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GEOLOGY OF THE EASTERN HIGHLANDS OF NEW GUINEA.

by

N.J. McMILLAN & E.J. MALONE.

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SUMMARY.

The geology of the eastern portion of the Central Highlands of New Guinea was mapped on vertical aerial photographs at a scale of approximately 1 inch = 4200 feet and plotted at a scale of 1 inch to 2 miles. The Bena Bena Formation, the Goroka Formation and the Bismarck Granodiorite, all tentatively judged to be pre-Permian in age, comprise the basement complex in this area. Upper Cretaceous, Eocene, Oligocene, Miocene and younger rocks unconformably overlie the basement complex. The Miocene is the most widespread of these and contains the greatest thickness of sediments.

The main orogeny since the Palaeozoic started during the Miocene with the deposition of thick volcanics. Both basement and younger sediments were folded during the subsequent culmination of the orogeny which probably happened during the late Pliocene. Faulting, which accompanied the folding, is continuing at the present time.

INTRODUCTION

This report describes the results of mapping carried out during 1956 and 1957 by field parties of the Bureau of Mineral Resources, Canberra. The work was the first investigation undertaken by the Bureau in a continuing programme of regional mapping of areas in Papua and New Guinea.

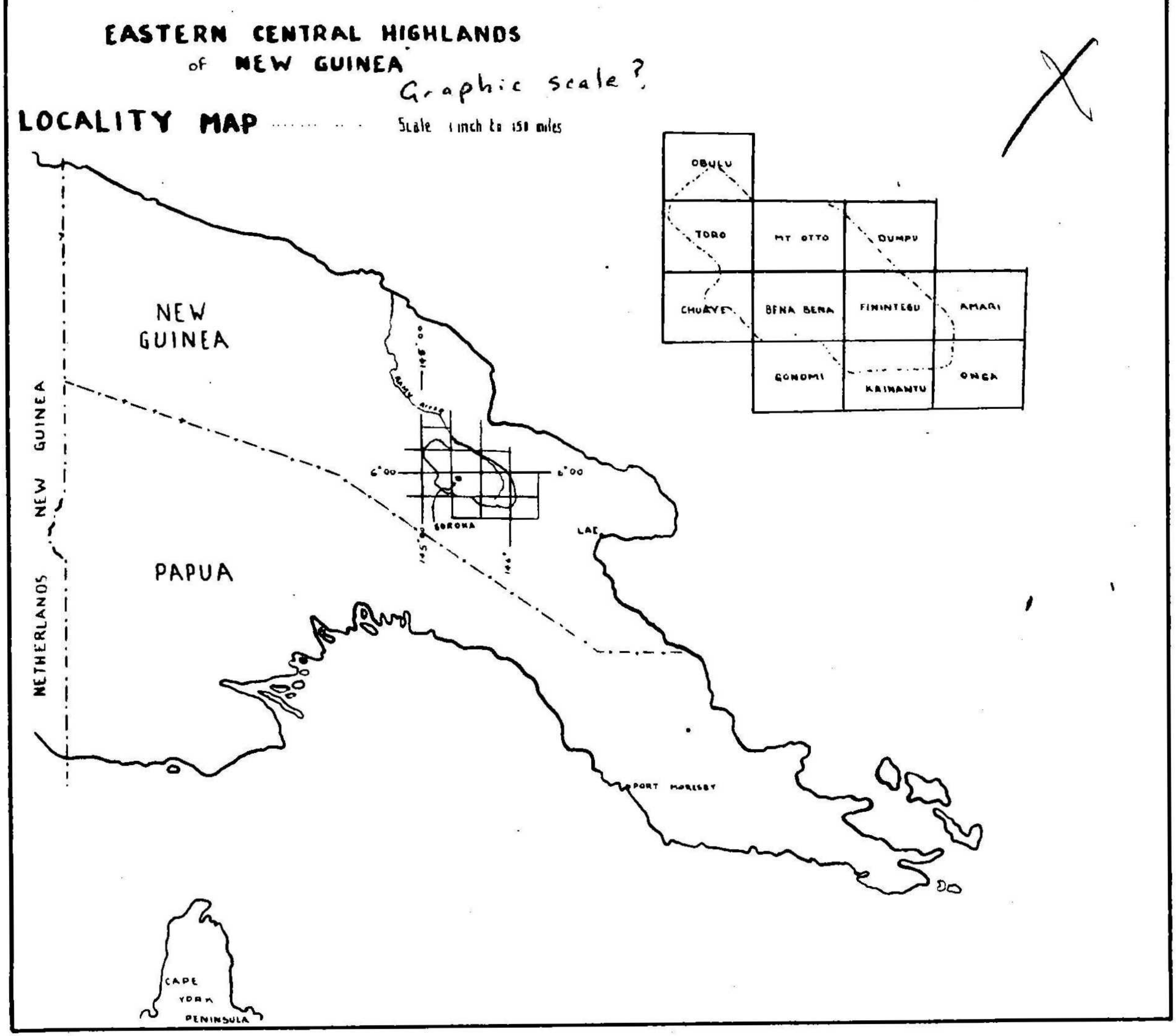
The 1956 New Guinea regional party consisted of N. J. McMillan and J. E. Johnson, and operated from June till November, inclusive. G. Siedner, of the Territory of Papua and New Guinea Administration Resident Geological Staff, was a member of the party for the first 6 weeks. The 1957 party consisted of E. J. Malone and K. K. Hughes, and operated from July till November, inclusive.

LOCATION

The area mapped includes portions of 11 sheets of the New Guinea 1 - mile series. Parts of Obulu, Toro, Chuave, Mt. Otto and Bena Bena 1 - mile areas were mapped during 1956. The Mt. Otto and Bena Bena sheets were completed during 1957, together with Finintegu and parts of Dumpu, Amari, Onga, Gonomi and Kainantu 1 - mile areas. Each of these 1 - mile areas is bounded by 20 minutes of longitude and 15 minutes of latitude, and comprises approximately 390 square miles in area. The map area lies within longitudes 145°00'E. and 146°05'E, and within latitudes 5°30'S. and 6°20'S. The total area mapped is approximately 2,000 square miles. (See locality diagram Text figure 1.).

The area investigated lies east of the Western Highlands mapped by Rickwood (1955). It includes the Upper Ramu area which Mackay investigated briefly in 1954. Rocks of the basement complex were known to crop out in this area, but they had not been previously mapped in any detail. The main purpose of the survey was to assess the economic potential of the basement complex and to establish the stratigraphic and structural relationships of the complex with the overlying Mesozoic and Tertiary rocks.

Most of the area investigated lies within the Main Ranges physiographic province, at an elation of 5,000 feet or more and has a cool, tropical climate. The 1957 party operated from the Ramu Valley for about eight weeks and the climate there is hot, humid and enervating.



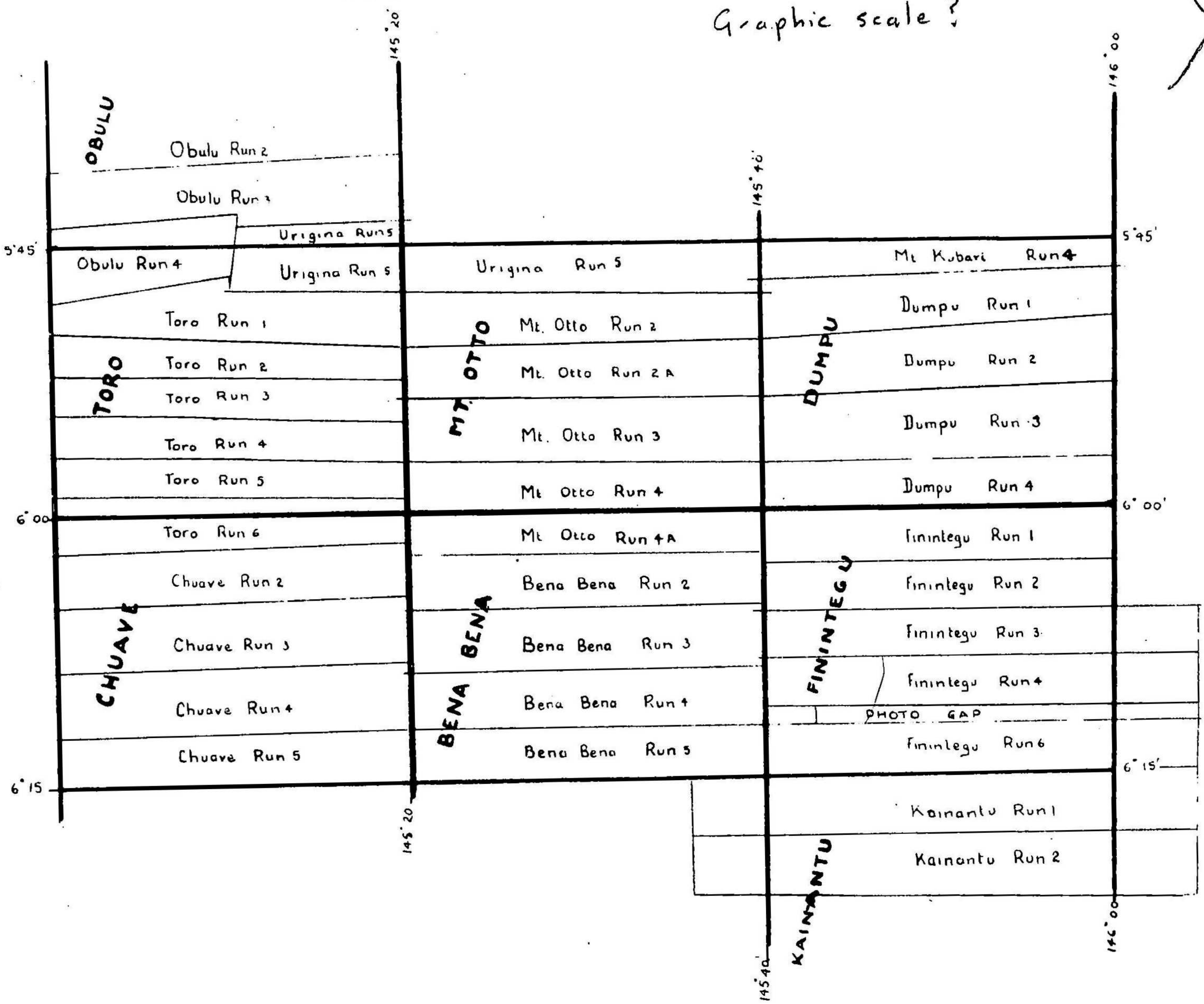
TEXT FIGURE 1

TEXT FIGURE 2

EASTERN CENTRAL HIGHLANDS of NEW GUINEA

AERIAL PHOTOGRAPH INDEX 1 inch = 10 miles

Graphic scale ?



The index shows only those runs which were used in compiling the slotted template compilations of the 1mile areas sheet.

ACCESS

A road links Lae with the Eastern Highlands, crossing the area mapped from east to west. Numerous smaller roads branch off this, giving access to much of the highlands. These roads are all suitable for use by four-wheel drive vehicles under almost any weather conditions. The majority are trafficable by conventional vehicles, under normal circumstances.

Airstrips are located at many places in the area. The fields at Goroka and Kainantu in the Highlands and at Gusap and Dumpu in the Ramu Valley may be used by D. C. 3 aircraft. Other fields, suitable only for light aircraft, are situated at Asaloka, Keglsugl, Bundi, Rintebe, Arona and Aiyura.

A good network of foot tracks exists throughout most of the map area. These are maintained by the Administration for patrol purposes. Government rest houses are situated at intervals of about two or three hours walking along these tracks, except in the Bismarck Range where they may be six to eight hours walk apart. Native paths through the grass and timber are common in many places, and are extremely useful. There were few tracks and paths on the northern slopes of the Bismarck Range, and this proved a considerable hindrance to the investigation in that area.

Goroka was used as a supply centre for both the 1956 and 1957 parties. This town is the administrative centre for the Eastern Highlands District. It contains an adequately stocked government store, as well as good mail and telegram services, and several well stocked general stores. Goroka has a population of 350 Europeans, and, besides being an administrative centre is rapidly becoming an important agricultural centre.

METHOD

Vertical aerial photographs of the whole area are available and can be obtained from the Royal Australian Air Force. See Aerial Photograph Index, Text Figure 2. They were used exclusively for topographic control and for the location of rock exposures. Uncontrolled photo mosaics were first used for base maps on which the information was plotted as it was obtained. This method was soon discarded because the control between adjacent sheets was inadequate and the scale too small for the amount of information being collected. Later, base maps were made in the field from the aerial photographs. These were found to have only limited use due to discrepancies caused by the great change in relief over short distances.

Slotted template compilations of the 1 - mile areas were subsequently produced by National Mapping Office, Canberra. Most of these were available early in 1957, and the 1957 party was thus able to plot the data gained in the Bena Bena, Mt. Otto and Dumpu areas directly onto a controlled base map. The compilations for the Kainantu and Finintegu 1 - mile areas were not available until early 1958. The final geological map is based on the slotted template compilations, reduced from photo-scale to 1 inch to 2 mile scale.

It was originally intended to complete the mapping of this area during the 1956 season. However, the geology was soon found to be much more complicated than was expected. This necessitated a high density of traverses and spot investigations, and resulted in less than half the area being mapped that year. The area was completed during the 1957 season, but the same density of traverses could not be maintained. This is particularly true of the least accessible portions of the northern slopes of the Bismarck Range, where the relationships of the stratigraphic units are still rather vague.

Spot heights below 10,000 feet elevation were recorded with army type aneroid barometers. Higher elevations were measured with a bank of three aircraft altimeters.

The good access roads throughout the Goroka-Kainantu area made it possible to map much of that area by means of one day traverses from a series of base camps. A Landrover was available to each party, and was used for transport as near as possible to the starting point of a traverse, and for returning to the base camp. Not all the area was so easily accessible, however, and many longer traverses were necessary. The 1956 party mapped the Bundi area during a continuous six week traverse. The 1957 party also spent six weeks on continuous traverse, mapping part of the northern slopes of the Bismarck Range.

Outcrops are confined mainly to the valleys, so that most investigations were made in the stream channels. On tracks and native trails, contacts between rock types were approximated, but it was usually impossible to obtain fresh specimens.

Native labour is plentiful, and in many areas is the only feasible means of transporting supplies. However, aerodromes are scattered throughout this part of New Guinea and, in many cases, aircraft are more efficient for transporting stores and personnel.

ACKNOWLEDGEMENTS

The authors wish to extend special thanks to Mr. W. Seale, District Commissioner of the Eastern Highlands District, to Mr. H. West, Acting District Commissioner during much of the 1957 season, and to the staff of the District and Sub-district offices, for the considerable and varied assistance received during the survey.

Assistance was granted in a number of ways by the missions, and special assistance was given by Father Yaworsky of the Bundi Mission.

Numerous discussions were held with Dr. E. Reiner, of the Commonwealth Scientific and Industrial Research Organisation, who was a member of a Land Research and Regional Survey party operating in the same area. The benefit of these discussions is gratefully acknowledged.

PHYSIOGRAPHY

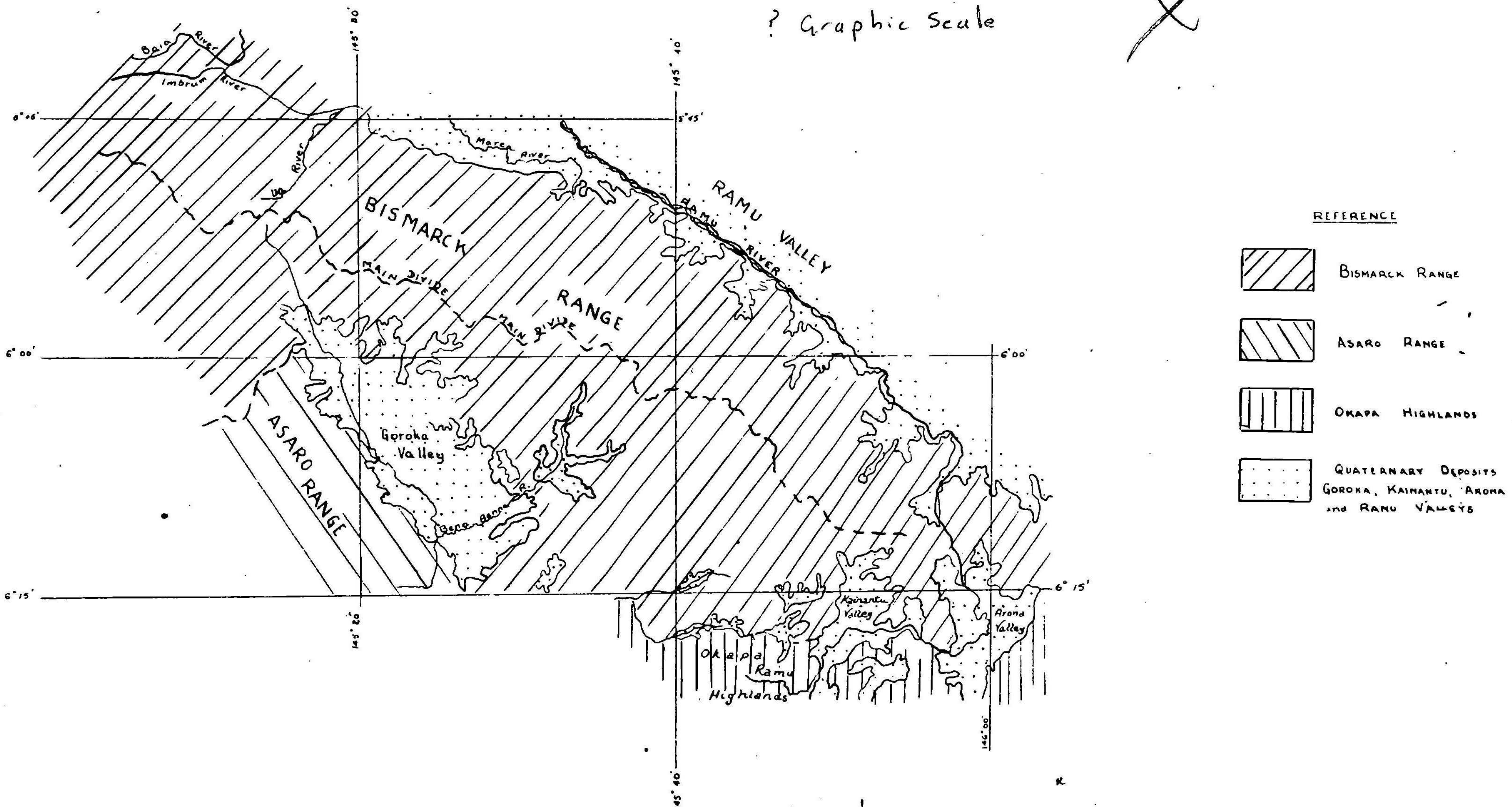
New Guinea is the largest island of the East Indian Archipelago (see van Bemmelen, 1949, p.2). It is divided politically into Netherlands New Guinea on the west and the Australian administered Territory of Papua and New Guinea on the east. The Main Ranges (termed Central Ranges of New Guinea by van Bemmelen, 1949, p.55) constitute the major physiographic region of the island. They extend from near the "neck" of Netherlands New Guinea to the eastern extremity of Papua, a distance of more than 1,200 miles. They are flanked on the north by the Central Depression, a lowlands region occupied by the Sepik, Ramu and Markham Rivers, and on the south by the Southern Foothills.

TEXT FIGURE 3

EASTERN CENTRAL HIGHLANDS of NEW GUINEA

Physiographic Sketch Map .... Scale 1 inch to 10 miles

? Graphic Scale



The map area is located in Australian New Guinea. It lies almost entirely within the Main Ranges except for a small portion eastward of Bundi which is part of the Central Depression.

Five distinct physiographic features are recognized in the map area. Four of these are within the Main Ranges, and the fifth is the Ramu Valley. (See Physiographic Sketch Map, Text Figure 3.).

The Bismarck Range is the most important of the four distinct features within the Main Ranges present in the map area. It is a north west trending chain of mountains, about 125 miles long, and occupies by far the greater part of the map area. It is sometimes called the Bismarck Mountains (Geological Sketch Map of Eastern New Guinea, 1945). The range is bounded on the north east by the Central Depression, here occupied by the north-west flowing Ramu River. It is bordered on the south-west by the Goroka Valley and, north-west of the map area, by the Jimmi River Valley. The southern end of the Bismarck Range divides, north of Kainantu, into a number of spurs which trend south and abut against the Okapa Highlands.

In the map area, the Bismarck Range reaches an elevation of 15,400 feet at Mt. Wilhelm. The next highest peak is Mt. Otto, 11,600 feet, located to the north of Goroka. Several other peaks, for the most part unnamed, exceed 9,000 feet in elevation.

A chain of mountains trends south-east from the Bismarck Range north of Daulo. These mountains are here called the Asaro Range.

A number of intermontane basins are found in the Main Ranges of New Guinea. Three of these, the Goroka, Kainantu and Arona Valleys, are situated in the map area.

The Okapa Highlands, including the highlands along the southern boundary of the map area, and the Ramu Valley, a part of the Central Depression, are the remaining two physiographic regions recognized in this area.

TOPOGRAPHY

Bismarck Range - General

The rugged, steep, north east sloping zone located between the line of peaks of the Bismarck Range and the Ramu River floodplain is topographically distinct from the south-western slopes of the Range. This steep zone is called the Ramu Fall, a name which has been used locally for many years. In general, the elevation of the terrain on the Ramu Fall drops from 10,000 feet to less than 1,000 feet in a distance of ten miles or less. The gradient on the south-western slopes of the Range is steep in some places, relatively gentle in others. In general it involves a drop of up to 5,000 feet over a distance of four to ten miles.

The Ramu Fall is bordered by the flood plain of the Ramu River along a fairly straight line. By contrast, the boundary of the south-west slopes is very vague. On the South-western slopes, the Bismarck Range breaks up into a number of spurs separated by fairly mature river valleys. The spurs either slope down to the level of the intermontane basins or extend south to the Okapa Highlands.

Ramu Fall

The Ramu Fall exhibits a very youthful topography. It is drained by swift-flowing, cascading streams of which the larger are difficult and, in some places, dangerous to negotiate. The rivers occupy steep-sided, V-shaped, generally fairly straight valleys, though, in places, a tortuous drainage pattern is developed. Many of the straight river valleys appear to be fault-controlled. Valley walls usually range from 15 to 40 degrees in slope, though almost sheer gorges, up to 100 feet in height, are found in places. The junctions of the larger tributaries with the main streams, are accordant, but the majority of the minor tributaries join as water-falls.

The rivers draining the eastern end of the Ramu Fall flow north-east at right angles to the trend of the range, and discharge directly into the Ramu River floodplain. In the Bundi area, however, the rivers draining the Ramu Fall flow north-east until they reach a distinct, south-east trending depression. Thereafter, the drainage is into the south-easterly flowing portions of the Baia and Inbrum Rivers which occupy the depression. The Baia and Inbrum Rivers eventually turn north and flow into the Ramu River. A gently rounded massif, about three miles wide by about fifteen miles long lies parallel to the south-east trending depression and between it and the Ramu River.

delete

South-west Slopes of the Bismarck Range

The topography of the south-west slopes is rugged close to the divide, with high, sharp ridges and steep slopes, and a youthful stream pattern, but becomes relatively subdued a short distance away from the divide. The main streams occupy wide valleys in an early mature stage, with extensive alluvial deposits. They are separated by divides considerably more rounded than those o the Ramu Fall.

The south-west slopes are drained by tributaries of the Purari and Ramu River Systems. These two systems are separated by a range of hills forming the headwaters region of the Komperi River and linking the Bismarck Range and the Okapa Highlands. Many of the rivers draining the south-west slopes, such as the Karmanuntina, Dunantina and the Komperi itself, flow through mature valleys for many miles. They are then rejuvenated, flowing through narrow valleys for several miles before joining a major tributary of the Purari River. This rejuvenation is present also in the Upper Ramu River. It is reflected in the latest level of erosion in the intermontane basins.

Mature soil profiles are widely developed on the south-west slopes, particularly in the river valleys. More extensive agriculture and a denser indigenous population in this area reflect the difference in topography between it and the Ramu Fall.

Numerous upland valleys of mature topography are present in the Bismarck Range on both sides of the divide. These valleys are usually about 8,000 to 10,000 feet above sea level. One such valley is located north of Mt. Otto. It is about 15 to 20 square miles in area and is drained by meandering streams which become rejuvenated at the valley edge. Similar mature valleys are found on the south-west slopes of the Bismarck Range near Mt. Kerigomna. A typical example is the valley of the Gemboli River. This river follows a meandering course across the valley and has built up alluvial terraces at a number of places. On reaching the valley edge, it cascades stepwise for about 1,000 feet to join the upper part of the Chimbu River.

The mature topographyof these valleys has greatly assisted soil development. Black soil up to three feet thick, rests directly on deeply weathered bedrock. The vegetation consists mainly of thick forest. Open grassland occurs in some valleys which have been deforested, possibly by fire. Alpine grassland is common at elevations above 10,000 feet.

Asaro Range

The Asaro Range is located along the south-western edge of the Goroka Valley, extending south from Daulo. The mountains rise to an elevation of between 6,000 and 8,500 feet, and trend in a north-west direction. In general the mountains are steeper on the north-east than on the south-west. Youthful rivers occupy V-shaped valleys and flow swiftly over falls and boulder beds until they reach the Goroka Valley where the grade lessens and a late youth to mature aspect is assumed.

Soil development is not advanced, mainly owing to the steepness of the uplands. The vegetative cover is about 80 per cent kunai and kangaroo grass and 20 per cent shrubs and trees.

Intermontane Basins

The Goroka, Kainantu and Arona Valleys are the three intermontane basins recognised in the area. The floors of these valleys are occupied by sub-horizontal lake or alluvial deposits, which produce a distinctive topography.

Goroka Valley

The Goroka Valley is the largest of the three. It extends along the Asaro River from near its headwaters to its junction with the Bena Bena River. The valley is bounded on the south-west by the Asaro Range, and on the north-west by the Kerigomna Plateau and on the north-east by the Bismarck Range. Gently undulating uplands constitute the south-eastern boundary of the valley, a few miles south-east of the Asaro-Bena Bena junction. Some of these uplands have a hummocky surface controlled by the underlying bedrock. These hummocky areas occur in patches from a few acres to several square miles in extent.

The valley is approximately 23 miles long by about 6 miles wide, and is occupied by a level, gently sloping plain, eroded into steps and terraces to a depth of 100 feet. The elevation of the plain averages 5,200 feet south-east of Miruma, 5,100 feet near Goroka and 4,600 feet near its south-east boundary. Streams flowing south-west out of the Bismarck Range and north-east out of the Asaro Range assume a late youth to early mature aspect on reaching the Goroka Valley. The alluvial deposits of the plain extend up some of these stream valleys for several miles.

Two main rivers drain the Goroka Valley. The largest, the Asaro River, rises north of Miruma and flows south-eastward to the southern edge of the map where it changes course. It cuts across the Asaro Range in a south-westerly direction to join the Wahgi River. The second largest, the Bena Bena River, rises in a low saddle of the Bismarck Range. It flows south-west across the Goroka Valley and joins the Asaro River. Both these streams meander across the plain and, in places, have ~~cut incisions leaving vertical banks of alluvium, up to 100 feet high~~ incised the alluvium to a depth of 100 feet.

The beds of the Asaro and Bena Bena Rivers contain well rounded boulders ranging from one to two feet in diameter. The boulders are smaller near the centre of the Goroka Valley, but near the edges of the valley, the average size increases and some boulders are ten feet across, or more.

In general, the surface of the Goroka Valley is stable compared with both slopes of the Bismarck Range. Consequently, brown to black soil profiles are well developed in many places. Kunai and kangaroo grassland covers most of the valley. Pine trees and casuarinas, for the most part planted by natives, occur in stands and individually in the vicinity of native villages. Stream valleys are bordered on each side by "pit

pit".

Kainantu and Arona Valleys

The Kainantu and Arona Valleys are located in a roughly triangular area between the southern foothills of the Bismarck Range and the Okapa Highlands. A low range of hills, including the Yonkie Dome, links the Bismarck and Kratke Ranges and separates the Kainantu Valley, to the west, from the larger Arona Valley. These valleys are similar to the Goroka Valley, though considerably smaller and more extensively eroded.

They are occupied by a dissected, level plain consisting of flat-lying lake deposits. The original lakes were drained by the Ramu River, which has cut back through the Bismarck Range and pirated the original drainage system, thus initiating a new cycle of erosion. During this cycle of erosion, the lake deposits have been eroded to a depth of over one hundred feet and, in many stream beds, the original bedrock is now exposed.

The average elevation of the dissected Kainantu Plain is about 5,200 feet near Kainantu. The Arona Plain is lower, being about 4,400 feet in elevation near Arona Agricultural Station.

Okapa Highlands

The Okapa Highlands consist of the uplands along the southern boundary of the map area, including those which mark the southern boundary of the Goroka Valley. They are linked to the Bismarck Range by such north trending lines of hills as the Yonkie Dome. Topographically, they are similar to the southern foothills of the Bismarck Range. The relief in these highlands is of the order of 2,000 feet, the highest ridges rising to about 7,000 feet in elevation. The divides are steep, though somewhat rounded, and the larger streams, at least, are
Open/ in a late youthful stage. /~~Often~~ grassland, ~~with a few pine stands~~ and thick forest growth, cover about equal areas. South of the map area forest predominates.

Ramu Valley

The Ramu Valley constitutes the north-east boundary of the area mapped. The valley is occupied by an extensive, level floodplain, built up of a considerable thickness of stable alluvium. The Ramu River and its tributaries have incised this plain to depths of up to 40 feet. Gently sloping scree deposits debouch from the major valleys in the
on/ Ramu Fall, and fan out ~~to~~ the valley floor. The elevation of the floodplain is 1,350 feet near Gusap and drops to 600 feet near the northern margin of the map.

A large, low-lying swampy area occurs south of the Ramu River, between the Tauja and the Aimi Rivers. This area is drained and, occassionally, flooded by the meandering Marea River which eventually flows into the Ramu River. The southern margin of this area is roughly in line with the linear depression occupied by the south-east flowing part of the Imbrum River.

Open grassland with scattered trees covers most of the Ramu Valley, though thick forest predominates around the Marea River.

Glaciation of Mt. Wilhelm

The glaciation in the Mt. Wilhelm area was mainly restricted to areas above 11,000 feet in elevation. However, morainic material was deposited in some of the larger valleys at elevations as low as 10,000 feet. The extent of the glaciation is revealed by the distribution of distinctive morphological features, many of which are visible on the aerial photographs. These features include cirques, some of which contain lakes, hanging valleys and U-shaped valleys.

Johnson (1958) describes glacial features observed in a traverse to the summit of Mt. Wilhelm up a tributary of the Chimbu River. In that valley, a small terminal moraine was developed at 10,500 feet above sea level. The river, above the moraine, occupies a U-shaped valley. ~~with~~ No spurs project~~ing~~ into the valley, ~~The valley~~ which is mainly straight or follows large radius curves. Tributary streams occupy hanging valleys, 200 to 300 feet above the valley floor. Two large lakes, Lake Runde and Lake Piunde, are present in the valley. Lake Piunde is upstream of Lake Runde and between them is a 400 feet high step in the valley floor. The lakes occupy what are possibly dissected cirques, rock basins with steep sides rising to 1,000 to 1,500 feet above the valley floor. A steep walled 2,000 feet deep cirque is located above Lake Piunde at the head of the valley.

Noakes (1939, unpub.) recorded a depth of 172 feet in the centre of Lake Piunde. Therefore, this rock basin is the result of super-scooping and was certainly produced by glacial action. ~~A steep walled 2,000 feet deep cirque is located above Lake Piunde at the head of the valley~~.

Cirques were visible on the aerial photographs at the heads of most of the valleys leading down from the summit. In many of these valleys, morphological evidence of glacial action is even more abundant than in the valley traversed.

FLORA AND FAUNA

FLORA

The following is based on observations made in the field, using the classification outlined in "The Resources of the Territory of Papua and New Guinea" Vol. I, 1951.

Four main groups of vegetation are present in the map area. These are grassland, lowland and mid-mountain forest, moss forest and alpine vegetation.

Grass, consisting mainly of kunai and "kangaroo", covers most of the intermontane basins and the lower slopes of the mountains surrounding them. This part of the map area contains the bulk of the population, who have been responsible for almost total deforestation of the area. Grass is the main vegetation in the Ramu Valley and on the northern foothills of the Bismarck Range, where repeated burning off has resulted in deforestation.

Lowland and mid-mountain forest occupy most of the map sheet not covered by grassland and below an elevation of 8,000 feet. This forest is, for the most part, very thick with dense undergrowth. Penetration on foot is a slow and arduous process where no track is available.

Alpine vegetation occupies a few acres on the three small knobs which collectively form the top of Mt. Otto. The same type of growth occurs on the eastern slopes of Mt. Wilhelm, above 11,000 feet. It is characterised by stunted, twisted trees sparsely scattered amongst shrubs and low grasses.

The moss forest is found between the alpine vegetation and the mid-mountain forest. The trees in the moss forest are generally smaller than in the mid-mountain, but grow closer together and are accompanied by dense undergrowth. The main characteristic of the moss forest is the thick moss which covers the ground, tree trunks and lower branches alike.

FAUNA

Indigenous mammals are rare in the map area, with the exception of rats. These are common, particularly in the walls and roofs of Kunai houses. Wild pigs are present on the Ramu Fall but are not numerous. Bird life is more plentiful and varied, at least in areas well away from native villages. Many types of birds, including cassowaries, cockatoos, parrots and pigeons were seen in the forest on the Ramu Fall and numbers of ducks were seen near the Ramu River. The pigeons and ducks supplied excellent eating as a variant from tinned meat.

Very few snakes were seen during either season. No death adders were seen in the Ramu Valley, an area where they were once plentiful. Presumably repeated burning off of the kunai has greatly reduced their numbers.

Leeches were the most troublesome of the pests encountered in the area. They are abundant on the Ramu Fall at elevations below 6,000 feet, and in the timbered parts of the Ramu Valley, particularly in the swampy area about the Marea River. Leech bites often became infected, resulting in sores which were very difficult to heal. Mosquitoes were a source of discomfort in the Ramu Valley but were uncommon at higher elevations. Sandflies and the extremely persistent and numerous sweatflies were troublesome during the day in some areas.

PREVIOUS INVESTIGATIONS

The first geological investigation in the Central Highlands was made by N. H. Fisher, then Government Geologist of the Territory of Papua and New Guinea. He visited the area in 1937 and collected fossiliferous limestone specimens from Mt. Hagen and Chimbu. These were examined by Miss I. Crespin, then Commonwealth Palaeontologist.

K. Washington Gray collected Mesozoic fossils from Mingende in 1939. As a result, L. C. Noakes, the Assistant Government Geologist, was sent to the area in 1939. He carried out the first systematic work in the area, measuring and sampling the Mesozoic and Tertiary section in the Lower Wahgi and Chim Rivers. His samples were examined petrologically by A. B. Edwards, palaeontologically by M. F. Glaessner and also by Miss Crespin. The results of Edwards' and Glaessner's examinations were published in 1953.

N. H. Fisher carried out a reconnaissance of the area, between Kaiapit and Bena Bena in December, 1940 - January, 1941, but his maps and notes were lost when the Japanese invaded New Guinea.

G. A. V. Stanley and K. Llewellyn, of the Australian Petroleum Co., made the first post war investigations in the area. They conducted a reconnaissance survey through the Central Highlands in 1949. M. F. Glaessner (1950) examined the samples they collected and recognised Permian foraminifera in a specimen of limestone from Kuta.

F. K. Rickwood, in his "Geology of the Western Highlands of New Guinea" (1955), deals mainly with an area of which the eastern edge is a few miles to the west of the area covered during the present survey. In 1954, N. J. Mackay (1955) ~~made~~ briefly investigated that part of the area around the upper Ramu River

GEOLOGY

GENERAL

The oldest rocks in the area consist of a metamorphic complex in which two formations, the Bena Bena and Goroka Formations are recognized. These are intruded by a vast, differentiated or composite intrusive mass, ranging in composition from quartz diorite to granodiorite and, more rarely, to gabbro. This intrusive is called the Bismarck Granodiorite.

The metamorphic complex and the Bismarck Granodiorite comprise a basement of probably pre-Permian age, which is unconformably overlain by an incomplete and discontinuous marine succession. This succession contains sediments of Upper Cretaceous, Eocene and Oligocene age and a much greater thickness of Lower and Middle Miocene sediments and volcanics.

Both the basement and the younger sedimentary succession were involved in the folding orogeny which took place during the Pliocene. The basement was folded into a number of vast, geanticlinal arches, the crests of which have since been stripped of their sedimentary mantle. The gently or, in a few places, tightly folded sediments crop out on the flanks of, or in the troughs between, these arches.

? Wrong word

One such arch is present in this area. It is reflected topographically in the Bismarck Range which contains all the outcrop of the Palaeozoic basement. Cretaceous, Eocene, Oligocene and Miocene sediments crop out south of this arch in the Goroka area, and north of it in the Bundi area. Only Miocene sediments are found flanking this arch at its south-eastern end.

The Pliocene orogeny was accompanied by considerable intrusive and extrusive activity. The vulcanism continued into the Quaternary, resulting in outpourings on a grand scale in adjacent areas. Faulting, initiated during the orogeny, is still taking place, and is responsible for part of the uplift of the Bismarck Range.

Quaternary rocks in the area consist of extensive alluvial, lacustrine and piedmont deposits and minor volcanics.

The accompanying table, Table 1, introduces and briefly describes the rock units mapped in the area. East Indian alphabetical Tertiary zone symbols are used in this report.

STRATIGRAPHY

METAMORPHIC COMPLEX

In 1922, E. R. Stanley published a list of metamorphic rock types occurring in the Central Highlands of New Guinea. He based his list on a study of the pebbles and boulders found in the streams flowing out of the Bismarck Range, onto the Ramu River floodplain. In the map accompanying his report, he showed the metamorphic complex extending from the Dutch border to south of Morobe. Stanley regarded all of the metamorphic rocks as being Palaeozoic or Pre-Cambrian in age.

Fisher (1944) applied the name "Kaindi Series" to the metamorphic sequence intruded by the Morobe Granodiorite and cropping out in the area south of the Lower Markham River. He considered them to be at least as old as the Palaeozoic but noted that there were probably several systems represented. Dr. F. W. Whitehouse collected fossils from a greywacke outcrop in the Snake River valley in 1943. Glaessner (1949) assigned these fossils to the Cretaceous. It has not been established that these fossiliferous beds are part of the "Kaindi Series".

Mackay (1955) discusses the metamorphic rocks which crop out over a wide area around Kainantu. He regarded these rocks as being Palaeozoic in age.

Rickwood (1955) applied the name Omung Metamorphics to the rocks intruded by the Kubor Granodiorite and the Bismarck Granodiorite. Near the Kubor Granodiorite, the Permian Kuta Group unconformably overlies the Omung Metamorphics.

Two formations, the Goroka and Bena Bena Formations, were recognized in the metamorphic rocks cropping out in the area of the present survey, the western boundary of which is located a few miles to the east of Rickwood's area. The Goroka Formation is intruded by the Bismarck Granodiorite. It contains rock types which are similar to some described by Rickwood in the Omung Group.

The Bena Bena Formation is nowhere directly in contact with the Bismarck Granodiorite. Its relationship with the not well known Goroka Formation is vague but it is possibly older. In many places it exhibits a higher degree of regional metamorphism than is common in the Goroka Formation.

GOROKA FORMATION

The Goroka Formation crops out over a large part of the map area. On the southern slopes of the Bismarck Range it extends from the western edge of the map sheet to the headwaters region of the Dunantina River. On the northern fall, it extends from the main mass of the Bismarck Granodiorite to the north-easterly flowing part of the Ramu River. A small wedge of the formation crops out north of the Bismarck Granodiorite in the Bundi area.

The formation was first studied in a west-north-west trending line of outcrop, about 25 miles long, situated to the north of Goroka. The formation is intruded by the Bismarck Granodiorite, which crops out in at least 13 separate exposures and must be close to the surface throughout this area. In this area the Goroka Formation shows strong contact metamorphism.

The dominant rock types in the formation near Goroka are grey biotite schist, andalusite biotite schist and black, commonly quartz veined, schistose siltstone. Knotted schist, containing light grey patches about 1/8 inch across, of andalusite and felspar, is common near the intrusive contacts. These metamorphic rocks were apparently derived from impure sandstone or greywacke and siltstone. The sedimentary bedding is commonly preserved and, in many cases, the schistosity is parallel to the bedding. The individual beds are from a few inches to a few feet thick. In some of the coarser rocks, graded bedding is visible.

Grey-green phyllite is found interbedded with andalusite schist over a large area north of Asaro government rest house. The phyllite is bedded, slightly calcareous in places and commonly knotted with ~~rice grain sized~~ patches. Buff gneiss, containing lit-par-lit injections of components of the Bismarck Granodiorite crops out to the west of the phyllite sequence. The rock types in the Asaro area, though more highly metamorphosed, are comparable in part with Rickwood's Omung Group, as exposed along the road beside the Chimbu River.

Bodies of amphibolite ~~is~~ are conspicuous in the Goroka Formation, northwest of Goroka. They are altered basic sills, and possibly flows, interbedded with the gneiss and schist of the formation. In most places the amphibolite bodies were found to be rather shallowly dipping. The degree of metamorphism strongly suggests that these sills were intruded prior to the original deformation of the Goroka Formation.

Soft, black, carbonaceous, schistose siltstone crops out in the formation about six miles east of Goroka, apparently conformably underlying rocks of the Bena Bena Formation. Small lenses of grey, finely laminated limestone are included in this sequence. Buff, hard, massive quartzite, composed of more than 90% quartz, crops out in beds up to 200 feet thick, interbedded with the black siltstone. Minor amounts of conglomerate are also found in this sequence.

Grey micaceous schist, containing lenses and beds of light grey limestone, crop out east of the Bena Bena River, south of Geppavi Hill. The limestone is recrystallized in part and occurs in beds up to two feet thick. It was closely examined for microfossils but none were found. However, Dr. E. Reiner, of the C. S. I. R. O., collected a specimen of limestone from this locality, containing undoubted organic remains. These were thin, radiating laminae, up to 2 mms. across, indicating the presence of corals.

A thick wedge of Goroka Formation, about 14 miles long by one mile wide, was mapped north of the ~~[illegible] Batholith~~ Bismarck Granodiorite, in the Bundi area. This part of the formation consists mainly of dark grey, biotite-andalusite schist, knotted in places near the batholith. These rocks are regarded as Palaeozoic in age because they are intruded by the Bismarck Granodiorite. They are placed in the Goroka Formation because of their lithological similarity to the rocks of that formation. They are separated by a fault from fossiliferous Tertiary "e" stage sediments to the north-east.

The sediments of the Goroka Formation cropping out in the headwaters region of the Bena Bena River show considerably less contact metamorphism than those cropping out north of Goroka. These sediments consist essentially of black, schistose siltstone, in part calcareous or carbonaceous, greywacke, partly silicified quartz greywacke and sandstone, mica and sericite schist, and rare cordierite hornfels. Quartz muscovite phyllite crops out in a few places. The siltstone is commonly pyritic and quartz veined. It is very similar to the black, schistose siltstone cropping out north of Goroka.

A black siltstone sequence crops out over much of the northern fall of the Bismarck Range, from the Tauja River south-east to the Upper Ramu River. This sequence consists mainly of quartz veined siltstone and calcareous siltstone, pyritic in places and commonly schistose. It includes some greywacke, silicified quartz greywacke and sandstone, calcarenite, phyllite, quartz muscovite phyllite, mica schist and rare albite-actinolite schist.

This sequence was mapped by a series of creek traverse extending into the Bismarck Range from the Ramu River Valley. They are overlain by north-easterly dipping Miocene "e" stage limestone and siltstone, but the contact was not exposed. They were first thought to be Miocene in age because of their similarity to the Miocene siltstone. However, this idea was rejected for a number of reasons. First, a lens of Eocene "a" or "b" stage calcarenite was mapped near Dumpu, disconformably underlying the Miocene and overlying the black siltstone sequence. It is thus, in this area, Eocene or older in age. Further, no micro fossils were found in any of the specimens collected out of this sequence.

A traverse across the black siltstone sequence was made up the Oija River, over the Bismarck Range and into the headwaters region of the Bena Bena River. In this traverse, it was found that it was impossible to separate this sequence from the Goroka Formation. It is, therefore, tentatively included in the Palaeozoic Goroka Formation.

Only a relatively small number (45) of specimens were collected from this siltstone sequence and examined for micro-fossils. More detailed sampling may well reveal that Tertiary or Mesozoic sediments constitute a part of the sequence.

BENA BENA FORMATION

The Bena Bena Formation includes the metamorphic rocks cropping out in the vicinity of the disused Bena Bena airfield and on both sides of the Bena Bena River Valley for a distance of eight miles from the Goroka Valley. The formation extends east to the Ramu River, cropping out on both slopes of the Bismarck Range. It occupies a north-east trending, slightly elliptical area, some 30 miles long by about 18 miles wide. Along its southern boundary, it is unconformably overlain by Miocene or unfolded Quaternary sediments. Its northern and western boundary is against the Goroka Formation. Neither the position of the northern boundary nor the actual relationship involved between the two formations are definitely established.

This formation contains rocks which have undergone considerable regional metamorphism. In places, the grade of the metamorphism reaches the albite-epidote-amphibolite facies. Some specimens show evidence of a second stage of dynamic metamorphism which has modified the fabric developed during the first stage.

The most common rock types in the formation include green actinolite-chlorite schist; quartz muscovite schist, with small garnets developing in places; knotted hornblende-felspar gneiss; granitic gneiss; garnet quartzite; mica schist and hornfels.

Many rocks in the formation are considerably less highly metamorphosed. These include metamorphosed siltstone, greywacke, felspathic siltstone and arkose. Felspar porphyroblasts are present in many of these rocks. The growth of the porphyroblasts is controlled in part, by the composition and texture of the original rock. The bedding of the sediments is preserved in many cases, and modified by recrystallization to produce a pseudo-gneissic banding.

Ortho- and paragneiss

~~Ortho- and para~~-gneiss are present in many places. South of Rintebe, pink gneissic material was first mapped as granite intruding the Bena Bena Formation. Thin section examination, however, revealed that much of the felspar consisted of secondary porphyroblasts, and that the rock was probably a metamorphosed arkose.

Specimens of gneissic granite were collected beside the Karmanuntina River, some two miles east of the Finintegu airfield. Similar material was collected from the north slope of the Hagulagaby River valley, opposite the head of the vehicle track. Both these were almost identical in texture and composition to specimens of granitic gneiss collected from the metamorphosed sediments cropping out throughout the area. In many places, the granitic gneiss was interbedded with sediments showing few effects of the metamorphism.

Quartz sericite schist is extremely common in the formation. It crops out in the Bena Bena River area in beds from a few inches to tens of feet thick, interbedded with actinolite-chlorite schist. An apparently continuous sequence of quartz sericite schist, nearly 1,500 feet thick, was mapped in the area north-west of Rintebe. A quartz mica schist sequence of the same order of thickness crops out south-west of Hengenofi.

Not on Plate X

Sheared and metamorphosed basic sills and small intrusives are present in the formation in a few places. Many of these now consist of tremolite schist.

There are marked differences between some of the rock types in the Bena Bena Formation. These differences may be due to initial differences in the sediments from which they are derived. Thus, the commonly felspathic gneiss-schist-metasediment sequence was apparently produced by metamorphism of quartzose, felspathic and argillaceous sediments, such as those derived from an "acid" land mass. On the other hand, the actinolite-chlorite schist could be produced by metamorphism of basic tuffs.

The relationship between the Goroka and Bena Bena Formations is not fully understood. The contact between the two was studied only in the Bena Bena - Dunantina Rivers area and is, in part, arbitrary. The formations are quite distinct in bulk, but the actual boundary between them is not always clear cut.

West of the Bena Bena River, black schist of the Goroka Formation possibly underlies the green actinolite-chlorite schist of the Bena Bena Formation. Farther south, it appears to overlie the Bena Bena Formation. In the headwaters region of the Dunantina River, rocks correlated with the Goroka Formation overlie the Bena Bena Formation. These two formations may possess/a conformable, interfingering relationship.

It is possible, however, that the Bena Bena Formation contains two units separated by an unconformity. There is a suggestion of an unconformity in the area south-east of Hengenofi. In that area, tightly folded gneiss and schist crop out in a creek section. Immediately above them, mica schist crops out in a strike ridge. The mica schist shows no sign of the complex folding revealed in the creek section, but does dip in the direction of plunge of the tight structures. The tight folding may simply fade out up the section and may never have affected the mica schist. The section between the tightly folded gneiss and the mica schist is not exposed. If the unconformity does exist, however, then the younger unit would include the mica schist - actinolite - chlorite sdhist sequence of the Bena Bena River area. This would explain some of the differences in lithology within the Bena Bena Formation, referred to above.

Whether or not such an unconformity exists, the Bena Bena Formation cannot be subdivided on the basis of the present mapping.

"CORRUGATED" ARENACEOUS LIMESTONE

On the Ramu Fall, particularly southward from Guebe, the stream valleys contain numerous large blocks, up to 20 feet across, of brown to green, arenaceous limestone, and rounded boulders of crystalline, white limestone. This type of limestone was not found in known Tertiary or Cretaceous rocks in the mapped part of the Ramu Fall.

One mass, exceeding one mile in length, was found in situ about two miles north of Yanderra, near the Imbrum River. In this area, banded, light-brown to light-green arenaceous limestone and conglomerate were found unconformably overlying the ~~Wilhelm Batholith~~ Bismarck Granodiorite. Thirty feet of consolidated boulder conglomerate directly overlies the Bismarck Granodiorite. The conglomerate contains boulders of granodiorite and hornfels, the latter probably derived from the Goroka Formation. Tilted, evenly bedded, arenaceous limestone, having a maximum thickness of about 200 feet, crops out above the conglomerate. Differential erosion of the bands causes a very characteristic corrugated surface.

Several samples were examined for fossils but none were located. Fossils may be found higher up the precipitous limestone face and a close examination of the white limestone found as floaters may aid in establishing the age of these rocks.

Two outliers of the basal conglomerate were mapped in the Imbrum River valley, near Karimoki.

It seems unlikely that the arenaceous limestone and conglomerate are part of the Cretaceous and Tertiary sequence cropping out on this part of the Ramu Fall. They may be equivalent to the Permian Kuta Group, mapped by Rickwood (1955).

MESOZOIC

Noakes (1939) made the first systematic examination of the Mesozoic rocks in the Central Highlands. He measured and sampled a section along the Chimbu and Lower Wahgi Rivers and introduced the term Wahgi Series to include Mesozoic and Lower Tertiary sediments. Palaeontological examination of his specimens by Crespin, (1940, unpublished) Glaessner, (1943) and Edwards and Glaessner, (1953) revealed that the Wahgi Series included Upper Jurassic, Cretaceous and Tertiary rocks. Edwards and Glaessner (1953) and later Rickwood (1955) subdivided the Wahgi Series and that name is no longer in use.

Sediments of Upper Cretaceous age were the only Mesozoic rocks found in the area of the present survey. They crop out in four, widely separated localities:- near Watabung, Kami, Bundi and Guebe.

UPPER CRETACEOUS

WATABUNG AREA

Fossiliferous Upper Cretaceous rocks crop out in an area two miles long by half a mile wide, situated about one mile north of Watabung Patrol Post. The rocks include light grey mudstone and grey shale, with lenses of grey, fine grained limestone. This shale and mudstone is soft, calcareous and greasy when wet. Silty lenses are present but not abundant. The limestone lenses are discontinuous and range from a few inches to fifty feet in thickness.

The southern boundary of these Cretaceous rocks is a fault which separates them from Miocene "f1-f2" stage tuff and greywacke. The Daulo Volcanics, also of "f1-f2" age, overlie them around their roughly circular northern boundary. The Daulo Volcanics were apparently extruded on an eroded Cretaceous surface. This lens of Cretaceous was a high area on that land surface and is now exposed after the erosion of comparatively thin volcanic cover.

Numerous basic dykes, similar in composition to the Daulo Volcanics, intrude these Cretaceous rocks. The dykes are amygdaloidal or vesicular, indicating that they were intruded at shallow depths.

The sequence dips at various angles to the north. Continuous exposures are rare and the maximum thickness can only be estimated. It is about 1,000 feet.

Certain bands within the sequence contain an abundance of foraminifera. The most important species present are *Pseudorbitoides* sp. cf. *P. israelskii* Vaughan and Cole and *Globotruncana lapparenti* Brotzen. Crespin and Belford (1957) refer these rocks to the Upper Senonian.

This sequence near Watabung does not appear to have any equivalents in the Wahgi-Chimbu section. Their age, however is the same as that of the Mango Marls (Rickwood,1955) which crops out some 120 miles to the west.

KAMI AREA

Upper Cretaceous limestone, shale and mudstone crop out in three separate localities south of Kami, near the southern boundary of the Bena Bena one mile area. Small blocks of grey, fossiliferous limestone are found on the north-west slopes of Mt. Trulatrulaga, about ten miles east of Kami. In general, the lithologies are similar to those at Watabung. The limestone in the Kami area is recrystallized in places due to intrusions of post-Miocene serpentinite.

It was impossible to estimate the thickness of the Cretaceous sediments cropping out south of Kami. The area is one of complex faulting and exposures are generally poor. It was, also very difficult to work out the relationships between the Cretaceous and younger sediments. In places, the Cretaceous rocks are in contact with Eocene limestone, elsewhere with Miocene "f1-f2" shale. East of Kami, the Cretaceous limestone may be an erosional remnant. It is surrounded by Miocene "e" stage sediments but no contacts were seen. Eocene and Cretaceous rocks occur within 200 feet of each other about 500 feet east of the junction of the Tufa and New Tribes Mission roads. There are no signs of faulting in the vicinity and it seems likely that the two units are conformable.

The Cretaceous rocks contain *Pseudorbitoides*, *Globotruncana stuarti*, Neoflabellum sp., and *Dorothia* cf. *bulletta*. Crespin and Belford (1957) suggest that these rocks belong to the Maestrichtian stage.

BUNDI AREA

The first published account suggesting that Cretaceous rocks occur near Bundi was made by Erni in 1944. He described a *Ceno*manian ammonite, *Cunningtoniceros hoeltkeri* (Erni), which was collected from natives in the area but its original source is not known. It is comparable with fossils collected near Mingende, about 50 miles to the south-west, and may have been "traded" into the district.

Fossiliferous Upper Cretaceous rocks crop out north of Bundi Airstrip, in a triangular area about three miles long by one mile wide. The Bundi Fault forms the south-west boundary of these Cretaceous rocks and separates them from Miocene "e" stage sediments. Eocene sediments appear to overlie them conformably along their southern margin, east of the Bundi fault. They are separated by a possible fault from Miocene "f1-f2" volcanics cropping out to the north.

Double-keeled *Globotruncana* were found in a number of specimens, establishing the Upper Cretaceous age of these rocks. Belford (pers. comm.) tentatively judges them to be Senonian.

The dominant lithology is a slightly calcareous, dark grey shale. Light pink to dark grey limestone lenses, ranging from 1/8 inch to several feet in thickness, are common. In general the bigger limestone lenses are lighter in colour. The sequence is crumpled and dragfolded, and is intruded by many basic dykes, few of which are more than five feet wide. The dykes probably represent an intrusive phase of the Miocene extrusives.

There is probably about 1,000 feet of Cretaceous sediments in this area but, because of the folding, it is difficult to estimate the thickness accurately.

GUEBE AREA.

A fault wedge of rocks, at least 2 miles long and more than ½ mile wide, is located at Guebe, eight miles north-west of Bundi. These rocks also contain double keeled *Globotruncana* and are thought to be Senonian. (Belford, pers. comm.). They are definitely not older than Turonian.

These rocks are bounded by the Bundi Fault on the north-west and by another fault on the south-west. Lithologically, they are very similar to the Cretaceous at Bundi. Limestone is not as abundant and the shale seems to be darker. They are intruded by numerous amygdaloidal and vesicular basic dykes, ranging up to several hundred feet in thickness. It is possible that some of these igneous rocks were extruded.

Summary of Cretaceous

The Cretaceous rocks cropping out in the map area on the southern slopes of the Bismarck Range are soft, calcareous, grey shale and mudstone containing lenses of light coloured, fairly clean limestone. They are probably Maestrichtian in age.

There are no Maestrichtian rocks in the Wahgi-Chimbu section a few miles to the west. The Mango Marls, which crop out about 120 miles to the west, are equivalent in age but no limestone was described in the type section.

The age of the Cretaceous rocks cropping out on the Ramu Fall is not definitely established. The presence of double killed Globotruncana indicates that they are definitely Turonian or later in age. The Cenomanian ammonite, described by Erni, indicates that some rocks of that age may crop out in the area, but none were found during the present survey. The Cretaceous rocks seen are mainly dark grey to black shale containing discontinuous lenses of limestone. The limestone is generally darker coloured than that found south of the Bismarck Range.

TERTIARY

Tertiary rocks were first discovered in the Central Highlands of New Guinea by N. H. Fisher in 1937. He collected specimens of what was subsequently called the Chimbu Limestone from a locality near the Chimbu Airfield. Fisher's samples were examined by Miss I. Crespin and were shown to be Eocene in age. (Crespin, 1938). Noakes, in 1939, named a thick limestone sequence in the Wahgi-Chimbu section as the Chimbu Limestone. Crespin (1940, unpublished) showed that this rock unit contained Eocene and Oligocene rocks. In 1940-41 Fisher collected limestones from several localities in the area between Bena Bena and Kaiapit, all of which were assigned by Miss Crespin to the Miocene. Rickwood (1955) tentatively assigned Globerigina marls which overlie the Chimbu Limestone to the Lower Miocene.

EOCENE

Eocene rocks were mapped in the vicinity of Bundi and Dumpu on the northern side of the Bismarck Range and near Kami at the southern end of the Goroka Valley.

Bundi Area

The largest body of Eocene rocks was mapped at Bundi where they occupy an area four miles long by perhaps one mile wide. Diagnostic fossils were found at a few localities but most outcrops were mapped as Eocene on the basis of lithological similarity to the fossiliferous rocks. The southern boundary is tentatively placed at the Bundi Fault. Here, Miocene "e" stage shale is faulted against rocks which are regarded as being part of the Eocene sequence.

Near Bundi, the Eocene may conformably overlie the Cretaceous. One mile east, in a stream section it is faulted against volcanics at present correlated with the Miocene "f1-f2" stage. In the Ua River, the Eocene is faulted against post-Miocene serpentinite and peridotite intrusives.

There appear to be more than 3,000 feet of sediments exposed in the section one mile east of Bundi. It is impossible to estimate the true thickness exposed in the Ua River sections because of probable repetition by folding and faulting.

The rocks mapped as Eocene which crop out in the Bundi area, are mainly black shale and slate, calcareous in part, with interbedded grey green sandstone. They contain a few lenses of limestone ranging from a fraction of an inch to 20 feet in thickness. The limestone is a grey to cream coloured, massive rock, containing angular fragments of green shale up to two inches long. Conglomerate beds from one to 20 feet thick are common, particularly in the section one mile east of Bundi. The conglomerates contain subangular fragments of quartzite, dolerite and banded slaty shale. The fragments are from 1/4 inch to eight inches in length and in places, are oriented parallel to the bedding.

Numerous granodiorite, diorite and some basic rocks intrude the sequence, particularly in the Ua River section. These minor intrusives have been extensively metasomatized. Quartz veins are common in some places.

These rocks are regarded as Eocene "a" or "b" stage by Crespin and Belford (1957). This is based on the presence of fragments of tests of *Nummulites* and *Discocyclina* in limestone specimens collected from three localities.

The rocks cropping out in the east-flowing tributary of the Tanja River, some twelve miles east of Bundi, are included in this Eocene sequence. No fossils were found in the black shale and slate cropping out in this creek but they are lithologically similar to the fossiliferous Eocene rocks. Intense shearing and quartz veining, and the regularity of the drainage revealed in the aerial photographs suggest these rocks are bounded on the south-west by a fault. This fault is probably the continuation of the Bundi Fault, which bounds the Eocene farther to the west.

<u>Dumpu Area</u>

Fossiliferous calcarenite crops out in a few small exposures on a hillside, two miles west of Dumpu airfield. The calcarenite underlies Miocene "e" stage limestone and sediments cropping out 200 feet higher up the hill. It contains numerous *Discocyclina* and was assigned to the Eocene "a" or "b" stage, by Belford. (Personal communication).

<u>Kami Area</u>

The third area of outcrop of the Eocene is in the Kami area, where "a" or "b" stage rocks crop out west of the Asaro Fault. North-west of Kami, the Eocene rocks dip to the west and are overlain apparently unconformably by westward dipping conglomerate of the Miocene "f1-f2" stage. The relationships between the Eocene and the other rocks in the area are not clear. It appears to overlie conformably the Maestrichtian limestone and shale in the vicinity of the New Tribes Mission. However, the relationship is obscured by folding, faulting and the intrusion of large masses of post-Miocene serpentinite.

The only fossiliferous Eocene in the area consists of fine-grained, massive or thin bedded, light grey to mauve coloured Globigerina limestone. Some calcareous grey shale cropping out in the area is tentatively included in the Eocene.

Crespin and Belford assigned these rocks to the Eocene "a" or "b" stage on the basis of the fossils contained in the limestone. They recognised the species *Nummulites bagelensis*, *Discocyclina* cf. *pratti*, and *Actinocyclina aster*.

<u>OLIGOCENE</u>

Oligocene "c" stage rocks were recognized at and near Asaro, at Geppavi Hill and at a locality 2½ miles east of Geppavi Hill.

Asaro Area

At Asaro, the rock is a massive, light coloured foraminiferal limestone. No contacts were observed but the Palaeozoic Goroka Formation crops out a few hundred feet upstream from the limestone. At Urabagga Hill, less than a mile to the south-west, the Oligocene limestone unconformably overlies both the Goroka Formation and a small stock of the Bismarck Granodiorite. At the contact there are a few rounded pebbles of quartz and granodiorite, up to one inch in diameter. These occur as individual pebbles or in thin, discontinuous conglomerate lenses. The limestone grades upward into dark grey calcareous shale which may be Upper Oligocene or Lower Miocene. The Lower Oligocene rocks at Asaro and Urabagga Hill are less than 200 feet in thickness.

The Oligocene index fossil, Nummulites intermedius, was the only diagnostic form present in the samples collected. Crespin and Belford (1957) refer the sequence to the "c" stage because of the absence of typical Upper Oligocene forms.

Geppavi Hill Area

A 50 foot thick lens of limestone, lithologically similar to that at Asaro, crops out at Geppavi Hill. This limestone contains abundant Nummulites intermedius and is also referred to the "c" stage. It is separated by a shear zone from schists of the Goroka Formation cropping out to the south. To the north, fossiliferous shale and siltstone, probably conformably underlying the Oligocene Limestone, are exposed in road cuttings. The top 50 feet of shale is bedded and fossiliferous. The sequence contains 2 to 5 feet thick beds of conglomerate and, lower down the hill, it is separated from the Goroka Formation by massive conglomerate. The conglomerate consists mainly of unsorted, subangular schist fragments, from two to three inches long, and is intruded by basic dykes. The age of the shale and conglomerate is not known but may be Eocene.

Oligocene "c" stage rocks crop out about 2½ miles to the east. They consist of grey-green, hard to soft calcareous shale, intruded by small basic dykes, and contain Nummulites intermedius. The sequence is about 100 feet thick, and probably directly overlies the Goroka Formation. Though exposures are poor in this area, it is thought that here "e" stage rocks overlap the Oligocene. Certainly, no Oligocene rocks were found east of here.

MIOCENE

Miocene sediments and volcanics are the most widely distributed of the Tertiary rocks in this part of New Guinea. They include sediments and volcanics of "e" and "f1-f2" stages. For the purposes of this report, the "e" stage includes the uppermost part of the Oligocene and all of the Lower Miocene.

"e" Stage

Rocks of the "e" stage crop out on the Ramu Fall near Bundi and Guebe, and along the foothills of the Bismarck Range. South of the Bismarck Range, they crop out between Asaro and Daulo, and from the Bena Bena River to the eastern margin of the map sheet.

Bundi-Guebe Area

The rocks cropping out from the Baia River to the Ua River, a distance of 13 miles, are regarded as belonging to the one sequence. Diagnostic "e" stage fossils were collected at only two widely separated localities in this area. However, because of stratigraphic continuity and similar lithology throughout, the whole sequence is considered to be "e" stage.

This large body of rocks is separated by a fault from the Bismarck Granodiorite and the Goroka Formation, cropping out to the south-west. At its north-east boundary, it is faulted against Cretaceous, Eocene and other Miocene rocks.

Black to dark grey shale and slate are the most common rock types in the sequence. Small lenses of dark grey, Globigerina limestone are common in the sequence in some places. A 200 foot thick band of bedded, grey fossiliferous limestone crops out 1¾ miles west of Guebe, on the Baia River. It is conformably enclosed within the black slate sequence. Several smaller bands of limestone, up to a few feet in width, crop out elsewhere but only one contains diagnostic fossils.

The Baia River section may involve as much as 8,000 feet of sediments. Shearing was observed in several places, but is not thought to be of regional importance. It probably has not resulted in significant additions to the apparent thickness of the section.

The age of the rocks is based on the presence of the following foraminifera:- Spiroclypeus margaritatus, S. orbitoides, Lepidocyclina (Eulepidina) cf. Murrayana and L. verbeeki. One sample from the Baia River section contained Operculinella.

Rocks, tentatively referred to the "e" stage, crop out north of the Bundi and Imbrum River Faults. These contain Globigerina in places. They are mapped as "e" stage because of their lithological similarity to the fossiliferous "e" stage rocks in the vicinity. It is quite possible, however, that they belong elsewhere in the stratigraphic column.

Wararais-Dumpu Area

Miocene sediments crop out along the south-west margin of the Ramu-Markham Valley from the vicinity of Wararais to about eight miles north-west of Dumpu airfield. These sediments consist of lenses of limestone, up to 200 feet thick and several miles long, interbedded with black siltstone, shale and greywacke.

A fairly complete section through the Miocene sequence is exposed in the creek joining the Ramu River, opposite Gusap airfield. The youngest limestone lens in this section contains f1-f2 foraminifera, including Operculina. Lower lenses in the section contain "e" stage foraminifera. The sequence examined consists of approximately 10,000 feet of massive and thin bedded grey, grey-blue or cream coloured limestone, sandy limestone, marl, black siltstone and shale, brown friable greywacke and tuff. The siltstone is sheared in places and shows some tight, minor folding. Several micro-diorite and hornblende-felspar porphyry dykes intrude the sequence and have produced some local hardening of the siltstone.

The Miocene rocks are not so extensive to the north-west of this section. They consist of black schistose siltstone and shale interbedded with limestone lenses.

The limestone lenses contain only "e" stage foraminifera and are apparently equivalent to the lower part of the section measured south of Gusap airfield. They crop out as dip slopes, having a relief of up to 1,000 feet. Their strike is consistently north-west, except where they are affected by faulting, as in the outcrop west of Dumpu airfield.

The Miocene sequence cropping out in the vicinity of the Wararais consists of limestone, calcareous greywacke, sandy mudstone and siltstone. Thinly bedded, impure marl is common, and is silicified and contact metamorphosed in the vicinity of diorite and quartz diorite intrusives. A distinctive rock type is a thinly banded prehnite-epidote hornfels, intruded by quartz micro-diorite. This rock was possibly originally a calcareous arkose.

Andesitic flows, crystal tuffs and agglomerate, with minor micro-gabbro dykes, crop out in the road cuttings of Cassam Pass. These volcanics are presumably Miocene "e" stage. They are lithologically similar to the volcanics inter-bedded with fossiliferous "e" stage limestone cropping out south of Kainantu.

Diagnostic "e" stage foraminifera were found in almost all the limestone lenses in the sequence, though some specimens contained only corals and algae. The genus Spiroclypeus was represented in most specimens. In some, it was associated with the subgenus Nephrolepidina, in others with Eulepidina. The characteristic lower "e" stage species, E. murrayana and E. insulaenatalis, were recognized in many specimens (Crespin and Belford, personal communication).

The relationship of the Miocene sequence to the underlying rocks is not known. The bulk of the outcrop information in the Miocene was obtained from the ridge out-crops of limestone and the immediately underlying siltstone beds. The black schistose siltstone sequence, which underlies the Miocene, crops out only in the stream channels. In every case, there was a gap of some miles between the Miocene and the closest outcrop of the underlying rocks.

The base of the Miocene was placed more or less arbitrarily immediately below the lowest limestone horizon. West of Dumpu airfield, the base of the Miocene is established more accurately. Fossiliferous Eocene "a" or "b" stage calcarenite crops out some 200 feet below "e" stage limestone, apparently with a disconformity but no unconformity.

In the Wararais area, the dip of the limestone lenses becomes shallower towards the south-west where a large intermediate intrusive body crops out. No contact was seen but it is possible that the Miocene overlies the intrusive unconformably.

ASARO-DAULO AREA

A folded sedimentary sequence, mapped as "e" stage, crops out between Asaro and Daulo in an east-west trending area about eight miles in length by three miles in width. This sequence is overlain in the eastern part of the area by thin Quaternary deposits but is exposed in the stream channels. The Asaro River Fault bounds the sequence on the south-west and separates it from the f1-f2 stage Daulo Volcanics. The sequence overlies the Goroka Formation along its north-western margin and overlies Lower Oligocene rocks at Unahagga Hill.

Urabagga

Insufficient fossil evidence was found to establish accurately the boundary between the Lower Oligocene and the "e" stage sequence. Its boundary is only approximate.

The sequence consists mainly of grey to dark grey shale and mudstone, in places calcareous, with lenses and thin beds, up to a few feet thick, of grey green, slightly calcareous greywacke, conglomerate and limestone. The conglomerates contain rounded pebbles about one inch in diameter, of grey to cream chert and granodiorite, the latter probably derived from the Bismarck Granodiorite. The limestone is light to dark grey or pink in colour, hard, dense and fine grained. Dark grey limestone lenses are common west of Asaro.

Two large bodies of limestone cropping out near Korfena are included in this "e" stage sequence. East-dipping conglomerate beds, underlying the limestone, are exposed in Korfena Waters. The conglomerate unconformably overlies the Goroka Formation. The limestone contains poorly preserved *Globigerina* but no diagnostic fossils. It is hard, dense, finely crystalline grey, generally massive and calcite veined. These rocks are included in the "e" stage because the larger limestone mass grades upwards and laterally into calcareous grey shale, similar to fossiliferous "e" stage shale cropping out to the south.

The sequence probably contains both Upper Oligocene and Lower Miocene rocks. Crespin and Belford (1957) assigned it to the "e" stage, on the basis of the following fossils which were recognised in several samples: *Spiroclypeus margaritatus*, *Lepidocyclina* (*Eulepidina*) cf. *insulaenatalis*, *L.* (*Nephrolepidina*) cf. *sumatrensis* var. *inormata*, *Neoalveiolina pygmea*, *Gypsina howchini* and *Miogypsinoides dehaartii*. Some samples contain *Operculinella* and all contain *Globigerina*.

The thickness of this sequence is estimated at 8,000 feet. This is based on the section exposed in a stream in the southern part of the area, where there appears to be no repetition due to folding or faulting.

Bena Bena River - Aiyura Area

"e" stage rocks crop out in an east-west trending area, extending from the south-east end of the Goroka Valley, near the Bena Bena River, to beyond Aiyura. These rocks attain their maximum development south of the map area.

An outlier of "e" stage rocks was mapped at the western end of this area, three miles north-east of Geppavi Hill. A bed of conglomerate crops out at the base of these rocks, unconformably overlying the Goroka and Bena Bena Formations. The conglomerate is from 5 to 50 feet in thickness and contains well cemented cobbles of granite, dolerite and quartz up to two inches in diameter. The contact with the Palaeozoic rocks is extremely well exposed in the north flowing stream near the western end of the outlier. The rocks above the conglomerate are bedded, grey, fossiliferous limestone and hard, calcareous greywacke.

The unconformity at the southern end of the outlier is not exposed but grey schist of the Goroka Formation crops out about 100 feet south of the overlying limestone. The outlier appears to occupy the core of a small syncline in the basement complex.

The "e" stage sediments cropping out along the southern margin of the map area are markedly different in lithology from those cropping out in the Asaro-Daulo area and on the Ramu Fall. In both the latter areas the sediments of fine clastics and limestone with, in some places, subordinate conglomerate near the base. In this area, the basal "e" stage sediments consist of a considerable thickness of conglomerate and coarse clastics. These pass upwards into calcareous siltstone, shale and marl with interbedded limestone lenses. These, in turn, are succeeded by interbedded limestone and volcanics.

A bed of conglomerate, from 500 to 1,000 feet thick directly overlies the Palaeozoic basement between Hengenofi and Aifunka. North of Hengenofi, conglomerate constitutes a considerable proportion of the basal section but crops out in discontinuous lenses. The conglomerate consists of subangular pebbles, cobbles and boulders of igneous rocks, quartz, blue slate and schist, and other metamorphic rocks in a grey or brown, commonly ferruginous greywacke matrix. Many of the metamorphic and igneous fragments are completely decomposed. In one place, the conglomerate contained fairly well rounded pebbles, mainly of quartz, while the larger fragments were quite angular.

The remainder of the basal "e" stage in this area consists of friable, brown, white flecked, fine to coarse grained, micaceous greywacke and grit; black and white, calcareous greywacke; grey to dark blue, finely bedded siltstone and carbonaceous shale, in places thinly interbedded with brown greywacke; fine, blue, micaceous siltstone, in places hardened; yellow, friable mudstone and claystone.

The folding in the sequence adjacent to the Palaeozoic basement makes it difficult to estimate the thickness of the coarse clastics. They are probably more than 2,000 feet in thickness.

The sediments overlying the coarse clastics consist of grey to black, thinly interbedded siltstone and sandy siltstone, calcareous in part, grey calcareous mudstone, marl and silicified marl. Near the base, the siltstone contains numerous lenses and thin beds of greywacke. The sequence includes several lenses of limestone, some of which contain diagnostic "e" stage fossils. Silification and pyrite mineralization along joint surfaces is common in the sequence near igneous intrusives and immediately below the overlying volcanics.

The fine-grained, calcareous sequence crops out in a south-east trending area, extending from near the Bena Bena River to the southern boundary of the map area. To the south-west, they are overlain by f1-f2 stage sediments and volcanics. On the northern slopes of Mt. Trulatrulaga, a lense of fossiliferous "e" stage limestone is overlain by 50 feet of schistose siltstone and then by the Daulo Volcanics, apparently conformably. Near the Bena Bena River, a sequence of fossiliferous "f1-f2" stage shale and mudstone overlie the "e" stage rocks, and are in turn overlain by the Daulo Volcanics. Apparently, the Daulo Volcanics overlap the "f1-f2" sediments to the south-east and directly overly the "e" stage.

The complete "e" stage sequence in the Hengenofi area is about 4,000 feet in thickness.

The easternmost outcrop of coarse clastics referred to the "e" stage is in the Okapa Road section, where about 1,500 feet of conglomerate, greywacke and mudstone crop out. Farther east, in the Aiyura-Arona road section, the rocks cropping out are basic volcanics, andesitic and basaltic lava flows, tuffs and agglomerates, intruded by numerous dioritic and gabbroic bodies. The volcanics are similar to volcanics interbedded with "e" stage limestone, which crop out south of the area. In 1940, N. H. Fisher collected specimens of "e" stage limestone from a creek one mile north of this road, four miles east of Aiyura. It seems probable that the volcanics are "e" stage.

Diagnostic fossils were recognized by Crespin and Belford (personal communication) in specimens from four limestone lenses in the "e" stage sequence. These include *Spiroclypeus margaritatus*, *Miogypsinoides dehaartii*, *Amphistegina* sp. and species of *Lepidocyclina* and *Nephrolepidina*.

"e" Stage (?) Chert Beds

Banded chert crops out North of Daulo in an oval area about 2½ miles long. The chert is evenly bedded in beds ranging from a fraction of an inch to several feet in thickness. It is commonly dirty yellow in colour but green, grey and black bands are also present. The rock is of uniform grain size, hard and dense, and breaks with a conchoidal fracture.

The contact of the chert and "e" stage rocks to the south and north, though defined within a few feet in many places, could not be studied because of soil cover. Conglomerate and breccia beds crop out near the southern contact where "e" stage shale apparently conformably overlies the chert. Rounded masses of recrystallized limestone, two feet in diameter, are enclosed in the chert beds near the southern contact.

The chert beds are either part of the lower "e" stage or are older than "e" stage. This conclusion is based on the presence of chert pebble conglomeratebeds at the chert - "e" stage contact. Further, the "e" stage shale appears to overly the chert beds, without any sign of faulting.

"f1-f2" STAGE

Three groups of "f1-f2" stage rocks are recognized in the area. They are fine grained calcareous sediments, the Daulo Volcanics and the Asaro River Conglomerate, a greywacke-conglomerate sequence derived from the Daulo volcanics. The calcareous sediments are exposed near Watabung and Kami in the Highlands, and in a small area on the Ramu Fall south of Gusap airfield. The Daulo Volcanics crop out near Watabung and in the south-west corner of the map area. The Asaro River Conglomerate crops out between the two main areas of outcrop of the Daulo Volcanics.

Some rocks cropping out in the Bundi area are tentatively assigned to the "f1-f2" stage. They are volcanics and sediments lithologically similar to the Daulo Volcanics and associated sediments.

Calcareous "f1-f2" Stage Sediments

"f1-f2" stage sediments crop out west of Watabung in the Marifutica River where they are conformably overlain by Daulo Volcanics. A north-west trending fault wedge of these sediments crops out at Watabung. The wedge is faulted against Daulo Volcanics to the south, and against Upper Cretaceous sediments and Daulo Volcanics to the north. The base of this sequence was not seen but in all probability they overlie the Chimbu Limestone to the south.

The lowest beds of the sequence comprise mainly fossiliferous grey shale and mudstone, calcareous in part, containing interbedded lenses of grey limestone. The lenses range in thickness from a few inches to 200 feet. Bedded greywacke constitutes most of the upper part of the section. The greywacke generally does not contain foraminifera but plant fragments and coaly stringlets are common. The largest coaly stringlet observed was two feet long by ¼ inch wide. The topmost 300 feet of section contains massive, discontinuous lenses of conglomerate generally three or four feet thick, but in places up to 40 feet thick. The pebbles range up to eight inches in diameter and include dolerite, limestone and greywacke in approximately equal amounts. The limestone fragments generally contain micro-fossils. They include limestones of Upper Cretaceous, Eocene and Oligocene age and of the "e" stage and "f1-f2" stage. Thus, the plant bearing greywacke and enclosed conglomerate were produced by erosion of rocks of all these ages, including part of the "f1-f2" stage.

The shale and limestone of the sequence contain the following fossils, indicating their "f1-f2" age:-

Lepidocyclina (Nephrolepidina) angulosa, L. sumatrensis, L. (N.) parva, L. (Trybliolepidina) verrucosa, Miogypsina kotoi, M. polymorpha, M. mamillata, Katacycloclypeus annulatus. (Crespin and Belford, 1957) Echinoids, corals and lamellibranchs are also present.

The "f1-f2" sequence in the Marifutica River area includes at least 5,000 feet of sediments, intruded by numerous dykes and sills of the Kenangi Intrusives. In places, the calcareous shale and limestone are silicified and recrystallized over a distance of up to 40 feet from the intrusive contact.

A fairly thick section of "f1-f2" stage rocks crops out east and north-east of Kami, at the south-eastern end of the Goroka Valley. The fine-grained sediments at the base appear to overlie conformably "e" stage rocks cropping out to the north. Volcanics, correlated with the Daulo Volcanics, form the top part of the "f1-f2" section here. The sediments, below the volcanics, consist mainly of grey calcareous shale and mudstone containing a few thin beds of grey green calcareous greywacke. Limestone crops out as discontinuous lenses, ranging from a few inches to tens of feet in thickness. The limestone is grey to light grey, finely crystalline, hard, dense and generally massive.

Although a few fragments of lamellibranchs were found, only the microfossils Lepidocyclina and Cycloclypeus were useful in dating. In the absence of other foraminifera, this sequence is regarded as being "f1-f2" stage. (Crespin and Belford, 1957).

Some 400 to 500 feet of fossiliferous "f1-f2" stage sediments crop out due south of Gusap Airfield. These sediments are at the top of a 10,000 feet thick sequence of mainly "e" stage sediments. They consist of a limestone lens containing "f1-f2" stage fossils, interbedded with calcareous siltstone and shale. Apparently, it is the result of sedimentation in this area continuing through from the "e" stage into the "f1-f2" stage.

The limestone specimens contained some species of Operculina as well as corals and algae. (Belford, personal communication).

DAULO VOLCANICS

The extrusive, basic igneous rocks of the "f1-f2" stage are herein named the Daulo Volcanics. The type locality is in the vicinity of Daulo (latitude 6° 2'S., longitude 145° 14'E.) situated at the mountain pass between the Goroka Valley and the Marifutica River valley. The body of extrusives mapped in this area is at least twelve miles long by about five miles wide. It is bounded on the north-east by "e" stage sediments at the Asaro River Fault. At Watabung, a wedge of "f1-f2" sediments is faulted against the volcanics. East of the wedge, a remnant of Upper Cretaceious is exposed, unconformably overlain by the Daulo Volcanics. West of Watabung, the volcanics overlie "f1-f2" stage sediments. In most places in the Marifutica River valley the lower 100 to 200 feet of Daulo Volcanics is characterised by agglomerate, commonly overlying conglomeratic "f1-f2" sediments. In some places, tuffs are interbedded with the agglomerate.

The volcanics consist mainly of hornblende-feldspar porphyries, vesicular and amygdaloidal in part. Amygdules are filled with calcite, analcite, heulandite, pennite and chlorite. Flow lines are common.

East of Kami, a body of volcanics crops out in an area six miles long by about three miles wide. These volcanics are correlated with the Daulo Volcanics. They are underlain by "f1-f2" stage sediments. In general, these volcanics are finer grained than those at Daulo, are not commonly porphyritic and are serpentinous in many places.

ASARO RIVER CONGLOMERATE

The Asaro River Conglomerate is a thick sequence of greywacke and conglomerate, interfingering with the Daulo Volcanics. The unit crops out to the south west of the Goroka Valley. The type area is in the Asaro River (latitude 6° 13'S., longitude 145° 25'E.) west of Kami. The conglomerate contains well rounded pebbles, cobbles and boulders of Daulo Volcanics. Some tuff, agglomerate and lava flows are interbedded with the conglomerate and greywacke in the north, but these become less important farther to the south. Tongues of volcanics again become common in the formation at the southern end of its area of outcrop, near the Daulo Volcanics in the Kami area.

The Asaro River Conglomerate crops out over an area at least nine miles long by five miles wide. To the north-east, the Asaro River Fault separates them from the Goroka Formation. Towards the south-west, they probably disconformably overlie Eocene limestone and shale. At the southern end of their area of outcrop, they are faulted against upper Cretaceous shale and limestone, and are probably intruded by serpentinite. The unit may attain a maximum thickness of 10,000 feet.

Lenses of light coloured, fine-grained limestone are fairly common within the conglomerate. These were sampled by Dr. E. Reiner of the C. S. I. R. O. They contain "f1-f2" stage foraminifera, thus dating the Asaro River Conglomerate and the Daulo Volcanics.

Volcanics, tentatively regarded as "f1-f2" stage crop out over a large area in the vicinity of Bundi. These are mainly basic volcanics, lava flows, tuffs and agglomerates. In places, the volcanics overlie "e" stage sediments, and are possibly contemporaneous with the Daulo Volcanics. No fossils were found in the volcanics or in the sediments associated with them.

PLIOCENE

AIFUNKA VOLCANICS

The Aifunka Volcanics are a succession of basic to intermediate volcanic rocks which unconformably overlie the Miocene sediments in the vicinity of Aifunka, south-west of Kainantu. They consist of fine-grained and porphyritic andesite lavas, with quartz porphyry and porphyritic augite basalt as flows or sills and dykes. Approximately 100 feet of thin bedded tuff with a few thin flows constitute the top of the succession. Beds of agglomerate are present in the sequence, particularly near the base.

Mt. Munefinka, located west of Kainantu, is a long narrow mass of rock rising to a height of [illegible],700 feet. It is a

/x dyke of coarsely porphyritic pyroxene-biotite-andesite. The andesite contains phenocrysts of felspar, up to 5 millimetres in length and smaller phenocrysts of biotite and pyrogene in a fine-grained, light grey matrix. In composition it is very similar to the Aifunka Volcanics. Probably this dyke is an intrusive phase of the magma which produced the Aifunka Volcanics.

These volcanics are apparently younger than the orogeny which folded the Miocene and older sediments. They are overlain by Quaternary lake deposits. In the absence of any fossil evidence, they are regarded as Pliocene in age.

Deeply weathered rocks cropping out south of Kainantu are very similar in appearance to the weathered outcrop of the Aifunka Volcanics. Since the general disposition of these rocks suggest a volcanic origin, they are tentatively correlated with the Aifunka Volcanics.

Gold mineralization has occurred in the Aifunka Volcanics. A certain amount of development and testing has been done at Aifunka itself but the results are not promising.

QUATERNARY

Quaternary deposits cover a considerable portion of the map area. They consist of shallow dipping to flat lying, poorly consolidated, lacustrine, alluvial and piedmont deposits. The four largest areas of Quaternary sedimentation are the Goroka, Kainantu and Arona Valleys in the Highlands and the Ramu Valley.

Mackay (1955) referred to the deposits occupying the Kainantu and Arona Valleys as the Kainantu Beds. They are extensively eroded and are regarded as Pleistocene in age.

Fairly extensive alluvial, piedmont and swamp deposits were mapped in some other stream valleys in the map area.

GOROKA VALLEY

Flat-lying, poorly consolidated boulder beds, gravel,sand and clay deposits, totalling about 200 feet in thickness, occupy the floor of the Goroka Valley. These are alluvial or mixed alluvial and lacustrine deposits.

The material was derived from piedmont fans issuing out of the steep valleys of the Bismarck and Asaro Ranges into the broad Goroka Valley. The unstratified piedmont material was distributed across the floor of the valley by the Asaro River and its tributaries, being sorted and bedded in the process.

Near the margins of the valley, flat-lying bedded deposits interfinger with unstratified piedmont.material. The latter, regarded en masse, dips shallowly basinwards. The interfingering is well displayed at the northern end of the valley. Close to the Bismarck Range, north of Asaro, the piedmont fans consist of large rounded boulders, of all sizes, in a clay and sand matrix. No bedding is present and the boulders are commonly not in contact. A few miles to the south, beds of sand, commonly two to three feet thick, though some are up to twenty feet thick, separate thicker tongues of unstratified boulder deposits. In the Asaro River, there are a few three to ten feet thick boulder beds, but the bulk of the section consists of thinly bedded clay, silt, sand and gravel deposits.

Deposition of material is still continuing in parts of the Goroka Valley. Piedmont deposits migrate down tributary valleys and are spread out in fans across the valley floor. However, the drainage in the valley is now actively eroding the deposits. The Asaro River, formerly the main agent of sedimentation, has cut its channel through the hills to the south to a lower level than the valley floor. It has now incised the Quarternary deposits to a depth of 100 feet.

The deposits in the Goroka Valley are mapped as Quaternary undifferentiated. They range in colour from light grey to dark grey, olive and brown. They are commonly carbonaceous, containing whole three trunks, twigs, leaves and finely macerated debris. The sediments consist of thinly bedded or massive clay, silt, sand and gravel. The coarse beds are usually crossbedded and occur in irregular bodies, suggesting channel fillings. An exception is a well bedded, 100 foot thick cobble conglomerate, extending over an area of about one square mile, north of Kami.

The fragmental material in these beds consists of the more resistant rock types cropping out in the surrounding hills. They include volcanics, granodiorite, quartz, limestone and some metamorphic rocks. Shale and other sedimentary fragments are rare.

KAINANTU BEDS

The Kainantu Beds consist of some 100 feet of flat lying, fairly well bedded cobble and pebble conglomerate, gravel, sand and clay. They produce a distinctive pattern on the aerial photographs and are easily distinguishable from the younger alluvial deposits. The Kainantu Beds were probably deposited under lacustrine conditions in the Kainantu and Arona Valleys. Subsequently the Ramu River cut back through the Bismarck Range, drained the lakes and pirated their drainage system. At present, the Ramu River has incised deeply into the lake deposits, in many places exposing the underlying bedrock.

The cobbles in the conglomerate beds are mainly quartz, quartzite, diorite, gneiss and other resistant igneous and metamorphic rocks. Near Munefinke, the conglomerate contains mainly quartz fragments. This is because the bulk of the source material here is the basal Miocene conglomerate, and only the quartz fragments in that conglomerate survive the two periods of weathering.

RAMU VALLEY

The Ramu Valley is an extensive level plain, occupied by an unknown thickness of alluvial deposits. The alluvial material originates in the piedmont fans issuing forth from the steep valleys in the Bismarck and Finisterre Ranges. The piedmont material is redistributed across the Ramu River flood-plain which occupies the entire floor of the valley. At present, the Ramu River has cut into the valley floor to a depth of about 40 feet. The alluvial deposits of the valley consist mainly of cobble and pebble beds, gravel, silt and clay. Huge boulders, ten feet and more across, are common in the piedmont fans issuing out of the mountains.

QUATERNARY VOLCANICS

Quaternary volcanics were mapped by Mackay in 1955, at two localities, some eight miles north of Kainantu. The volcanics consist of sub-horizontal rhyolite flows and rhyolitic breccia, unconformably overlying the Bena Bena Formation. They are approximately 600 feet thick and are deeply dissected.

These volcanics are regarded as being late Pleistocene in age. They are similar to volcanics cropping out in the Wau area, which overlie the Pleistocene deposits.

Alluvial deposits were mapped in many of the river valleys on the southern slopes of the Bismarck Range, such as the Bena Bena and Dunantina Rivers. These deposits are essentially the same, in composition and origin, as these in the Goroka Valley.

Swamp deposits are being laid down in some places, such as the large, swampy area, four miles north-west of Kainantu. The deposits consist largely of black, carbonaceous silt. Ferruginous material is being deposited in some parts of this swamp, rather in the manner of a bog iron ore deposit.

IGNEOUS INTRUSIVES

There are several groups of intrusive rocks cropping out in the area, some of which represent different periods of intrusion. One group, the Kenangi Intrusives, is formally named in this report. The remaining groups include the Bismarck Granodiorite intermediate to basic intrusives of unknown age, acid to basic late-Tertiary intrusives and late-Tertiary basic and ultrabasic intrusions. Two small, metamorphosed granites of probable Palaeozoic age were also mapped.

Metamorphosed Palaeozoic Intrusives

This group includes two fairly small igneous bodies. The first crops out over an area of about 16 square miles in the Karmanuntina River Valley, two miles east of Finintegu airfield. A smaller body crops out north of the Hagulagaby River, opposite the end of the road.

Both these granitic bodies are gneissic in texture. They are similar in lithology, consisting of 30 to 40% quartz, 50 to 70% felspar, 1 to 10% biotite, muscovite and accessory iron ore and sphene. The felspar is mainly albite and orthoclase or perthitic orthoclase in nearly equal amounts. Both these granites have undergone considerable deformation, with the result that it is difficult to be sure they are of magmatic origin and not highly metamorphosed arkosic sediments. The smaller body may best be described as a cataclastic granite.

These two bodies intrude the Bena Bena Formation. Because of the degree of deformation they have undergone, it is suggested that they were intruded during the Palaeozoic.

~~BISMARCK BATHOLITH~~ Granodiorite

The Bismarck Granodiorite (Rickwood, 1955) crops out in the Bismarck Range at Mt. Wilhelm and for many miles to the south-east and north-west. Thirty two igneous bodies believed to be related to the batholith were mapped. The largest of these extends from the headwaters of the Asaro River to the western edge of the map area and, according to Rickwood (1955), for a further 50 miles to the north-west.

The other 31 bodies are very much smaller stocks which crop out to the south-east of the main mass. The batholith is believed to plunge gradually to the south-east. These smaller bodies are possibly due to irregularities in the shape of the roof of the batholith and to small stocks arising from the main mass.

Noakes (1939, unpub.) made the first systematic investigation of these rocks. He referred to them as the Wilhelm Granite. In 1950-51, Rickwood (1955) remapped part of the batholith and referred to it as the Bismarck Granodiorite. The batholith contains a wide variety of rock types, including granite, quartz oligoclase rock, gabbro and ultrabasics as well as the more common granodiorite and quartz diorite.

The Bismarck Granodiorite is fairly similar in lithology and disposition to the Kubor Granodiorite which is known to be pre-Permian in age. The two intrusives are probably of the same age. A small stock of the Bismarck Granodiorite is unconformably overlain by Oligocene sediments at Urabagga Hill. Therefore, the batholith is certainly older than the Oligocene and cannot be related to the intrusive epoch associated with the late Tertiary orogeny.

Examination and sampling of the main mass was confined to the Yanderra, Bononi, upper Asaro River, Pombameri-Keglsugl and Mt. Wilhelm areas. The petrological sample locality map shows the relationship of these areas to the mass as a whole. Mrs. K. Lovering of the Bureau of Mineral Resources examined 57 thin sections of specimens collected from the main mass and a further 20 sections of acid and basic dyke rocks intruding it.

At Yanderra, the batholith is mainly grey, jointed granodiorite. Some specimens are porphyritic. The granodiorite consists of laths of partly sericitised oligoclase (60%), grains of hornblende and biotite, interstitial quartz and orthoclase and accessory magnetite and apatite. The hornblende is commonly altered to biotite, actinolite and penninite. Sphene is an accessory in many of the specimens from this area, some of which have been extensively sheared and crushed.

Granite and a rock consisting almost exclusively of quartz and oligoclase were the main variants in the rock types found in this area.

The porphyritic phase of the granodiorite consists of large, zoned plagioclase grains in a fine grained groundmass of hornblende feldspar, quartz, chlorite and apatite. It may represent a separate intrusion.

In the Bononi area, the batholith is commonly granodiorite similar to that found at Yanderra. Zoned plagioclase, either oligoclase or oligoclase and andesine, makes up 50 to 65% of the rock. Interstitial quartz (20%) and orthoclase (5%), laths of hornblende (5 to 10%) and fragmental biotite (5%) are the other major constituents. Accessory minerals include magnetite, apatite, secondary penninite and less commonly, zircon. Sphene was a conspicuous accessory in some specimens.

The south-eastern end of the main mass of the Bismarck Granodiorite was studied in the valleys of the upper Asaro River and its tributaries. Here, the batholith consists mainly of quartz diorite with some more acid variants including tonalite, granodiorite and quartz oligoclase rock. Acrystalline, equigranular texture is most common though porphyritic types do occur. Some of the specimens are extensively fractured and crushed. Some show gneissic texture and may be part of an earlier intrusion. Zenoliths of country rock are common in the batholith in this area, near the contact with the Goroka Formation.

The quartz diorite consists of fairly basic, zoned plagioclase, relict pyroxene, hornblende and some interstitial quartz and orthoclase. Magnetite, apatite and sphene are the accessories. The plagioclase consists of andesine grading to oligoclase at the margins. In some specimens the andesine surrounds residual blebs of labradorite. Secondary sericite replaces some zones in the feldspar.

The variation in the batholith in the Asaro area lies mainly in the percentage of feldspar and quartz. Plagioclase ranges from 45 to 65%, orthoclase from 0 to 15% and quartz from 5 to 30%.

The rock types of the batholith cropping out in the Pombameri-Keglsugl area are substantially the same as found in the upper Asaro River area. A specimen of granodiorite from this area is typical of much of the Bismarck Granodiorite. It consists of subhedral grains of zoned plagioclase (55%), quartz (20%), interstitial orthoclase (10%), brown biotite (7%), green amphibole (5%) and accessory magnetite, sphene and apatite. The plagioclase is zoned from andesine to acidic oligoclase. Some sections of similar rocks show amphibole replacing pyroxene.

Porphyritic quartz diorite is a more basic variant which is fairly widespread in this area. The phenocrysts have cores of bytownite grading abruptly to a margin of oligoclase. In some specimens from this area, ferromagnesians comprise up to 30% of the rock. They include hornblende, actinolite, pyroxene and biotite.

The rock types of the batholith in the Asaro-Pombameri-Keglsugl area are significantly more basic than those in the Yanderra-Bononi area. In the Yanderra area, oligoclase is the dominant feldspar, quartz is common and pyroxene rare. In the Asaro area, andesine is the dominant feldspar, quartz is less abundant and pyroxene is a common, though minor, constituent.

The Bismarck Granodiorite is well exposed on the slopes of Mt. Wilhelm above an altitude of 12,000 feet. The rock types cropping out in this area are mainly basic and ultrabasic in composition, quite different from the remainder of the batholith. These rocks were sampled during a single traverse from Lake Piunde to one of the peaks on the summit ridge of Mt. Wilhelm. Basic rocks are widely distributed in this area but their relationships with the remainder of the batholith are not known.

On the summit ridge of Mt. Wilhelm, the rocks are mainly black and white, coarse-grained gabbros. They consist of unzoned plagioclase (60%), ranging in composition from bytownite, (An75) to labradorite (An55), pyroxene (25%), brown hornblende (5%), magnetite (5%) and accessory apatite. The pyroxene is mainly diopside with some hypersthene and is commonly partly altered to chlorite.

A more basic variant is a pyroxenite consisting of hypersthene (60%) intergrown with magnetite (20%), bytownite (10%) and chlorite (2%) replacing what may have been olivine. Another variant is hornblendite consisting of pleochroic, yellow-brown hornblende (75%), bytownite (15%), pyrite (5%) and some chlorite, epidote, calcite and clay minerals.

A black and grey stratified rock, about 100 feet thick, is exposed on the slopes of Mt. Wilhelm, above Lake Piunde. The rock is a troctolite consisting of layers of dunite and peridotite, interspersed with anorthosite.

These basic rocks are possibly part of an intrusion which preceded the granodiorite-diorite intrusion of the Bismarck Granodiorite.

The isolated bodies related to the batholith are generally very similar in composition to the main mass. They range from granodiorite to diorite in composition and contain numerous xenoliths of the Goroka Formation. The main differences between the smaller stocks and the main mass are in texture and grainsize. They are generally finer-grained, darker in colour and the smaller stocks, at least, are porphyritic.

The largest of these bodies crops out around Mt. Otto, north-east of Goroka. It is mainly quartz diorite with some orthoclase-rich differentiates. The feldspar is mainly andesine with outer zones of oligoclase. The orthoclase content is as high as 15% in some specimens.

The second largest stock crops out a few miles to the south of the Mt. Otto stock. It is mainly a diorite with some more basic, gabbroic phases. The diorite consists of laths of labradorite, plates of green hornblende, magnetite and accessory apatite and sphene. A little quartz is present in a few specimens. Remnants of pyroxene surrounded by amphibole occur in some specimens from this stock.

Numerous dyke rocks intrude the Bismarck Batholith. They include quartz dolerite, andesite porphyry, oligoclase hornblende porphyry, amphibolite, basalt, aplite and other acidic intrusives. The dykes are commonly intruded along joint planes in the batholith. Many of these intrusives are possibly late stage differentiates of the original magma. However, some of them exhibit some peculiar features. A group of amphibolite dykes intruding the batholith in the Yanderra area were found to be recrystallized. The dykes are about 10 feet in width and have sharp contacts with the granodiorite but no detailed investigation of their relationships was made. Under the circumstances, there is nothing to indicate the caus cause of the recrystallization.

<u>Intrusives of Unknown Age</u>

The intrusives grouped under this heading intrude the Palaeozoic rocks. Their relationship to the Tertiary sediments is not known. Included in this group are the Yonkie Stock, the Cassam Diorite, a number of granodiorite bodies in the vicinity of the Pumassi River, gabbro and granodiorite east of Aifunka and several small granodiorite and diorite bodies intruding the Bena Bena Formation.

The Yonkie Stock is apparently a composite intrusion. It consists mainly of hornblende gabbro, in places metasomatized to monzonite and granodiorite. A more basic phase, consisting of olivine gabbro and verging on pyroxenite in some specimens, is also present in the mass. A specimen of hornblende granodiorite was collected from the northern end of the Yonkie Mass. The minor intrusives associated with this intrusive consist mainly of olivine micro-gabbro. It is possible that this mass is the result of an initial gabbroic intrusion and a later, more acid intrusion. This could explain why several specimens show signs of being altered from an original hornblende gabbro composition to a final monzonitic composition. The felspars in these specimens have calcic cores surrounded by rims of orthoclase or sodic plagioclase.

The igneous intrusive exposed near Cassam is a hornblende diorite. It consists of 50 to 60% plagioclase, 20% orthoclase, 5 to 10% quartz and accessory biotite, augite, sphene and iron ore. The granodiorite specimen from the northern part of the Yonkie Stock is extremely similar in composition to this diorite. North-west of Cassam, there is a suggestion that "e" stage sediments unconformably overlie the Cassam Diorite. The contact was not seen but the lenses of limestone close to the diorite dip shallowly north-east off the intrusive while those farther away dip much more steeply to the north-east.

The Pumassi intrusives consist of six granodiorite bodies all similar in composition. They are much more acid than the other intrusives included in this group. They are composed of approximately 20% quartz, 50% plagioclase, 10% orthoclase, 10% hornblende, 10% biotite and minor accessory minerals. Some of these intrusives may be part of the one mass. They were exposed in creek sections and it is not possible to tell from photo interpretation whether they link up or not. They are almost certainly comagmatic. The Pumassi granodiorites are differentiated from the Bismarck Granodiorite because they contain a much higher percentage of biotite than is usual in that mass.

Olivine gabbro crops out in a land-slip a few miles east of Aifunka. Granodiorite crops out east and south of the gabbro. The relationship between the two is not known, but they may be part of the one composite mass, possibly similar to the Yonkie Stock which contains the same diversity of rock types. The relationship of these intrusives to the "e" stage sediments is not known. The basal "e" stage conglomerate dips shallowly to the south-west away from the granodiorite. The gabbro exposed in the landlip is overlain by agglomerate correlated with the Aifunka Volcanics. The gabbro and agglomerate are similar in weathered outcrop and in overall composition. Also, some of the minor intrusives in the Aifunka Volcanics are lithologically similar to the gabbro. Thus, the gabbro is possibly associated with the Aifunka Volcanics of Pliocene age.

Kenangi Intrusives

The Kenangi Intrusives consist of sills, dykes and stocks of granodiorite, diorite and hornblende gabbro. They intrude both "e" stage and "f1-f2" stage rocks. They crop out mainly between Kenangi and Watabung, and north of Watabung along the line of the Asaro Fault. Few outcrops of Kenangi Intrusives were mapped intruding the Daulo Volcanics. The two are lithologically similar and it is possible that they represent intrusive and extrusive phases of the one magma.

The intrusives range in size from stocks, more than one mile across to dykes only a few inches in width. Many of the smaller intrusions have a fine-grained chilled margin, usually not more than two inches wide, which grades imperceptibly into the coarser-grained part of the intrusion. In places, the dykes and sills are vesicular and amygdaloidal, indicating that they were intruded at shallow depths.

The Kenangi Intrusives are mainly grey-green porphyritic rocks, including andesine porphyry, diorite porphyry, porphyritic dolerite and hornblende-pyroxene porphyry. Some of the larger stocks are granodiorite. The phenocrysts are commonly euhedral, and range from a few millimetres to one half inch in length. The ground-mass is finely crystalline, containing variable amounts of felspar, amphibole, pyroxene, biotite, chlorite and quartz with accessory magnetite, apatite and pyrite. The felspar is mainly within the andesine-labradorite range. SCALE MIXED

A hard, siliceous zone is developed in the Lower Miocene shale adjacent to the larger Kenangi Intrusives. This metamorphic aureole is pyritic in many places. Two samples of the pyritic hardened shale were assayed for gold and yielded results of 4 and 6 dwts. per ton.

The Kenangi Intrusives are thought to be equivalent to the Ga Intrusives, cropping out to the west, (Rickwood, 1955), and to the Late Porphyries of the Edie Creek area. (Fisher, 1944).

Late Tertiary Intrusives

The largest body intruding the Tertiary sediments is a hornblende gabbro cropping out in the Dunantina River. This mass is about seven miles long by about three miles wide. Several small stocks and numerous dykes of similar lithology crop out to south and south-west, intruding "e" stage and f1-f2 stage sediments and the Daulo Volcanics. The smaller intrusives are very similar to the Kenangi Intrusives and are almost certainly equivalent.

The hornblende gabbro consists of 65 to 70% plagioclase, 25% hornblende and accessory pyroxene, orthoclase and iron ore. In some specimens, the percentage of augite is much higher and the rock is a gabbro. The minor intrusives include andesine porphyry, hornblende-andesine porphyry, micro-diorite and porphyritic dolerite. One stock of granodiorite crops out east of Kami.

The late Tertiary intrusives cropping out on the Ramu Fall are all of fairly small size. They range in composition from granitic to dioritic. Dozens of grey-green, pyritic intrusives crop out in the Bundi-Guebe area, particularly in the Ua River section, and farther to the south-east in the Oija River section. They range from dykes a few feet in thickness to stocks one quarter of a mile across. They consist of porphyritic andesite, andesite, micro-diorite, micro-granodiorite and rhyodacite. In the Bundi area, these intrusives are generally oriented in a north-west direction. Many are intensely sheared and schistose, and some are undoubtedly associated with zones of shearing. Metasomatism also has affected some of these minor intrusives.

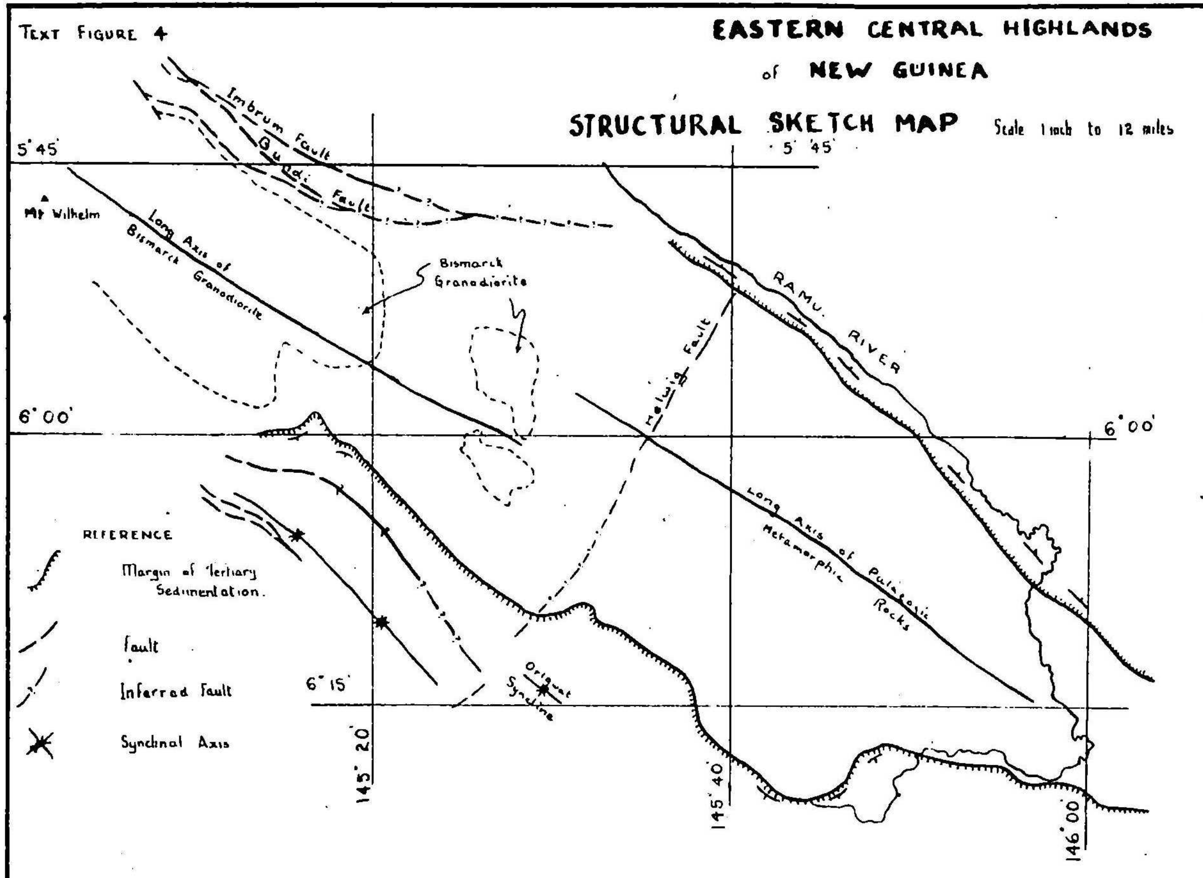
No orientation of the intrusives in the Oija River section was noted. Some bodies showed alteration effects but none were markedly schistose.

Other late Tertiary intrusions cropping out on the Ramu Fall include hornblende diorite, micro-gabbro, altered syenite, trachyte and rhyolite. Rhyolite intrudes "e" stage sediments near Wararais and a similar rock type intrudes the Eocene sediments west of the Tauja River. Both these consist of 20 to 30% quartz, 60 to 70% felspar and accessory iron ores, biotite and hornblende.

Late Tertiary Basic and Ultrabasic Intrusives

These include bodies of serpentinite, peridotite and gabbro. They were mapped in the vicinity of Kami and in the Bundi area of the Ramu Fall.

Two masses of serpentinite were mapped south of Kami, the largest more than two miles long by one mile wide. The rock is dark green, schistose and soft. It was intruded into Cretaceous and Eocene rocks probably at the same time as the late Tertiary faulting and folding. The serpentinite has recrystallized the Cretaceous limestone but has not affected the associated shale to any extent.


TEXT FIGURE 4
EASTERN CENTRAL HIGHLANDS
of NEW GUINEA
STRUCTURAL SKETCH MAP
Scale 1 inch to 12 miles
5°45'
5°45'
6°00'
6°00'
6°15'
145°20'
145°40'
146°00'
Imbrum Fault
Bundi Fault
Mt Wilhelm
Long Axis of Bismarck Granodiorite
Bismarck Granodiorite
Ramu River
Helwig Fault
Long Axis of Palaeozoic Metamorphic Rocks
Oriquat Syncline
REFERENCE
Margin of Tertiary Sedimentation.
Fault
Inferred Fault
Synclinal Axis

A body of peridotite, now mainly altered to serpentinite by shearing, crops out in the lower part of the Ua River. It is bounded to the south by Eocene shale and limestone at the Imbrum River Fault and extends north for at least 2½ miles.

Two miles east of Bundi, a gabbro of unknown dimensions crops out. This gabbro is in contact with "f1-f2" stage Volcanics at its southern boundary, but the nature of the contact is not known. Gabbro is also exposed 1¼ miles east of Bundi in the Tauja River, on the line of the Imbrum Fault. This body is extremely altered, containing pseudomorphs of hornblende after augite, and of pyroxene, clinozoisite and epidote after felspar. The original constituents of the rock were augite, labradorite and hornblende. It is possibly related to the peridotite and gabbro cropping out north of the Imbrum Fault.

Other basic rocks are reported farther to the north. Specimens of serpentinite, hornblende-plagioclase pegmatite, peridotite, altered dunite and other basic rocks were collected in the Imbrum River north of the map area. Dr. E. Reiner of the C. S. I. R. O. Land Research and Regional Survey collected boulders of dunite and peridotite in the streams flowing north out of the hills to the north-west of the Imbrum River. It seems possible that the area north of the Imbrum Fault is one of extensive basic and ultrabasic intrusion.

QUARTZ VEINING AND SILIFICATION

Quartz veining is common in the Goroka and Bena Bena Formations and in the Tertiary sediments of the Bundi area. There were possibly two periods of veining: The first occurred before the Upper Cretaceous and probably during the Palaeozoic; the second is post "e" stage in age and affected the sediments of the Ramu Fall area.

The presumed Palaeozoic quartz veins are plentifully distributed throughout the rocks of the metamorphic complex. In general, the quartz is milky white and glassy, but grey and white, sugary veins are common. The contacts with the country rock are sharp. Individual veins are rarely more than six inches wide and a few tens of feet long, but, in many places, dozens of veins occur as swarms. They fill tension fractures in the Palaeozoic rocks and were possibly emplaced at the same time as the Bismarck Granodiorite.

Swarms of small, white to glassy quartz veins fill tension fractures in shear zones and are distributed sporadically throughout the sediments on the Ramu Fall. They are found intruding Upper Cretaceous, Eocene and "e" stage rocks as well as the Goroka Formation. They are undoubtedly associated with the major faulting in the area.

South of the Bismarck Range, quartz veining is rarely found in the Tertiary and Upper Cretaceous rocks. Although major faulting affects the Upper Cretaceous and Tertiary rocks at Kami, Daulo and Watabung, they contain very few quartz veins. Silicification with minor quartz veining accompanies some of the Kenangi Intrusives along the Marifutica River.

Pyritic, silicified country rock crops out over some hundreds of feet near the southern end of a large stock of the Bismarck Granodiorite, about five miles east of Goroka. Typically, this and other silicified zones in the area are hard, dense, buff coloured and sugary textured. They may represent contact silicification effects in the vicinity of intrusives, or possibly silicification along fault zones.

STRUCTURAL GEOLOGY

The major structural feature in the map area is the predominant north-west trend. This trend existed in Mesozoic and Tertiary time, being reflected in the long axis of the depositional basins. It was more firmly established as a result of the late Tertiary orogeny. The trend is reflected now in the north-west striking axis of the geanticlinal Palaeozoic block, in the strike of the axes of the Tertiary Yaveufa and Orlowat Synclines, in the linear Ramu-Markham Valley and in the strike of the "e" stage sediments along the margin of that valley and, lastly, in the strike of such faults as the Imbrum, Bundi and Asaro Fault. (See Structural Sketch Map, Text Figure 3.).

? Wrong word trend

Folding

The outcrop of the Palaeozoic rocks, the Bena Bena and Goroka Formations and the Bismarck Granodiorite, is found in a north-west trending belt extending diagonally across the map area. This belt is the dissected crest of a geanticlinal arch, topographically expressed as the Bismarck Range. The development of this arch may have commenced earlier than the Tertiary. Land masses of Palaeozoic rocks possibly existed in much the same place as the present Bismarck Range during most of the Mesozoic and early Tertiary. The presence of conglomerate beds at the base of the "e" stage sediments cropping out between Hengenofi and Kainantu suggest the existence of a near land mass to the north. The folding and faulting of the late Tertiary orogeny accelerated the process of uplift of these areas, a process which is continuing at the present time.

The broad arching was superimposed on the original folding in the Palaeozoic sediments without greatly modifying the earlier trends. Many steep dips were measured in the Bena Bena and Goroka Formations but almost as many dips of less than 45° were recorded. In general, the impression is not of tight folding. The structures which can be traced are rather broad, gently plunging folds with, in many places, the flanks of the folds striking at right angles to one another. In some areas, there are indications of overfolding. The Goroka Formation sediments on the Ramu Fall are much more tightly folded. The trend of the folding is mainly north-west, and this folding is probably due to the Tertiary orogeny.

Sediments of Upper Cretaceous to Miocene age are exposed along the south-western and north-eastern flanks of the arched Palaeozoic rocks. In the south-west of the map area, Cretaceous and Tertiary sediments crop out in a broad synclinal structure between the Bismarck Range arch and the Kubor Range arch, south-west of the map area. This syncline, called the Yaveufa Syncline, was probably an actively sinking basin of deposition during most of Tertiary time. It was certainly so when the "f1-f2" stage volcanics and associated sediments were laid down. The synclinal strudture involves mainly the f1-f2 stage volcanics and sediments. The axial plane of the syncline appears to dip steeply to the south-west and was traced over a distance of about eighteen miles. The Orlowat Syncline, a few miles to the south-east of the Yaveufa Syncline, involves "e" stage and "f1-f2" stage sediments. It was also probably an active basin of deposition during those times. The bulk of the Orlowat Syncline is located south of the map area. Its axial plane is apparently vertical.

? Tilt better

The Yaveufa and Orlowat Synclines are more or less parallel though slightly off line. Cretaceous rocks crop out in a faulted and intruded zone south of Kami, between the south-east end of the Yaveufa Syncline and the north-west end of the Orlowat Syncline. It is possible that this zone is a ruptured anticlinal structure separating the two synclines.

Tightly folded "e" stage sediments crop out west of Urabagga Hill. This tight folding is possibly due to the sediments being compressed between the Palaeozoic basement and the extremely competent mass of the Daulo Volcanics.

Cretaceous, Eocene and Miocene sediments crop out in the north-east of the map area in a number of fault wedges. The area is one of intense faulting and intrusion. The sediments are steeply dipping but, generally, their relationships are concealed by the faulting.

The eastern end of the Bismarck Range arch is flanked by "e" stage sediments to the north and south. They crop out along the north-east flank, striking north-west and dipping at a more or less constant angle of 45° to the north-east. Some minor folding was found in this sequence, involving the siltstone and shale. The limestone lenses are apparently monoclinal.

Mainly broadly folded "e" stage sediments, dipping at 15° to 30° in most places, crop out south of the Palaeozoic block. North of Hengenofi, the basal "e" stage sediments are very tightly folded. This local tight folding is possibly due to the intrusion of a body of gabbro to the north-west and crumpling of the sediments against the Palaeozoic basement.

Faulting

Most of the faults which were mapped in the area trend north-west, parallel to the main structural trend. Two groups of north-west striking faults were recognized, the Asaro-Watabung Faults and the Bundi-Imbrum Faults.

The Asaro Fault separates the Asaro Range to the south from the Goroka Valley to the north. The fault is still active, as is evidenced by its displacing alluvial fans on the edge of the Goroka Valley. At Watabung, a fault wedge trends nearly parallel to the Asaro Fault but wedges out a few miles south-west of Watabung. The boundary faults of this wedge are probably the south-eastern extension of the Gorgme Thrust Zone (Noakes, 1939) which repeats the section exposed in the Chimbu River Valley.

The faults in the Bundi-Imbrum River area have resulted in wedges of Cretaceous, Eocene and Miocene rocks being faulted against one another and the Palaeozoic basement. The Imbrum Fault is the most important. It is expressed topographically by a long, narrow depression and a marked change in the direction of flow of the Imbrum and Baia Rivers. It is suggested that an easterly striking extension of the Imbrum Fault is the southern boundary of the swampy, low lying area drained by the Marea River.

The Bundi Fault is located south-west of the Imbrum Fault. These two faults meet near Guebe in the north-west corner of the map area. The eastern extension of the Bundi Fault possibly joins the Imbrum Fault east of the Tauja River. Thus, these two faults may enclose a crescent shaped wedge of Cretaceous, Eocene and Miocene sediments.

South-west of the Bundi Fault, and more or less parallel with it, is a major fault separating Miocene sediments from the Palaeozoic basement. This fault trends east and possibly joins the Bundi Fault.

These three faults dip steeply to the north-east. They are planes of differential uplift, resulting from the Tertiary orogeny. The existence of other north-west striking faults in the Bismarck Range is suggested by alignment of the drainage in places. These structures are evident in the aerial photographs though they were not mapped on the ground. It seems probable that much of the uplift in the Bismarck Range is due to movement of fault blocks along planes of differential uplift.

The north-east trending Helwig Fault is the only major structural feature in the map area which does not parallel the general trend. This fault displaces Miocene and Eocene sediments near the Ramu River. It strikes roughly north-north-east, and is expressed topographically in the precipitous fault scarp which constitutes the peak of Mt. Helwig; in the Bena Bena Gap which is the lowest divide in the Bismarck Range; and to some extent, in the direction of the Bena Bena River. North-east trending faults near Kami and east of Geppavi Hill are nearly on line with the Helwig Fault and are tentatively linked up with it. This fault marks the south-eastern boundary of the Goroka Valley.

HISTORY OF SEDIMENTATION

Little is known about the environment of deposition of the Palaeozoic sediments. The Bena Bena Formation seems to consist of elements representing more than one environment of deposition or representing deposition from more than one source. The abundant arkosic material in parts of the formation may indicate rapid deposition in a near source position, the sediments possibly being derived from a rapidly rising land mass. The green actinolite chlorite schist of other parts of the formation, however, does not seem to belong in such an environment.

The Goroka Formation contains an abundance of fine clastics, particularly black quartz siltstone and carbonaceous siltstone. The fine grainsize may reflect distance from source or the slow erosion of a fairly low land mass.

The Permian rocks overlapping the Kybor Granodiorite (Rickwood,1955) were deposited in seas of limited extent. They are nowhere exposed in the area of this report nor are they reported in areas to the south. The suggestion of Permian age for the "corrugated" arenaceous limestone unconformably overlying the Bismarck Granodiorite north of Yanderra, should be considered with the utmost caution.

Considerable thicknesses of Jurassic and Cretaceous rocks are exposed to the west and south of the Goroka area. In the Goroka area, however, only remnants of Upper Cretaceous sediments were found. Apparently, the Upper Cretaceous seas transgressed to the north-east and the Upper Cretaceous rocks at Watabung and at Kami resulted from that transgression. The Upper Cretaceous rocks at Bundi probably represent the initial sedimentation in that area.

The distribution of the Eocene rocks indicates that the Upper Cretaceous and Eocene seas were more or less co-extensive in the Goroka and Bundi areas. The presence of Oligocene sediments directly overlying the Palaeozoic basement at Urabagga and Geppavi Hills indicates a further north-easterly transgression of the seas after the close of the Eocene. It is also further confirmation that part, at least, of the present Bismarck Range was a positive area during most of Mesozoic and Tertiary time.

No Oligocene rocks were found in the Bundi area, but is quite possible that detailed investigation would reveal their presence. At all events, the Bundi area was one of almost continuous sedimentation from Upper Cretaceous to Miocene. This sedimentation apparently did not extend far to the south-east, as only Miocene sediments are found flanking the Palaeozoic rocks along most of the Ramu Fall.

The transgression on the south side of the Bismarck Range which was initiated during the Oligocene continued into the early Miocene. Rocks of the "e" stage probably overlap the Oligocene at Urabagga Hill, and certainly do so at Geppavi Hill. The "e" stage rocks directly overlie the Palaeozoic basement along the southern and north-eastern margins of the map area.

The Miocene seas probably covered considerably more of the basement than the present outcrop limits of Miocene sediments. However, it seems likely that much of the present outcrop area of the Palaeozoic rocks was land during the Miocene time also. In particular, the conglomerates and coarse clastics of the basal "e" stage near Hengenofi and Aifunka suggest the existence of a Palaeozoic landmass at no great distance to the north.

Trends in the "e" stage limestone lenses indicate that, at some time during the "e" stage, the seas were continuous around the south-eastern end of the Palaeozoic block. There are no equivalents of the basal "e" stage coarse clastics of the Hengenofi area in the Miocene section of the Ramu Fall. The latter seem to be equivalent to the calcareous sediments, limestone lenses and volcanics which overlie the coarse clastic sequence. Possibly the transgression of the Miocene seas into the Ramu-Markham Valley area took place after the deposition of the coarse clastic sequence to the south of the Palaeozoic basement.

The extent of the Miocene depositional area contracted during the "f1-f2" stage. Nowhere are "f1-f2" sediments found overlapping the "e" stage. Further, fossiliferous cobbles of "f1-f2" stage, "e" stage, Eocene and Upper Cretaceous limestone were collected from a conglomerate below the base of the Daulo Volcanics. This indicates that rocks of all these ages were exposed to erosion during the "f1-f2" stage. Probably, the contraction of the Miocene seas in the "f1-f2" stage is related to the rapid sinking of the depositional basins to accommodate the very great thicknesses of "f1-f2" stage volcanics and sediments deposited.

The Daulo Volcanics were poured out under partly terrestrial conditions. The vast thickness of the Asaro River Conglomerate is made up of Daulo Volcanic material, redeposited under marine conditions, with a few lenses of fossiliferous limestone. These two units were deposited on a surface consisting of "f1-f2" stage, "e" stage, Eocene and Upper Cretaceous rocks.

GEOMORPHOLOGY

A fairly close relationship exists between the topography and the major geological features in the eastern Central Highlands. This is mainly due to the recent date of the major orogeny and the rapid erosion rate. The depth of weathering, however, tends to obscure the less outstanding geological changes and makes photo-interpretation almost impossible.

The Bismarck Range directly reflects the folding and uplift of the Palaeozoic block. The amount of uplift increases towards the north-west, culminating at Mt. Wilhelm, where the Bismarck Granodiorite is exposed at an elevation of over 15,000 feet.

Within the Bismarck Range, the detailed topography is controlled by the hardness of the rock types. In general, the metamorphics are fairly resistant and produce a rugged topography. The most rugged features in the Range are the scarps of "e" stage limestone which crop out along the northern foothills beside the Ramu-Markham Valley. The Bismarck Granodiorite weathers rather easily. At many places in the range, mature valleys are developed at elevations of 8,000 feet or more, on rocks of the Batholith. It is possible that some of these upland valleys are produced by more rapid erosion of the intrusive rocks than of the contact metamorphosed aureole about the intrusion.

The many faults in the Bismarck Range are commonly expressed topographically in the very straight courses followed by some streams. Typical examples are the south-east flowing parts of the Inbrum and Baia Rivers.

The Asaro Range, with peaks rising to over 8,000 feet, is composed of the f1-f2 stage volcanics and sediments deposited in the Yaveufa Syncline. At the southern end of the Goroka Valley, the Daulo Volcanics weather into innumerable, small rounded hummocks. The reason for this unusual and distinctive morphology is not known.

The Goroka Valley is possibly a down-faulted block, in which Quaternary deposits have accumulated. The south-western boundary of the Goroka Valley closely follows the line of the Asaro Fault, and the south-eastern boundary follows that of the Helwig Fault.

ECONOMIC GEOLOGY

There has been no large scale mining activity in the Eastern Central Highlands. Alluvial gold won by individuals or small parties of European prospectors represents the bulk of the mineral wealth produced in the area. Though some prospectors have received good returns for their labours, the total value of gold production is not impressive. At present, the number of Europeans engaged in gold mining in the area is on the decline. However, over the last few years, the number of natives engaged in goldmining has greatly increased. The natives can operate successfully on returns which are too low to interest a European.

The bulk of the gold produced in the map area has been won in the Upper Ramu area. Yonkie Creek, Aifunka, Ornapinka, Barola and Nasananka Creeks have all yielded appreciable quantities of gold, though no accurate figures for quantity produced are available. Table 2, below, gives details of total production in the Upper Ramu area from 1948-49 to 1957-58, inclusive.

TABLE 2
Mineral production - Upper Ramu Area.

YEAR	GOLD Fine Ozs.	SILVER Fine Ozs.	PLATINUM Fine Ozs.	TOTAL VALUE
1948/49	1,309	71	--	£14,105
1949/50	1,335	54	--	18,352
1950/51	1,206	82	--	18,710
1951/52	995	71	--	15,492
1952/53	1,299	102	--	20,244
1953/54	1,073	71	--	16,713
1954/55	1,141	73	--	17,856
1955/56	1,501	117	.063	23,506
1956/57	1,864	117	.042	29,166
1957/58	1,538	86		24,070

The only lode mining in the area is at Aifunka where gold-garnet-magnetite lodes are being worked by underground mining methods. In general, the lodes are conformably associated with andesitic volcanics, the Aifunka Volcanics.

They are possibly the result of partial replacement of agglomerate lenses within the volcanics. The Territory of Papua and New Guinea Mines Department completed a drilling programme at Aifunka during 1958, designed to determine the grade and extent of the ore bodies. The results are not promising.

Gold won in Ornapinka, Barola and Nasananka Creeks and in some other tributaries of Ornapinka Creek, was mainly derived from a coarse, blocky, quartz pebble conglomerate. This forms a conspicuous unit in the Pleistocene Kainantu Beds in the vicinity of Mt. Munefinka. In this area, the source of the Kainantu Beds was partly the basal Miocene conglomerate. This contained a small proportion of quartz with other, more abundant rock fragments. However, on erosion of the Miocene conglomerate, most of the rock fragments weathered away, thus leaving mainly quartz fragments for inclusion in the Kainantu Beds.

A similar concentration process may be responsible for the workable quantities of gold contained in the quartz pebble conglomerate. The gold was possibly shed by the Palaeozoic metamorphic rocks, concentrated in the Miocene Conglomerate and reconcentrated in the quartz pebble conglomerate beds. At present, the Pleistocene conglomerate is being most intensively worked on Barola Creek.

In Yonkie Creek, a Pleistocene alluvial terrace is being sluiced for gold. The source of the gold is apparently associated with the Yonkie Stock. The fineness of this gold is much greater than of that mined at either Barola Creek or Aifunka.

At Efontera Creek, fairly good gold values have been found in a boulder conglomerate in the Kainantu Beds. This conglomerate contains mainly granodiorite and volcanic fragments, and little or no quartz.

Production of metals other than gold consists of several hundred pounds of hand picked copper ore, mainly malachite and covellite. This was mined from a small, dyke-like lode near Yonkie Creek.

During the 1956 and 1957 surveys, mineralization of one sort or another was found in many places but never in interesting quantities. Thirteen specimens were collected from various localities and assayed for gold. Two samples were collected of silicified, pyritic Miocene shale, intruded and metamorphosed by a body of Kenangi Intrusives. These two samples were hand-picked to contain the most intense pyrite mineralization. The assays showed they contained 4 and 6 dwts. of gold per ton.

An assay of 5 dwts. of gold per ton, was recorded for one sample of quartz and pyrite stringers in silicified Goroka Formation, collected 6½ miles north-east of Goroka.

Calcareous, cupriferous veins within the Bismarck Batholith near Yanderra were sampled and assayed at 4 dwts. of gold per ton. Natives are working the streams in this area for gold.

Assays of 3 and 4 dwts. per ton were recorded for samples of quartz veins in the Goroka Formation near the Seventh Day Adventist saw mill, north of Goroka. The remaining samples assayed at only 1 or 2 dwts. or traces of gold.

Small scale copper mineralization was observed in the Goroka Formation adjacent to a small intrusive, 7 miles south-west of Gusap airfield. Mineralization, other than pyrite, was seen at a few other localities. Pyrite mineralization was extremely widespread, particularly in the vicinity of intrusive bodies. Specimens of mixed sulphide ores, mainly pyrite and zinc sulphide, were collected near Efontera Creek in 1958. This deposit is not very extensive however.

The prospects of finding large scale economic mineralization in the Eastern Highlands do not appear to be bright.

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TABLE 1

STRATIGRAPHIC TABLE.

	Age	Formation	Estimated Max. Thickness	
Quaternary	Undifferentiated		100'	Clay, silt, sand, gravel and boulder beds. Alluvial and piedmant deposits.
	"		600'	Rhydite flows, rhyditic brecsia
	Pleistocenze	Kainantu Beds	100'	Well bedded cobble and pebble conglomerate, gravel, sand and clay.
Tertiary	Pliocene	Aifunka Volcanics		Andesitic flows, tuff, agglemerate
	Miocene $f_1 - f_2$ stage	Asaro River Conglomeration	10,000'	Conglomerait, greywacke, tuff, Limestone lenses.
	Miocene $f_1 - f_2$ stage	Daule Volcanics	10,000'(?)	Harblende pyroxene perphyry, tuff
	Miocene $f_1 - f_2$ stage		5,000'	Grey calcaneous siltsone, limestone, tuff, greywacke, conglomerate.
	Miocene e stage		10,000'	Limestone, calcareous siltstone, black slate, siltstone, greywacke, conglomerate.
	Miocene e stage			Barded chart.
	Oligocene c stage		100'	Nummulitic Limestone
	Eocene a - b stage		3,000'	Black siltstone, slate, limestone, calcarenite
Mesozoic	Cretaceous (Maestrichtian)		1,000'	Calcareous shale, limestone.
			200'	Arenaceous Limestone
Palaeozoic		Genoka Formation		Black schistone, siltstone, biotite andalusite schist, carbonaceous schist, quartzite, phyllite, quartz greywacke, calcarenite, calcareous siltstone, minor limestone.
		Bena Bena Formation		Chlorite actinalite schist, arkose, phyllite, quartz miscornite schist, granite gneiss, porphyroblastic felspathic siltstone, quartzite.