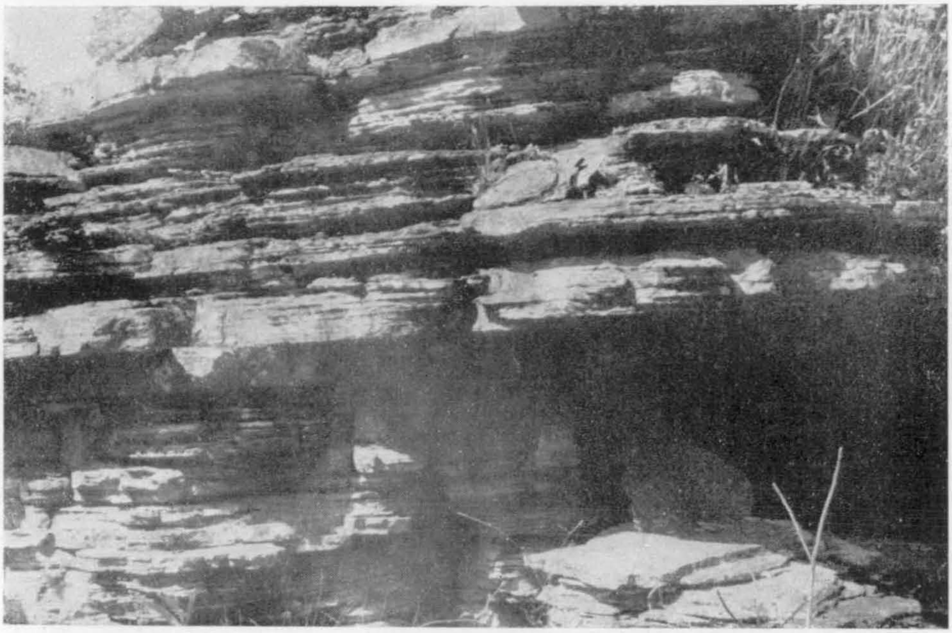


Fig. 1

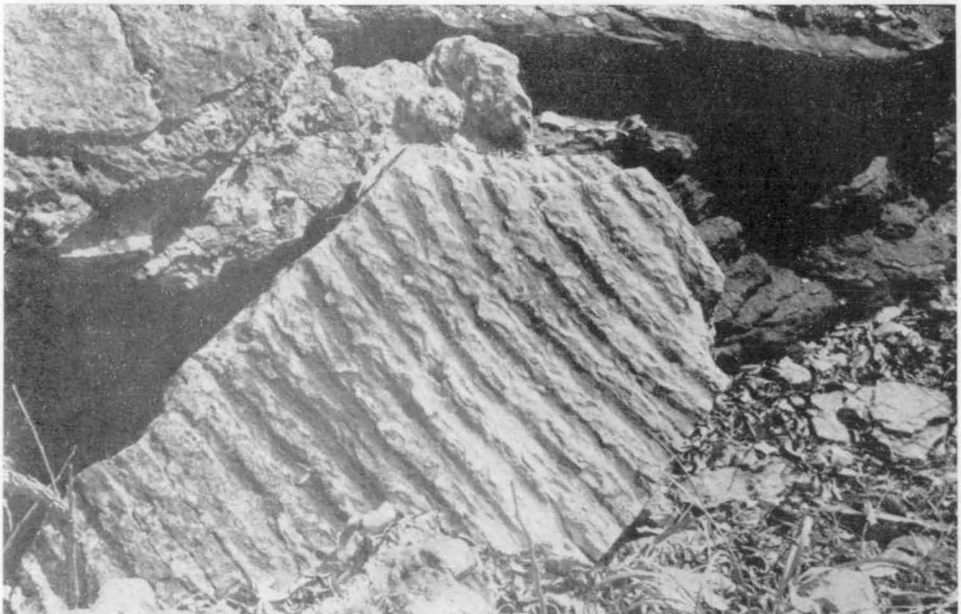


Fig. 2

PLATE 8

Fig. 1

Fig. 2

Fig. 1

Fig. 2

Fig. 1

Fig. 2

Fig. 1

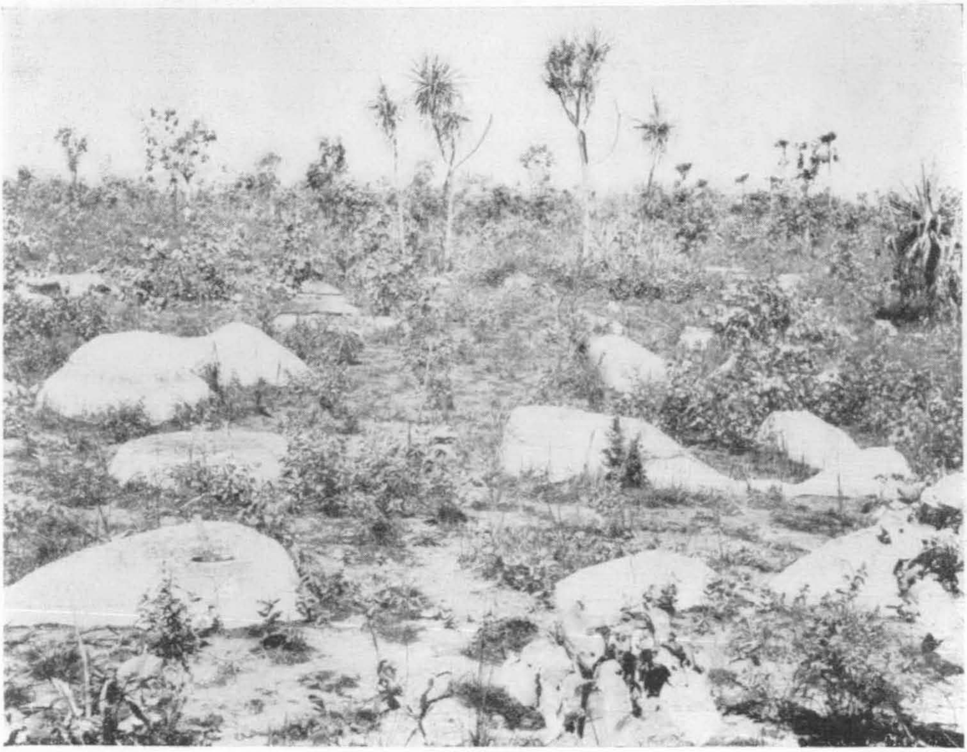


Fig. 2

PLATE 12

Fig. 1

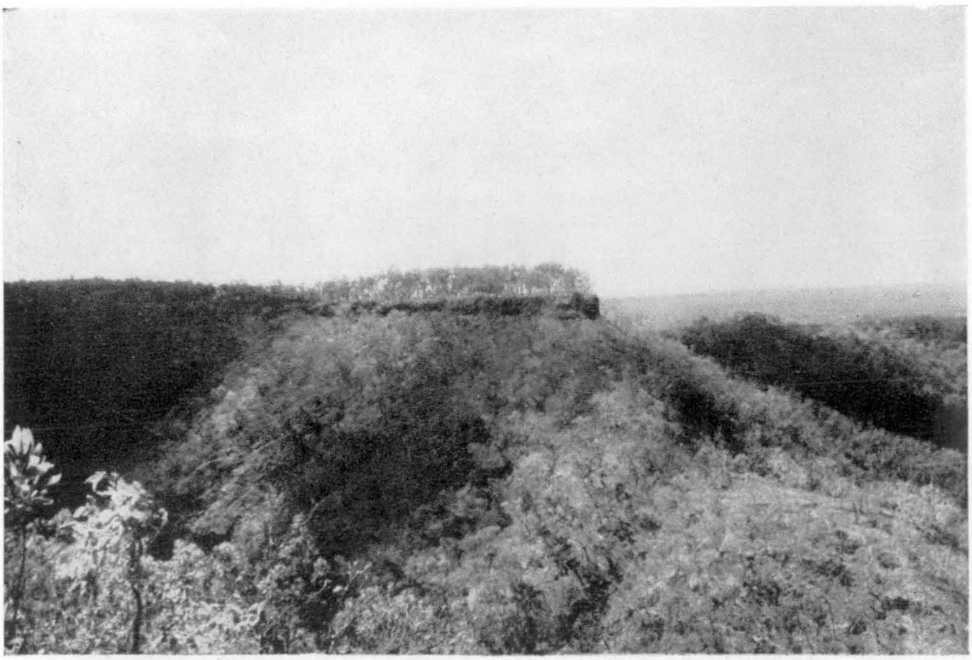


Fig. 2

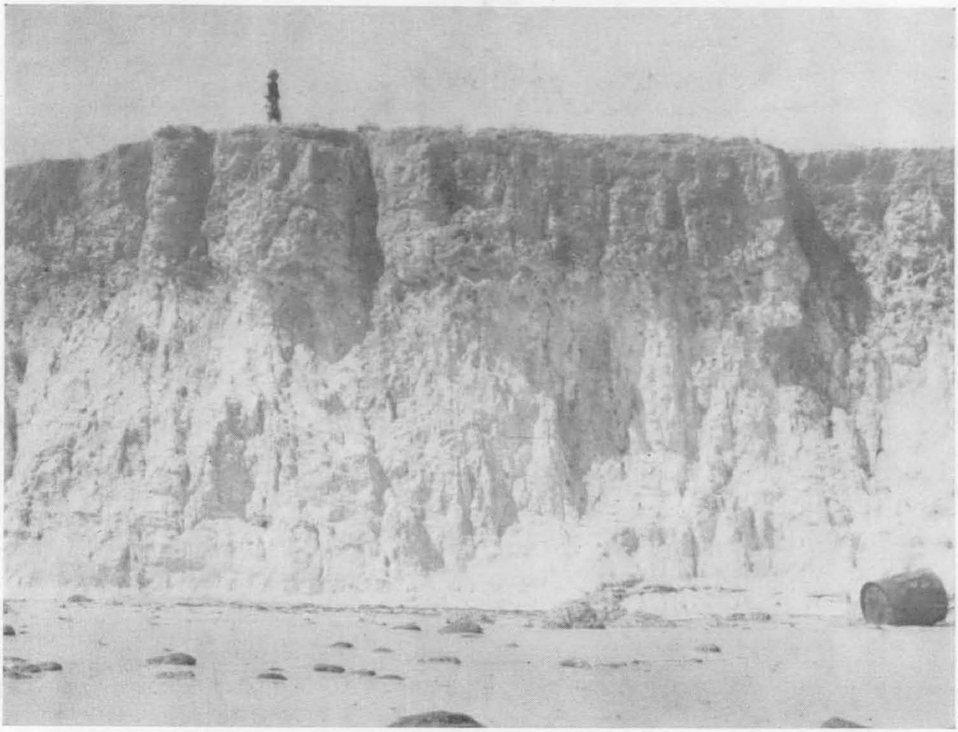


Fig. 1

Fig. 2