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B

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DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Report No. 52

B

THE GEOLOGY OF THE MUSA RIVER AREA,
PAPUA

BY

J. W. SMITH AND D. H. GREEN

Complimentary

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DEPARTMENT OF NATIONAL DEVELOPMENT

Minister: SENATOR THE HON. W. H. SPOONER, M.M

Secretary: H. G. RAGGATT, C.B.E.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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3. Mt Suckling (11,226 ft) from patrol post, Safia.
4. Dip slopes, Domara River Beds, Musa Gorge.
5. Interbedded conglomerate, greywacke, agglomerate, Domara River Beds.
6. Boroboro Gorge (Adau R.) area, South side of Musa Valley. Mt Korioko and Mt Avurum in background.
7. Adau River. In centre, hills surrounding Borobora Gorge - composed of conglomerates of the Domara River Beds.

SUMMARY

From May to October, 1958, a Bureau of Mineral Resources geological party mapped the Musa River area, Papua, where rocks of the Papuan basic-ultrabasic belt crop out and it was thought nickeliferous soils might exist.

The oldest rocks in the area, the Goropu Metamorphics, consist of regionally-metamorphosed phyllites, schists, and quartzites. They may be equivalent to the 'Owen Stanley Series' probably of Palaeozoic age. Unconformably overlying them are the Cretaceous (?) Urere Metamorphics, which consist of siltstone, greywacke-conglomerate, limestone, basalt, etc., all of which are thermally metamorphosed. Two members have been mapped in the Urere Metamorphics - the Amora Conglomerate and the Foasi River Limestone.

Gently-folded, non-marine Domara River Beds of Pleistocene age occupy approximately the area of the present-day Musa Valley. In several areas volcanic activity preceded the main sedimentation, and occurred locally and intermittently later.

The sub-horizontal Silimidi Beds overlie the Domara River Beds unconformably. The Sivai Breccia, a member of the Silimidi Beds, contains at least two beds of ultrabasic breccia. These are probably extrusive sheet equivalents of the breccia bodies within the basic-ultrabasic belt.

On the north side of the Didana-Sibium Range and the Goropu Mountains, the Recent Sesara and Waiowa Volcanics crop out.

The basic-ultrabasic rocks are the south-eastern end of the Papuan basic belt. The basic-ultrabasic suite, which includes peridotite, dunite, pyroxenite, picrite, and gabbro, shows differentiation but not on a simple pattern. Banding is commonly well developed and dips have been recorded. Peridotite and serpentinite breccia pipes and irregular bodies within the ultrabasic suite are common, and probably represent vents of a volcanic explosive phase. Other intrusives within the area include diorite-granodiorite, andesitic porphyries, and lamprophyric rocks.

Faulting trends east-south-east parallel to the strike of the rocks, and the Musa Valley itself is partly a faulted trough. The Goropu Mountains are strongly faulted on the north and west sides.

Soil samples collected during the season showed sub-economic nickel with a maximum nickel content of 1.06 percent. Disseminated pyrite and chalcopyrite introduced in part, at least, by the diorite-granodiorite bodies have been observed in the Goropu and Urere Metamorphics.

[illegible]

Bureau of Mineral Resources, Geology & Geophysics, May 1961.

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INTRODUCTION

The continuing world demand for nickel in recent years has stimulated a search for further superficial nickel deposits of the type explored in New Caledonia and Cuba, which together supply almost 20% of the free world's nickel. In these deposits nickel and cobalt are concentrated in particular horizons in lateritic soils developed over ultrabasic rocks.

In recent years the Papuan basic-ultrabasic belt has attracted attention as a place where such deposits might be found. At the end of 1957 soil samples submitted to the Department of Lands, Surveys and Mines, Port Moresby, from the eastern end of the Didana Range, Musa River area, Northern Districts, were found to contain nickel in values that might be commercial. Samples collected subsequently by J.E. Thompson, Senior Resident Geologist, Port Moresby, during a reconnaissance of the eastern end of the Musa Valley also gave positive nickel results.

In 1958 the authors mapped the Musa Valley area on a regional scale, paying particular attention to the basic-ultrabasic belt and collecting soil samples from the belt. The party was in the field for twenty weeks from the middle of May to the beginning of October. Throughout the season, the party was supplied by Anson aircraft of Papuan Air Transport Ltd operating to a wartime grass-strip at Safia. This strip is approximately 800 yards long and could be extended. A patrol post at Safia was occupied by a patrol officer of the Department of Native Affairs while the party was in the area. The post was used as a base camp. One field assistant and a permanent line of up to sixty natives were employed. The population of the administrative areas of the Upper and Middle Musa, in which the party mainly worked, is only just over two thousand, and casual labour is therefore not available.

About 1200 square miles were mapped, comprising much of the Dove, Ubo, Namo, and Moni River Sheets in the New Guinea 1-mile series. These have been photographed (vertical) at 1:43,000 by Adastra Airways Pty Ltd. No photo-mosaics were available at the time, however, and the only maps were the 4 mile to 1 inch wartime series, which were found to be very inaccurate. The geology was plotted on 1 inch to 1 mile uncontrolled photo-mosaics prepared by the National Mapping Division, Department of National Development, which were ready for use early in 1959.

Access to the area is mainly by way of stream and Government or native tracks.

Fossils from the Domara River Beds have been described by Dr N.H. Ludbrook (Dept. of Mines, S. Australia) and the descriptions have been included as an appendix. Thin sections of the rocks were described by one of the authors (D.H.G.).

PHYSIOGRAPHY

Topography

The area mapped is a hundred miles east of Port Moresby on the northern slopes of the Owen Stanley Range - the central dividing range of Papua. It can be divided into five physiographic regions:

- (a) The Musa Valley
- (b) The Goropu Mountains

- (c) The Didana and Sibium Ranges
- (d) The Owen Stanley Foothills
- (e) The Coastal Plain.

The Musa Valley, which is about 40 miles long and up to 5 miles wide, is the dominant feature of the region. The lowest point of the valley, near Gobera, is about 250 feet above sea level. East of Gobera the floor of the valley is a gently rising surface composed of fanglomerate deposits. This slope is very abruptly terminated against the Goropu Mountains block. West of Gobera the valley trends west-north-west and is largely an undulating surface on the Domara River Beds and the Urere Metamorphics, rather than a planar alluvial or fanglomerate surface, though a part of the valley around Liamu is covered with fanglomerate. There is a small fork in the valley west of Ibidura, and the smaller northern arm, which is occupied by the present course of the Musa River, trends west-north-west through Ibidura to Uriobo. Upstream from Uriobo the Musa River flows through a gorge in dissected country, but intersects the southern fork of the valley again near Namudi. The southern fork trends west to west-north-west as a broad valley through Moikodi and Liamu to Namudi. Upstream from Deune the valley is no longer a distinct topographic unit. Faults bound the valley in several places, and it probably owes its existence primarily to down-faulting of a trough in Pleistocene times.

The Goropu Mountains - the highest point of which is Mount Suckling, 11,226 feet - are an off-shoot of the Owen Stanley Range and form a very impressive mountain block at the eastern end of the Valley. The northern and western slopes rise steeply from the coastal plain and the Musa Valley floor respectively. They are precipitous and sharply dissected and entry is only possible along streams; waterfalls are quite common and further impede progress. Numerous large landslips have occurred at higher altitudes, especially on the northern faces.

The northern side of the Musa Valley is bounded by a range of hills formed mainly of basic and ultrabasic rocks. These hills are called the Didana Range in the east and Sibium Range in the west. (These two names are spelt in various ways; the spelling used here is the same as that used on the 40 mile : 1 inch New Guinea map.) The width of the range varies from eight to ten miles. At the eastern end the maximum height is about 4000 feet and the country is sharply dissected. Farther west, near Fiobobo, the range is about 1000 feet high and is in a youthful stage of erosion on the margins but has an older, more mature topography in the centre of the range. The Sibium range rises to 7164 feet at Mount Avinia, west of the area mapped, and in a youthful stage of erosion. Dip slopes of the Domara River Beds, also deeply dissected, are present on the southern slopes of the range, whereas the north side presents a steep face to the coastal plain.

In the north-east part of the area two villages, Sesara and Aurala, lie within the walls of a large volcanic crater. The crater floor is partly swamp and partly alluvium and is about 800 feet above the level of the Coastal Plain to the north and east. The rim of the crater varies greatly in height; it is highest east of Sesara and lowest west of Aurala and north of Sesara.

On the south side of the Valley the Owen Stanley Range swings south through Mount Clarence (6330 feet) and Mount Brown (7950 feet), both of which are just off the area mapped. The foothills of the Owen Stanley Range include two prominent mountains of 3000-4000 feet in the east, Mount Korioko and Mount Avuru, both composed of ultrabasic rocks. In the west the principal feature on the south side of the Valley is the Amora Range, some

4000 feet high, which is composed of Urere Metamorphics. South of the Amora Range a depression near Bubudi and Imuruwake is a downfaulted block of the Domara River Beds. The foothills of the Owen Stanleys generally have a rugged topography with youthful streams and valleys.

The Coastal Plain is a completely level surface of swampland, local grassland, and thick swamp forest, broken only in the north-west by several isolated remnants of Sesara Volcanics and in the north-east by the Recent volcanics from Mount Victory and Mount Trafalgar. The plain appears to be a depositional deltaic feature formed at the present sea-level.

The individual rock-types of the area generally have no consistent characteristic topographic expression. The Domara River Beds in some areas form dip and scarp slopes with grass and light eucalypt vegetation. In the southern foothills and occasionally on the north side of the valley the ultrabasic rocks tend to form smooth grass-covered ridges with very steep slopes but generally rounded crests.

Drainage

The area is drained by the Musa River system, except for streams from the northern face of the Goropu Mountains (the Dibou, Unido, Kovai, and other rivers) which flow eastwards to Collingwood Bay; and streams on the northern slopes of the eastern Sibium Range, which flow north and are lost in the coastal swamp and plain. The Wakioki and Bereruma flow from the northern side of the Goropu Mountains also, but disappear in the coastal swamp after flowing around the eastern end of the Didana Range. The divide (Wowo Gap) between these streams and the streams flowing into the Ibinambo River and thence into the Musa Valley is only about 1200 feet high and provides a good means of access into the valley from Wanigela, on the coast at Collingwood Bay.

The headwaters of the Musa River (also called the Moni River in its upper reaches) lie on the Owalama Divide roughly 20-25 miles north-west of Namudi. Upstream from Deune the river flows swiftly through a youthful rugged topography. At Namudi it approaches a local base level, before entering a gorge near Abiobo and Musia. From near Uriobo the river flows east-south-east through the Musa Valley before entering the Musa Gorge and flowing north-east through the Didana Range. In the Musa Valley itself cut-off meanders and ox-bow lakes are fairly common, although small rapids occur about every 20 yards. The river in the valley has a local base level controlled by the Musa Gorge, but this is steadily being lowered. The Musa River flows swiftly in a winding course through the Musa Gorge before meandering across the coastal plain to discharge into Dyke Ackland Bay through a deltaic mouth.

The major tributaries of the Musa River drain from the Owen Stanley foothills into the Musa Valley proper. The northern streams are generally shorter; the Sisiworo is twenty miles long, but most streams are 4-10 miles long, and the volume of water is not great. The two major tributaries on the south side, the Adau River with several large tributaries of its own, and the Awala River, both emerge into the valley through narrow steep-walled gorges. The Boroboro Gorge in the Adau is particularly spectacular, with sheer faces up to 1000 feet high cut in the Domara River Beds. The Silimidi, Domara, and Urere Rivers also emerge into the valley through gorges, the first two being cut into the Domara River Beds.

Run-off in the Musa River is very rapid and even at the mouth of the Musa Gorge the river may rise 3 to 4 feet in a day. In the upper reaches severe flash floods are common

and considerable care must be taken in the selection of camp sites. The streams draining the Goropu Mountains are the most dangerous in this respect. Waterfalls and discordant junctions are common, and all the upper reaches of the streams show youthful characteristics.

CLIMATE

New Guinea lies within the tropics and is subject to the north-west monsoons from November to April, and the south-east trade winds from May to October. The party was in the field from May to October and experienced the south-east season, which proved to be fairly dry because of the protection of the Owen Stanley Range. No figures are available, but the rainfall for the year is about 80-100 inches. Cape Nelson, the nearest recording station, has 130 inches a year. The day temperature remains fairly constant at approximately 85° and nights are warm and pleasant.

With the extreme differences in altitude many local variations are encountered. The East Didana Range and Wowo Gap area receives a much heavier rainfall than elsewhere. From May to October in the Valley itself strong northerly to north-westerly winds blow every afternoon.

More information on rainfall will be available in the future; the Commonwealth Works Department were arranging to establish rain-gauges at several villages, in furtherance of their river-gauging programme, when the party left the area.

FLORA

Most of the area is covered by lowlands and mid-mountain forest which varies from semi-open forest to forest with dense undergrowth. Areas which cover peridotite and dunite rocks are commonly open grassland with trees in the valleys. Grassland with very open eucalypt forest often covers the Domara River Beds. True grassland country occurs in the Musa Valley proper, where kunai grass grows up to 10 feet high. Fairly thick forest also occurs in places in the valley, in particular on the fanglomerate slopes. The highest parts of the Goropu Mountains appear to be fairly clear of vegetation and probably have an alpine environment.

PREVIOUS INVESTIGATIONS

Baker (1946) gives descriptions by local observers of the volcanic activity of 1943 and 1944 in the Waiowa area on the north side of the Goropu Mountains. In 1954 J.E. Thompson, Senior Resident Geologist, Department of Lands, Surveys and Mines, Port Moresby, paid a brief visit to the Boroboro gorge and Waiowa areas; and in February 1958 he reconnoitred about 400 square miles of the Didana Range and Silimidi areas. These are the only known previous investigations.

GEOLOGY

The geology is summarized in Table I.

Metamorphic Rocks

The first attempt at subdivision of the metamorphic rocks of Papua and New Guinea was made by A.G. Maitland (1893). Subsequently E.R. Stanley (1919) divided what he

TABLE 1.—STRATIGRAPHY OF THE MUSA RIVER AREA, PAPUA.

| Age. | Name. | Map Symbol. | Distribution. | Lithology. | Intrusive Igneous Activity. | Thickness. | Folding. | Remarks. |
|--------------------------|--|----------------|--|--|---|---|---|---|
| RECENT | Alluvium | Qa .. | Musa valley. Musa flood plain | .. | .. | .. | .. | Includes both valley fill and swamp alluvium |
| RECENT | WAIOWA VOLCANICS | Qrw .. | North side of Goropu Mountains | Intermediate agglomerate and minor tuff | .. | .. | .. | Erupted late 1943 and 1944 |
| PLEISTOCENE — RECENT (?) | LIAMO, UBO FANGLO- MERATES | Qrl/u .. | West side Goropu Mountains (Ubo) North side Amora Range (Liamo) | Boulders of Urere Metamorphics (Liamo) and Goropu Metamorphics | .. | .. | .. | Unconsolidated |
| RECENT(?) PLEISTOCENE(?) | SESARA VOLCANICS .. | Qps .. | Sesara, Korala areas | Basalt, basaltic agglomerate, and minor tuff and siltstone | .. | .. | .. | Cone still preserved at Sesara |
| PLEISTOCENE (?) | SILIMIDI BEDS .. | Qpl .. | East end Musa Valley | Interbedded greywacke-conglo- merate, greywacke, sedimentary breccia | .. | ? | Subhorizontal | |
| | Sivai Breccia Member .. | Qpr .. | East end Musa Valley .. | At least two sheets ultrabasic breccia interbedded with grey- wacke-conglomerate, sedimen- tary breccia, and greywacke —UNCONFORMITY— | 250 feet + | Subhorizontal | | |
| PLEISTOCENE | DOMARA RIVER BEDS | Qpd .. | Wide but mainly present-day Musa Valley | Interbedded greywacke-conglo- merate, greywacke, and subsidiary siltstone. Occasional inter- mediate agglomerate beds and basalt | Feldspar porphyry — Lamprophyres | 5,000 feet + | Moderately folded — Dips up to 65° | Lacustrine. Gastropods and pelecypods |
| | Musa, Imuru, and Awala Volcanic Members | Qpi/a/m | Widely separate localities .. | Intermediate and basaltic aggro- merate, intermediate tuff, and flows. Subsidiary greywacke- conglomerate and greywacke —UNCONFORMITY— | See text | Moderate. Variable be- tween 10° and 60°, avera- ging about 20° | Base or near base of Domara River beds | |
| CRETACEOUS (?) | URERE METAMOR- PHICS | Ku .. | Wide distribution | Hornfelsed basalt, greywacke-silt- stone. Often epidote and chlor- ite rich | Feldspar porphyry. Papuan Basic-Ultrabasic Belt. — Diorite-granodiorite Dolerite | ? | Bedding poor. Folding less intense than Goropu Metamorphics | Thermally metamorphosed only |
| | Foasi River Limestone | Kf .. | Mainly headwaters of Foasi and Ikumu Rivers | Laminated crumpled red and white altered limestone | .. | ? | Contorted | Possibly occurs as several discontinuous lenses. Ostracods? |
| | Amora Conglomerate Member | Ka .. | Amora Range | Hornfelsed greywacke-conglo- merate. Minor agglomerate, sand- stone —UNCONFORMITY— | .. | 3,000 + | Core of anticline. Dips average about 60° | |
| PALAEOZOIC (?) | GOROPU METAMOR- PHICS | Pzg .. | Goropu Mountains, south of Deune | Quartz, sericite schist and phyllite. Chlorite schist. Metaquartzite | .. | ? | Domal structure—Goropu Mountains. Strong south of Deune | Low-grade regionally meta- morphosed |

called 'the Metamorphic Rocks' into four classes - the 'Owen Stanley Series', the 'Astrolabe-Kemp-Welch Series', the 'Crystalline Limestone' and the 'Serpentine Series'. In his report 'The Geology of Papua' (1923) he describes the 'Owen Stanley Series' and the 'Astrolabe-Kemp-Welch Series', both of which he referred to the Precambrian with the possibility that the 'Astrolabe-Kemp-Welch Series' might be Palaeozoic. In a footnote, however, he reported the occurrence of *Globigerina* in a limestone in the 'Astrolabe-Kemp-Welch Series', indicating an age not earlier than Cretaceous. David (1932) believed this Series to be Miocene, and Glaessner (1952) suggested that part at least might be Eocene. Glaessner (1949) reported the finding of Cretaceous fossils in the Kaindi Series (Fisher, 1939) in the Morobe district. Rickwood (1955), however, mapping in the Western Highlands of New Guinea, described the Omung Metamorphics of definite pre-Permian age. The age and relationships of the metamorphic rocks are thus still in doubt.

In the Musa Valley area the age of the metamorphic rocks cannot be definitely determined, but they can be divided into two: the older, the Goropu Metamorphics, is related to the Owen Stanley Series; the younger, the Urere Metamorphics, is tentatively related to the Kaindi Series of Cretaceous age. Ostracods were found in the Foasi River Limestone, a member of the Urere Metamorphics, but did not prove diagnostic.

Goropu Metamorphics

The Goropu Metamorphics consist of quartz-mica phyllite, quartz-mica schist, chlorite schist, sericite schist, and metaquartzite containing epidote and chlorite. The metamorphics are low-grade regionally metamorphosed rocks with strong directed texture, minor folding, and often well developed schistosity. The typical exposures of the Metamorphics occur in Koval Creek on the north side of the Goropu Mountains.

The Goropu Metamorphics are known to crop out in only two areas. In the east they form the Goropu Mountains, which are possibly faulted along their western and northern margins. Traverses conducted in the Goropu Mountains up Kovai and Unido Creeks in the north and the Ibinambo River in the west indicate that the Metamorphics probably form a broad dome or anticline. The rocks in each area are constant in strike, and smaller structures, with the exception of very minor crenulations in the schistosity, are not apparent. Reliable dips, which range from 10° to 75° with an average of about 35° , are usually obtained only from the mica phyllites and schists, bedding in most places in the more quartz-rich rocks having been obliterated by metamorphism. Only in one place has cleavage been observed. Throughout the more compact quartzose rocks pyrite and occasionally chalcopyrite occur, usually as disseminated grains, but sometimes in small stringers.

The second area of outcrop of the Goropu Metamorphics lies in the western edge of the area near Namudi and Deune. In this area the rocks consist of laminated grey quartz phyllite, blue grey to greenish calcareous quartz phyllite with many veinlets of quartz and greenish chlorite, and sericite phyllite. The rocks, which show complex minor folding, are characterized by their phyllitic nature. They are considered to be low-grade regional metamorphics because of their low degree of recrystallization and their directed texture. Crenulations are common, and especially intense in more calcareous bands. Strikes are extremely varied, although minor folds generally plunge at low to moderate angles to the south-east (130° - 150°). In some places more competent beds are broken across and intruded by less competent beds. These Metamorphics are correlated with the Goropu Metamorphics on lithological grounds, both being regionally metamorphosed phyllites contrasting sharply with the blue-green hornfels typical of the Urere Metamorphics.

North of the Goropu Mountains, in Unido Creek, peridotite bounds the Goropu Metamorphics. Farther east is a possible fault contact with Urere Metamorphics. This contact is partly overlain and obscured by Recent volcanics from Waiowa volcano, which lies on the possible fault-line. The peridotite in Unido Creek, which is intrusive into the Goropu Metamorphics, may be similarly placed on the fault-line.

Near Namudi the Goropu Metamorphics are faulted against the serpentine intruding the Urere Metamorphics to the north. The contrast between the contorted schistose Goropu Metamorphics and the shallow-dipping massive blue-green fine-grained hornfels, the basalt and basaltic agglomerate, and the fissile but uncontorted greywacke siltstone of the Urere Metamorphics, is well shown in this area. Boulders in streams whose upper reaches are inaccessible suggest that blue-green hornfels, a red and white limestone, and probably some amphibolite of the Urere Metamorphics occur south of the Goropu Metamorphics in this area. These appear to overlie unconformably the Goropu Metamorphics, which lie in the centre of a faulted anticline in the Urere Metamorphics.

Since the Goropu Metamorphics are regionally metamorphosed and are overlain by younger metamorphics they are tentatively related to the oldest known metamorphics - the 'Owen Stanley Series' of Stanley (1919); but no estimates can be made of their thickness or age. The 'Owen Stanley Series' is generally considered to be Palaeozoic.

Petrography. Three thin sections of the Goropu Metamorphics show low-grade metamorphism under very strong stress conditions. Specimen 96292 (section no. 2648) is a calcite-quartz-chlorite phyllite in which original compositional lamination (the rock was probably a fine calcareous silt) has been sheared into lenses and irregular bands. The minerals, particularly the calcite and chlorite, have recrystallized.

Specimens 96284 (slide no. 2641) and 96290 (slide no. 2686) were considered in the field to be meta-igneous acid dykes intruding the Goropu Metamorphics. Specimen 96284 consists of quartz, calcite, and chlorite; the last two minerals generally, and quartz less commonly, show strong directed texture. The quartz occurs in part in comb-structure veinlets, and some crystals show growth stages by concentric hexagonal rows of inclusions. Magnetite is a rare accessory mineral. The rock has been recrystallized at a low temperature under strong stress conditions and has been considerably veined by quartz. The simple composition, quartz-calcite-chlorite, is possibly suggestive of a calcareous sediment rather than an acid igneous rock, but there is no evidence of its pre-metamorphic nature in the thin section.

Specimen 96290 is a quartz-calcite-sericite phyllite containing about 40% quartz, 40% carbonate (?calcite), 20% sericite with anhedral accessory magnetite and red-brown chromite, and several patches of radiating chalcedony. The rock has a distinct schistosity due to alignment of sericite and carbonate, but the schistosity is not uniform and penetrative and tends to be localized along subparallel movement planes. The distribution of the quartz, sericite, and calcite is very patchy, which may be due to original bedding variations or to coarse grain size.

Two specimens (nos. 4316 and 211) collected from the Wowo Gap area on the foothills of the Goropu Mountains proved to be chlorite phyllites probably derived by strong shearing from porphyritic basalts. The nature of the alteration suggests that these rocks belong to the dynamically altered Goropu Metamorphics, but their original composition agrees better with the intrusive and volcanic rocks of the Urere Metamorphics. The rocks consist

of clinopyroxene phenocrysts (up to 0.5mm. diameter) and turbid, sheared talc pseudomorphs after olivine, in an extremely fine groundmass of quartz, ?zoisite, and chlorite. Epidote occurs in patches and there are some crystals of plagioclase. Calcite, with quartz, occurs in several veinlets. The clinopyroxene (probably augite) has been granulated in some places and also shows marginal alteration to strongly pleochroic sodic amphibole, probably glaucophane (Z - pale cobalt blue, Y - pale violet, X - colourless: $Zc - 10^0$). A strong directed texture, due to shearing of the rock, is particularly evident in the matrix. The rocks are chlorite-zoisite-quartz phyllites in which the clinopyroxene grains are out of equilibrium and relict from the primary rock, which was probably a basalt. The presence of glaucophane, apparently replacing a non-sodic pyroxene, may include incipient soda metasomatism in this area, which is adjacent to major fault-zones.

Urere Metamorphics

The Urere Metamorphics are a hornfelsed sequence of sediments and basic volcanics. Hornfelsed greywacke-siltstone, greywacke, and basalt are the commonest rock types. Basaltic agglomerate, greywacke breccia, and blue, grey, and occasional purple silts (some with slaty parting) are less common hornfelsed rocks. Chlorite phyllites and amphibolites are locally developed. Two distinctive lithologies, the Amora Conglomerate (hornfelsed greywacke-conglomerate) and the Foasi River Limestone (altered limestone), have been separated out as members of the Urere Metamorphics.

The Urere Metamorphics mainly crop out in the south-west part of the area, on the north side of the Sibium Range between Kakasa and Bobolobo, and as roof-pendants in the Sibium Range/Didana Range area within the basic-ultrabasic belt. Typical exposures of the Metamorphics occur along Urere and Awala Rivers and in the Amora Range south and south-west of Liamu and Namudi. In the area on the north side of the Goropu Mountains are several outcrops of blue-green sediments lacking the schistosity of the Goropu Metamorphics. In Unido Creek these sediments are greenish-grey fissile slates dipping gently north. To the east in Konara Creek the typical rocks are green fine-grained basic rocks, possibly hornfels with minor epidote veining. In this area dips are very varied, in contrast to the regular northerly dip of the Goropu Metamorphics.

In the Didana-Sibium Ranges small bodies of fine-grained blue-green rocks, some of which are typical hornfelsed sediments, others fine-grained basalts and dolerites, occur as roof-pendants or xenoliths surrounded by gabbroic rocks of the basic-ultrabasic suite. South of Korala pillow structure occurs in these basalts. No contacts between these rocks have been observed. Similar rock types were mapped in the area between Bobolobo and Kakasa.

On the southern side of the Musa Valley fine-grained hornfels, often epidotized and chloritized, dolerite, and probable basalt are the major rock types in the Urere Metamorphics. Local shearing with well-defined cleavage is common in this area and contacts with bodies of serpentinite are generally sheared.

The relationships of the numerous dolerite bodies in the Urere Metamorphics are rather problematical. In the field it is commonly very difficult to distinguish between the fine blue-green hornfels and fine blue-grey dolerite. Near Kakasa particularly, medium-grained dolerite is associated with fine basalt with scattered amygdaloids. The dolerites generally appear to have suffered the same metamorphism, jointing, and shearing as the sediments, and some are definitely intrusive - probably pene-contemporaneous with the sedimentation and belonging to the same igneous phase as the basalts.

The Urere Metamorphics are intruded by diorite and granodiorite bodies. These are particularly common in the Amora Range and may be the main cause of the general thermal metamorphism of the Urere Metamorphics, although in the Sibium and Didana Ranges the basic-ultrabasic suite could have contributed to this: in these areas, particularly near Bobolobo and Korala Creek, diorite and granodiorite also occur and their intrusion into the Metamorphics appears to precede that of the basic-ultrabasic suite. Disseminated pyrite is fairly common and chalcopyrite less common throughout the Metamorphics. The diorite and granodiorite also typically contain disseminated pyrite, and some sediments adjacent to dykes of these rocks contain small concentrations near the contacts.

Little is known of the regional structure of the Urere Metamorphics, mainly because outcrops in which bedding is visible are scarce. They are probably faulted against the Goropu Metamorphics on the north side of the Goropu Mountains and they certainly are faulted west of Namudi, in the Amora Range, where the Urere Metamorphics to the north have a low northerly dip in contrast to the steeply-dipping, complexly folded, Goropu Metamorphics to the south. The structure in this area is believed to be a faulted anticline of Urere Metamorphics unconformably overlying a highly folded core of Goropu Metamorphics.

The Urere Metamorphics are unconformably overlain by the Pleistocene Domara River Beds in several localities, e.g., near the junction of the Awala and Musa Rivers and north of Bubudi and Imuruwake. In other areas the contact with the Domara River Beds is faulted, as near Moikodi and south of Musa.

Ostracods have been found in the Foasi River Limestone, but were not diagnostic, and the age of the Metamorphics is not known. Apart from local shearing they are only thermally metamorphosed and therefore are almost certainly younger than the regionally metamorphosed Goropu Metamorphics. They may be related to the Cretaceous Kaindi Series, which occur adjacent to the Papuan basic-ultrabasic belt farther north-west, near Morobe.

Amora Conglomerate Member. The Amora Conglomerate Member, which is considered to be low in the Urere Metamorphics' succession and possibly basal, is a pebble to boulder grey-wacke conglomerate with very occasional sandstone lenses and beds. Rare horizons of basaltic and andesitic agglomerate are associated with it in the Awala River. The conglomerate contains boulders of quartz, grey and blue-grey metamorphics, black slate, granitic rocks, and some amphibolite. No ultrabasic boulders were found. In this respect, and also in that it is strongly lithified and slightly hornfelsed, it differs sharply from the Domara River Beds which unconformably overlie it near Imuruwake and Bubudi. The thickness of the conglomerate is not accurately known but probably exceeds 3000 feet.

Typical exposures of the Member occur in the Awala River where it cuts through the Amora Range. The conglomerate again occurs in the headwaters of Liamu Creek, where it appears to have a north-east dip, opposite to that in the Awala River. The Member does not occur in the Urere River nor along the track between Moikodi and Ariari, and is believed to be folded around the nose of an anticline plunging south-east west of these areas.

Foasi River Limestone Member. The Foasi River Limestone Member is a finely crystalline pink, occasionally brown and white, laminated altered limestone, considerably contorted. Numerous small calcite veins cut the Member. It crops out at the headwaters of the Foasi and Ikumu Rivers, and in the latter area it is observed to grade upwards into green fine-grained hornfels typical of the Urere Metamorphics. Boulders of a similarly-laminated limestone occur

in a creek draining the Amora Range near the Awala River. Isolated outcrops of white laminated limestone have also been observed around Mioki. It appears possible therefore that the limestone may be several discontinuous lenses rather than one continuous bed, but whether on one stratigraphic horizon or not is not known. The base of the Member has not been observed, and because of this and the contortion of the limestone no estimate of thickness can be given.

Petrography. The characteristic rocks of the Urere Metamorphics are very fine-grained jointed blue-green rocks which in the field were usually hornfels. Rocks from the Metamorphics examined in thin section show a surprisingly high proportion of igneous extrusives and fine intrusive material; definite sediments are comparatively rare.

Specimen 96269 (b) (slide no. 2703) was collected near Imuruwake and was unusual in apparently being a laminated phyllite of sedimentary origin amongst more massive crystalline rocks. It consists of anhedral epidote porphyroblasts in a very fine-grained groundmass of quartz, chlorite, tremolite-actinolite, and epidote. The proportions of the minerals vary in the rock, giving a discontinuous lamination, and in particular some lenses rich in chlorite and quartz. The amphibole wisps do not lie in a plane of schistosity, but tend to form distinct crenulations. The rock is a greenschist, and some stress has probably aided its slight recrystallization. It may have been a greywacke siltstone originally.

Specimen 96269 (a) (slide no. 2697) was also collected near Imuruwake, and in the field outcrops showed medium and fine-grained amphibolite apparently grading to hornblendite. Specimen 96269 (a) is a hornblendite consisting of about 80% hornblende (Z - brown, rimmed by pale green, Y - pale brown, X - colourless to very pale brown; $Z \wedge C \approx 23^\circ$) with interstitial talc and several anhedral vesuvianite crystals. The texture of the rock is granular, although in hand-specimen there is slight parallelism of hornblende crystals. The original rock type is unknown, but may have been basic igneous, and its original crystalline character explains the coarse grain and greater degree of crystallization of this rock compared with specimen 96269(b), which occurs in the same area and apparently within the same sequence.

Specimen 96265 (b) (slide no. 2696) was collected from the Awala River north of Imuruwake, and in the field was considered to be a metamorphosed greywacke or tuff. In thin section the rock is porphyritic, with small to medium-grained euhedral crystals in a fine-grained matrix of chlorite, quartz, probable feldspar, and patches of ?magnetite dust. The phenocrysts are of two types, the more common being zoned and twinned plagioclase which is almost invariably pseudomorphed by calcite, sericite, and chlorite aggregates. The second type is green chlorite aggregates, commonly rimmed with magnetite dust and apparently pseudomorphing amphibole. The rock is a feldspar porphyry, probably of andesitic composition, which has suffered low-temperature alteration without the action of appreciable stress. It could have been either intrusive or extrusive.

Specimen 96265 (c) (slide no. 2694) was collected adjacent to 96265 (b); in outcrop the rock is distinctly fragmental, like a coarse agglomerate. The 'fragments' consist of about 30% epidote, 40% albite, 20% quartz and 10% sericite, chlorite, and opaque oxides. The rock appears to be a low-temperature alteration of a fine feldspar porphyry containing many small phenocrysts and comparatively little fine-grained groundmass. The rock enclosing the fragments is generally slightly finer-grained, but is porphyritic, with albite phenocrysts in a groundmass of secondary sericite, chlorite, feldspar, epidote, opaque iron oxide minerals, and possibly a little quartz. Epidote occurs as uncommon larger crystals and one area of chlorite

is probably a pseudomorph after an amphibole phenocryst. There is no evidence of fragmental clastic texture in the enclosing rock and the rock is interpreted as an altered andesitic porphyry enclosing xenoliths (or autoliths) of a slightly more quartzose but very similar porphyry. The rock could be either of intrusive or extrusive origin.

Specimen 9286 (slide no. 2650) was collected from within the Urere Metamorphics on the southern side of the Sibium Range. The rock is fine-grained and consists of about 25% quartz, 35% andesine-oligoclase, 10% pyroxene (with amphibole and chlorite), and accessory sphene and magnetite. Vesicle fillings of epidote and quartz with some chlorite and calcite constitute about 20% of the rock. The feldspar occurs as laths, commonly aligned, and other constituents are anhedral. The texture is typically igneous, and although there has been slight retrogressive alteration, the rock has not been extensively metamorphosed. It is a fine-grained dacite and probably related to specimen 96256 from the northern side of the Sibium Range.

Specimen 96250 (slide no. 2699) is a specimen of agglomerate collected from near Deune in an area which includes lava, agglomerate, related intrusions, greywacke, and siltstone. The rocks appear unmetamorphosed. The volcanic fragments contain euhedral phenocrysts (average 1-2 mm.) of green hornblende and colourless augite in a very fine-grained turbid matrix. Small vugs and several small veinlets are filled with a zeolite (chabazite). The groundmass contains small plagioclase (indeterminate) laths, small patches of matted ?sericite wisps, iron oxide granules, and much very fine, turbid, unidentifiable material (possibly devitrified glass). The hornblende phenocrysts are more abundant and generally larger than the augite. Both minerals are definitely primary. The presence of both hornblende and augite phenocrysts is unusual in a volcanic, especially as neither shows evidence of reaction with the groundmass. As the feldspar composition is unknown the rock is difficult to classify, but is probably andesitic rather than basaltic, and the change from crystallization of hornblende to crystallization of pyroxene (the latter are the smaller and probably later crystals) may be due to sudden release of volatiles from the magma as it was extruded or approached the surface.

Specimen 96256 (slide no. 2649) was collected from the north side of the Sibium Range near Korala. It is a very fine-grained blue-grey uniform, finely jointed rock and was mapped as a typical 'hornfels' of the Urere Metamorphics. In thin section the rock (average grain size about 0.2 mm.) contains about 45% plagioclase (andesine, about $Ab_{55}An_{45}$), 30% actinolitic hornblende, 10% quartz, 10% opaque iron oxide, and 5% sphene. The texture is random but not clastic and feldspar occurs as laths, whereas the amphibolite, containing sphene inclusions, and associated with chlorite, is probably pseudomorphing pyroxene, possibly titan-augite. The rock has suffered low temperature retrogressive alteration but no extensive metamorphism. It can be classified as a non-porphyrific pyroxene andesite or microdiorite; and the identification of this rock as primarily of igneous origin means that in the Didana-Sibium Ranges no definite sediments have been found in the Urere Metamorphics, which apparently consist of basalts, including pillow lavas, andesites, and related doleritic and andesitic fine-grained intrusives with occasional acid (dacite) flows.

Specimen 96223 (a) (slide no. 2698), collected near Kakasa on the northern side of the Didana-Sibium Ranges, is a fine-grained blue-grey basalt containing patches and amygdaloids of epidote. The rock has a basaltic texture with albite laths (probably secondary after calcic feldspar) and interstitial epidote, chlorite, iron oxide grains, and quartz. It is apparently unstressed, and altered at low temperature. A very similar rock collected from the

Sesara Volcanics area is probably part of the Urere Metamorphics included within the much younger Sesara Volcanics. This rock (specimen 96257 (a) slide no. 2707) contains small uncommon feldspar and rare hornblende phenocrysts in a felted groundmass of feldspar laths (probably albite), small hornblende laths, magnetite, and interstitial quartz. Chlorite-filled amygdalites rimmed with concentrations of extremely fine magnetite are common.

Specimen 96223 (b) (slide no. 2710) was collected near Kakasa and in the field was closely associated with and possibly gradational from basalt (specimen 96223 (a)). The rock is fine-grained, with average grain-size about 0.5 mm, and an intergranular to sub-ophitic texture. It contains about 35% augite, 40% labradorite ($Ab_{40}An_{60}$), 10% quartz, 10% chlorite, 5% magnetite, and accessory prehnite. The plagioclase is strongly zoned and commonly partly altered to fine-grained secondary material. The thin-section examination shows that the rock is a slightly altered dolerite.

In summary, the thin-section examination of the Urere Metamorphics has shown that a large percentage of the metamorphics consist of volcanic rocks most commonly andesitic or basaltic. They have commonly been slightly altered in an unstressed low-temperature environment, resulting in the breakdown of primary minerals to albite, epidote, chlorite, and amphibole.

Domara River Beds

The Domara River Beds consist of greywacke conglomerate, greywacke, and greywacke-siltstone, with less common sedimentary breccia and calcareous mudstone. Vulcanism with local deposition of agglomerate and tuffs and outpourings of lava flows occurred several times during the sedimentation. The Beds crop out on either side of the Musa Valley, particularly on the south side. Outcrops also occur around Imuruwake and Bubudi and occasional remnants overlie the Urere Metamorphics in the Amora Range area. The Beds are best exposed in the Domara River, where there is believed to be over 5000 feet of sediments. Nowhere are they fully exposed. Fossiliferous bands of calcareous mudstone and fine-grained greywacke containing thin-shelled trochospiral and planispiral gastropods with occasional pelecypods occur at several horizons. Examination of the fossils indicates that the rocks are freshwater sediments of Pleistocene age (see Appendix).

The greywacke conglomerate varies from very fine pebble to coarse boulder in size. The boulders within the conglomerate consist of rocks of the basic-ultrabasic suite, Urere and Goropu Metamorphics, and andesite derived either from the penecontemporaneous vulcanism or from older, possibly intrusive, rocks.

Rapid facies changes from conglomerate to greywacke occur along one stratigraphic horizon. Bedding is very often not distinguishable in the coarser conglomerates, but in the finer conglomerate beds cross-bedding on a fairly large scale is seen. Scour-and-fill was also observed in several places.

The arenites are poorly sorted and of greywacke to quartz greywacke composition, but they do not show typical characteristics of eugeosynclinal greywackes, e.g. slump structures, graded bedding, etc. Their composition is a reflection of rapid erosion. Carbonized wood fragments up to 3 feet long have been found in conglomerate and greywacke, and the whole sequence may very well be a freshwater lake and valley-fill deposit.

Three basal or near basal volcanic members, the Musa, Awala, and Imuru Volcanics, have been separated out from the Domara River Beds. Andesitic agglomerate with some lava occurs at several localities in the Domara and Foasi Rivers, but correlation is not possible from one river to the other. Andesitic - usually porphyritic - dykes also intrude the Beds, but are mainly associated with younger faulting. Near the southern edge of the area, in the Domara River, are several basic dykes and medium-grained vesicular flows. The position of the flows in the sequence is not known but they are probably quite high. On the north side of the Musa Valley the Domara River Beds unconformably overlie the basic-ultrabasic belt, except in Sivai Creek, where the contact is faulted. In most places the basalt beds are coarse boulder conglomerate containing mainly basic and ultrabasic boulders. Near the Awala-Musa River junction and near Bubudi in the south-west, the Domara River Beds unconformably overlie the Urere Metamorphics. Elsewhere on the south side of the Musa Valley the Domara River Beds are in fault contact with the basic-ultrabasic belt. The Beds generally strike south-east and have an overall dip south-west; dips range up to 65° and average $20-25^{\circ}$.

Musa Volcanics Member. The Musa Volcanics consist of at least three beds of basaltic agglomerate, 15-30 feet thick, with interbedded greywacke, possibly tuffaceous, and greywacke conglomerate band, and though the actual contact is not exposed the conglomerate probably lies basically on the basic-ultrabasic rocks. The extent of the volcanics is not known accurately; westwards they lens out to the east of Beroma Creek; eastward agglomerate was observed as boulders in a creek north of Obeia but none were seen in Lorupu Creek a little farther east.

Awala Volcanics Member. The Awala Volcanics Member is exposed west of the junction between the Awala and Musa Rivers. Unconformably overlying the Urere Metamorphics are moderately dipping conglomerates grading to breccias and interbedded with feldspar-rich, probably tuffaceous, sandstone. These are overlain by a red-brown feldspar porphyry with weathered-out ferromagnesian phenocrysts. This is probably an andesitic flow, although contacts are not evident and it may be an intrusion. It is overlain by a coarse, poorly-bedded conglomerate and above this are massive hornblende-feldspar porphyritic andesitic volcanics consisting of lava and some agglomerate. This horizon is probably about 1,000 feet above the unconformity, but the sediments below, for the most part, seem to have a volcanic influence and are therefore included in the Member. Further andesitic tuffs occur in the Urere River in this area and may overlie the andesitic agglomerate and lava mentioned above.

Imuru Volcanics Member. In the Imuru Creek, north of Imuruwake, the Urere Metamorphics are overlain by a coarse, well-rounded, boulder conglomerate with rare arenite lenses. This is overlain by very coarse sedimentary breccia, which in turn is overlain by andesitic agglomerate. The river passes through an inaccessible gorge in this locality and agglomerate occurs at both ends of the gorge. The thickness of the agglomerate horizon, if it is present throughout the gorge, is about 300-400 feet and below it the conglomerate and sedimentary breccia is of similar thickness. The agglomerate is andesitic and contains angular boulders up to 4 feet across. The agglomerate is overlain by greywacke conglomerate and sandstone (approximately 50 feet thick) and then by an 80-foot bed of andesitic agglomerate and by pebbly sandstone and conglomerate.

South-east of this area and east of Bubudi andesitic agglomerate and hornblende-feldspar crystal tuff rest directly on the Urere Metamorphics. North of Bubudi, Buri Creek cuts through a large area of massive rocks consisting of fragments of andesite (the same as in

the agglomerate which is interbedded with conglomerate in the Imuru River) in andesitic lava. The matrix is porphyritic but crystalline, as opposed to the weathered rubbly type which often occurs as the matrix of the normal agglomerate and is suggestive of an origin within or close of a volcanic vent. A roughly circular topographic feature in the area may be the vent which supplied the Imuru Volcanics, as typically exposed in the Imuru River.

Petrography of the Imuru Volcanics.- Specimen 96267 (a) (slide no. 2708) was collected from Buri Creek, north of Bunudi, and from the northern side of the possible vent mentioned above. In thin section the rock is seen to consist of tabular plagioclase (andesine, Ab₆₅An₃₅) phenocrysts (40% of the rock) and elongate amphibole crystals (10%) in a fine-grained groundmass. There is no evidence of clastic texture in the fine-grained areas or in the phenocrysts. The rock is strongly altered at low temperature; the feldspar is replaced largely by calcite, with small inclusions of deep green epidote. The amphibole has altered to fine-grained pleochroic chlorite, and the groundmass consists of anhedral magnetite, fine calcite, quartz, chlorite, and white turbid saussurite or clay mineral.

The rock was originally an andesine-hornblende porphyry (or porphyritic andesite) altered at a low temperature and possibly metasomatized. These effects could be due to fumarolic activity from the presumed andesitic vent.

The Silimidi Beds. - The Silimidi Beds consist of a horizontal to sub-horizontal sequence of poorly consolidated greywacke conglomerate, sedimentary breccia, lenticular greywacke, and two horizons, at least, of lithified breccia consisting of peridotite and dunite fragments in an olivine or, less commonly, serpentine matrix. These two horizons and the sediments between them have been separated out as the Sivai Breccia Member.

The Silimidi Beds crop out at the eastern end of the Musa Valley, particularly in the Sivia Creek-Darumu Creek and the Silimidi-Ibau Creek areas. In the Sivai Creek-Darumu Creek area the surface of the beds is a distinct flat topographic surface sloping less than 4° south-westwards towards the Musa Valley. It is dissected by Darum Creek and Sivai Creek, which now flow in V-shaped gorges. The same nearly flat surface is seen in the Ibau Creek area and stretches almost from the edge of the Goropu Mountains to Silimidi Creek. The beds probably covered the whole of the eastern part of the valley originally, but have been eroded away to some extent by the Ibinambo River. Near Silimidi the Beds are fairly well exposed, but east of Silimidi an intermittent cover of coarse fanglomerate boulders of the Goropu Metamorphics obscures them. That this area is in fact composed of the Silimidi Beds is strongly indicated by the boulders in the Ibau Creek, which include both sedimentary and ultrabasic breccias.

The conglomerate consists largely of boulders of the basic-ultrabasic suite, especially in the Sivai Creek-Darumu Creek area, where the source area is probably the Didana Range directly to the north. Overlying the Sivai Breccia Member in this area is a very coarse sedimentary breccia resembling the fanglomerate deposits in boulder size but consisting entirely of rocks in the basic-ultrabasic suite. On the south side of the Musa Valley around Silimidi the conglomerates and breccia contain metamorphic rocks as well as igneous ones, probably mainly Goropu Metamorphics. Sedimentary breccias with a soft earthy matrix occur in this area, usually directed above or below the Sivai Breccia Member.

The Silimidi Beds unconformably overlie the Domara River Beds and in places the basic-ultrabasic rocks, and in Sivai Creek overlie a major fault between these two. They are themselves faulted near Silimidi, the north side downthrowing towards the Musa Valley. Faulting

may also occur north of Mapu and east of Iwade. The Beds are not folded, but slight uplift in the east has caused dissection; this is probably related to the faulting mentioned above, both being a continuation of the downward movement of the Musa Valley trough.

The age of the Silimidi Beds is probably Pleistocene or possibly even Recent. No fossils have been found.

Sivai Breccia Member. - The Sivai Breccia Member forms distinct scarps along the sides of the Sivai and Darumu Creeks. It consists of two horizons of a hard, lithified yellow-green ultrabasic breccia separated by variable sediments, including conglomerate and sedimentary breccia. The breccia horizons consist of angular fragments of peridotite and dunite, unserpentinized in some places, in a matrix of fine to medium-grained yellow-green glassy olivine crystals with rare chromite and possibly pyroxene crystals. The ratio of matrix to fragments is variable, some outcrops being 60-65% matrix and others only about 35%. The size of the fragments is variable, but the common size range is one to four inches.

In Sivai Creek, although exposure is intermittent and the tendency is for the more resistant breccia horizons to form extremely large boulders which may or may not be in situ on the steep slope of the gorge, the lower breccia horizons appear to be 60-80 feet thick and overlain by about 50 feet of conglomerate, mainly of ultrabasic and basic boulders, and lesser greywacke, and then by a further 30 feet of peridotite breccia. This lies very near to the sub-horizontal topographic surface, but is overlain by patches of sedimentary conglomerate and sedimentary breccia, some of which are extremely coarse. The thickness of the sediments between the base of the lower peridotite breccia and the unconformity on the Domara River Beds is not known, but is no more than 100 feet.

Near Silimidi two peridotite breccia horizons again crop out. In this area both the Silimidi Beds and the Domara River Beds are sub-horizontal and this, together with the lithological similarity between the lowest Silimidi and the highest Domara River Beds, makes the unconformity hard to distinguish. South of Silimidi the lower peridotite breccia caps a prominent hill of greywacke conglomerate, part of which (at the base of the hill) is Domara River Beds; but no break was distinguished. In the Silimidi area the lower peridotite breccia is 80-120 feet thick and is overlain by 20 feet or more of sedimentary breccia and greywacke conglomerate and then by a further peridotite breccia horizon 15-20 feet thick. This is overlain by greywacke grading into boulder conglomerate, and there may be further peridotite breccia horizons above this. The top of the upper breccia horizon is well exposed and is gradational: the normal breccia with yellow-green olivine matrix grades irregularly into a breccia consisting of weathered peridotite fragments in a pale green non-granular and non-crystalline matrix which is probably serpentine. This is about 3 inches thick and in turn grades into a poorly lithified, angular-grained greywacke which appears to contain numerous small fragments of serpentine. Because the contact is gradational with no evidence of shearing or metamorphism, the peridotite breccia is considered to be part of the sedimentary sequence with a greywacke conformably overlying it. Descriptions of thin sections of the Sivai Breccia are described under Igneous Rocks, Ultrabasic Breccia.

Fanglomerate Deposits

Ubo Fanglomerates. - Fanglomerate deposits consisting of poorly-sorted, unconsolidated, very coarse boulder-conglomerate occur at the eastern end of the Musa Valley. Ubo lies roughly at the western edge of these rocks. Most boulders are between three and five feet long,

but some are larger. They consist essentially of rocks of the Goropu Metamorphics (quartz phyllites, etc.) but some appear to be more calcareous than the metamorphic rocks seen in the Goropu block. The fanglomerate probably owes its existence to the Ibinambo River and its minor tributaries, which together drain the west and south-west sides of the Goropu Mountains. The upward slope of this fanglomerate is evident when viewed from the Sivai Creek crossing near Obeia. The fanglomerate deposits almost certainly pass transitionally westward into the bedded conglomerate, coarse-grained sandstone, etc. forming the valley floor deposits of late Recent age near the Adau and Domara Rivers.

Liamo Fanglomerate. - Similar deposits of unconsolidated, very coarse boulder-conglomerate occur on the northern side of the Amora Range in the west of the area. This fanglomerate is derived from the Amora Range and consists mainly of boulders of the Urere Metamorphics. It probably owes its existence to the effects of the many small streams draining the faulted, steep northern flank of the Range.

Sesara Volcanics

The remnants of a large volcano of the central type occur in the extreme north-central part of the area. The villages of Sesara and Aurala lie within the actual crater, which is about six miles long and four across. The dissected sides of the cone fall rapidly to the coastal plain to the north and east, but to the south and south-west they rest on the upland formed by the Urere Metamorphics and basic-ultrabasic rocks. The southern rim of the crater forms the divide of the Sibium Range in this area. Isolated areas of volcanics, probably remnants of the volcanics from the major cone, rise sharply from the coastal swamp and plain north and east of Sesara.

The Sesara Volcanics consist of basalt, agglomerate, tuff, and some sediments. The basalts are very variable and include fine-grained, porphyritic, vesicular, and scoriaceous types. The porphyritic basalts usually contain phenocrysts of olivine and, less commonly, pyroxene. In some specimens olivine phenocrysts form up to 50% of the rock, so that the overall composition of the rock would approach ultrabasic. The sediments crop out principally on the eastern side of the cone near Korala, and include a soft yellow-brown siltstone containing ellipsoidal and rounded bodies generally 1/4" to 1/2" long consisting of a white calcite rim and core of green crystalline epidote. The enclosing rock has the appearance of a sediment though the ellipsoidal bodies are more suggestive of amygdaloids.

A small area of outcrop of agglomerate and some lava between Korala and Kakasa overlies the Urere Metamorphics and may be a separate vent. The rock types are identical with those of the Sesara Volcanics and the two are part of the same volcanic phase.

Basaltic rocks have been observed as boulders in streams in the Wowo Gap area, and an area of basaltic agglomerate crops out around Guara Creek. Both are considered to be younger than the basic-ultrabasic suite and are tentatively related to the Musa Volcanics in the Domara River Beds on lithology; but they may be related to the Sesara Volcanics.

Petrography. - Specimens 96257 (b) (slide no. 2704) and 96257 (c) (slide no. 2692) were collected from the Sesara Volcanics along the Sesara-Kinjaki track. Specimen 96257 (b) contains abundant euhedral and subhedral phenocrysts of olivine whose grain-size averages about 0.3 mm. but ranges up to 1 cm., and also very common phenocrysts of clinopyroxene about 1 mm. to 2.5 mm. long. The groundmass consists of plagioclase (?labradorite) laths

in typical basaltic texture with interstitial magnetite granules and isotropic glass. The olivine is biaxial with $2V \approx 90^\circ$; it is zoned in some crystals and invariably rimmed by or altered to bowlingite. The clinopyroxene is probably augite; it is colourless, biaxial (+)ve with $2V \approx 45^\circ$. The rock is a typical olivine basalt and is very similar in composition and texture to the olivine basalt fragments occurring in the peridotite-basalt breccia of Wowo Gap.

Specimen 96257 (c) contains an unusually large percentage of phenocrysts. The rock consists of about 55% euhedral and subhedral phenocrysts, 25% finely crystalline groundmass and 20% sub-isotropic, partly devitrified, glass. Of the phenocrysts about 40% are olivine and 60% clinopyroxene. The olivine is colourless and biaxial with a $2V \approx 90^\circ$, but does not show any alteration to bowlingite. The clinopyroxene is pale green, faintly pleochroic, biaxial positive, $2V \approx 50^\circ$ and $Z \wedge c \approx 48^\circ$, and is probably augite, possibly slightly sodic. Zoning is very common in the augite and shows as colour zoning, zoned extinction, and lines of liquid inclusions marking growth stages. The crystalline part of the groundmass consists of poorly crystallized clinopyroxene, calcic feldspar laths, common magnetite cubes, and elongate patches of criss-crossing, extremely fine magnetite wisps which may be a type of microlite. The rock is an olivine basalt related to specimen 96257 (b) but markedly enriched in phenocrysts and containing a slightly different pyroxene.

The Sesara Volcanics are clearly distinguished from basalts of the Urere Metamorphics by their freshness and high percentage of olivine.

Waiowa Volcanics. - At the end of 1943 and in 1944 a series of small volcanoes erupted along the northern side of the Goropu Mountains. The most westerly of these, which erupted in October 1943, is called Goropu or Waiowa and lies on the eastern edge of the area mapped. Waiowa volcano now has a crater-lake 600 feet across and the crater rim is about 75 feet above the lake; but the actual cone rises very little above the surrounding countryside. The volcano is perhaps an incipient strato volcano (Fisher, 1957) and the rocks mainly consist of andesitic agglomerate and occasional tuff. The agglomerate boulders range up to 2 feet in size, but appear to be slightly smaller towards the edge of the area of main outcrop. The occasional quartz fragments are only of pebble size. Epidote-rich, probably basaltic fragments were found near the vent. Baker (1946) reported the discovery, near the vent, of two ejected pebbles of serpentinized pyroxenite, indicating an eastward continuation of the ultra-basic belt. The tuff, which is normally very coarse-grained, is usually seen some distance from the cone. Both tuff and agglomerate contain occasional hornblende, biotite, and augite phenocrysts. Vegetation was devastated, as can be clearly seen from air photographs, as far as three miles away. Lapilli were recorded as much as 16 miles from the vents and volcanic dust as far away as Port Moresby (Baker, 1946). A ring visible on the air photographs just to the north of the present cone may have been an early centre of eruption. A strong lineation also visible on the photographs indicates that the Waiowa Volcanics may have erupted along a fault-line that probably bounds the Goropu Mountains on their northern side.

The Waiowa Volcanics are probably related to the Recent volcanics of Mount Trafalgar and Mount Victory, which form the high-standing country of Cape Nelson to the north. The south-western slopes of these volcanoes occur within the Dove 1-mile Sheet and may consist of flows.

Petrography. - Specimen 96288 (slide no. 2685) is a boulder collected from agglomerate about a mile from the vent of Waiowa Volcano. The rock is very fine-grained and contains very common small (0.1 mm.) augite phenocrysts and larger biotite phenocrysts in a very fine-

grained groundmass consisting of euhedral and subhedral magnetite, laths of plagioclase (?andesine), and isotropic glass. The feldspar laths are commonly aligned by flowage in the groundmass. One large phenocryst of brown hornblende is present in the specimen and this, and the biotite phenocrysts particularly, show evidence of reaction with reabsorption into the groundmass. The unstable biotite alters to clusters of magnetite crystals, some with clinopyroxene granules. This reaction is the converse of that observed in the lapilli derived from Waiowa and examined by Baker (1946); Baker observed that augite phenocrysts were unstable in their environment and were partly replaced by biotite. It appears that the existence of biotite or augite as a stable crystalline phase in the lava is subject to very sensitive controls: the percentage of volatiles present may be decisive.

Within the rock there are common ?autoliths consisting of clusters of biotite and augite with interstitial feldspar and also one xenolith of schist. This schist is considered to consist of anthophyllite with interstitial fine turbid material and clinopyroxene, but mineral identification is not certain. The xenolith is possibly derived from an ultramafic rock.

The rock may be classed as an augite-biotite andesite, but is mineralogically close to the augite biotite lamprophyre dykes occurring as small late intrusions in the area. The rock is unrelated to the basaltic volcanics of Sesara.

IGNEOUS INTRUSIVE ROCKS

BASIC-ULTRABASIC SUITE.

The existence of ultrabasic rocks on the north side of the Owen Stanley Range has been known at least since 1917. E.R. Stanley (1919) in a report of an expedition across the Owen Stanley Range in the Annual Report of Papua (1917-1918) included ultrabasic rocks (the 'Serpentine Series') found in the Kokoda, Mamama River, and other areas in the 'Metamorphic Rocks'. In 1924 he recognised that the ultrabasic rocks form a discontinuous belt. J.E. Thompson (1958) has carried out reconnaissance mapping of the ultrabasic rocks in the Waria River valley and Musa River valley areas. H.L. Davies (1959) mapped and collected soil samples in the Ajura Kujara Mountains in the Kokoda area in 1957-8.

The Papuan basic-ultrabasic belt is 230 miles long and up to 25 miles wide in places. The belt runs north-west, parallel to the main axis of the Owen Stanley Range. The north-western end crops out on the coastline just south of Salamaua and the south-eastern end is represented by the rocks in the Musa Valley area. Isolated outcrops are found farther south-eastwards in the Milne Bay area.

The basic-ultrabasic rocks in the Musa Valley crop out over a width of 25 miles. The outcrop is discontinuous because of the overlying younger sediments and volcanics, particularly the Domara River Beds. On the north side of the valley the Didana and Sibium Ranges are mainly composed of basic and ultrabasic rocks, with some Urere Metamorphics around Bobolobo-Kakasa and a thin cover of Domara River Beds on the south side. On the side of the valley the basic-ultrabasic rocks are partly covered by Domara River Beds. No such well-defined southern boundary has been recognised as in the Kokoda area, where the rocks on the south side are bounded by the Owen Stanley Fault.

Lithology. - The ultrabasic belt contains a variety of rock types, roughly divisible into three groups; an ultrabasic group, a transitional group consisting of an interbanded sequence of both basic and ultrabasic rock, and a gabbroic group.

The predominant rock type in the ultrabasic group is peridotite, containing varying proportions of olivine and orthopyroxene. The rocks are coarse-grained to very coarse-grained, the orthopyroxene crystals being larger than the olivine. The peridotite commonly appears to be uniform, but in some outcrops, usually where the percentage of orthopyroxene is high, there is a well-developed compositional banding. This banding is often rhythmical, with a concentration of orthopyroxene at the base of each layer. The bands are generally 3 inches to 12 inches thick. Dunite is also a fairly common rock type, and several examples of dunite show in hand specimen a well-developed directed texture with elongation and parallelism of grains. Commonly the peridotite is cut by thin irregular veinlets of pyroxene. These are usually only of single crystal width.

A very distinctive, but less common, rock type in the ultrabasic suite is a very coarse-grained deep-green pyroxenite in which crystals may be up to 6 inches. Many crystals have been observed to be bent, with distinctly curved cleavage faces. The crystals may be intergrown and cut across each other, and usually vary considerably in size in a small area. The pyroxene crystals are considerably coarser than those in the peridotites. No banding was seen in the rock and its relationship to other rocks of the basic-ultrabasic suite is not clear. Near Mamama and in Nuaro Creek it appears to form bodies which are probably concordant with the banding, though there is a sharp contrast in grain size. In Ucku Creek coarse-grained pyroxenites are associated with medium-grained gabbros and may also be concordant, but in Afaiee Creek the pyroxene grades into a very coarse pegmatitic gabbro containing euhedral pyroxenes in a feldspathic matrix. The pegmatite has very patchy distribution throughout the pyroxenite and both rock types apparently form a discordant intrusion into the banded sequence.

Both the transitional group and the gabbroic occur mainly on the north side of the valley in the Sibium and west Didana Ranges. The transitional group consists of a banded sequence of basic and ultrabasic rocks in similar proportions. The banding is variable and in some cases is simply rhythmical banding in gabbro in which ferromagnesian minerals are concentrated at the base of each band (generally 6-12 inches thick). Probably the next most common rock type is an ultrabasic picrite composed of pyroxene, some olivine, and a little feldspar. The pyroxene, probably orthopyroxene, occurs as very large crystals up to 1 inch in length, poikilitically enclosing many small grains of olivine. The olivine, and probably also the pyroxene, are commonly serpentinized. Interstitial to the ferromagnesian minerals is a small though varying amount of white feldspathic material, dull white, and probably saussuritized feldspar. Banding in the picrite is very variable and is due mainly to the variation in grain size of the orthopyroxenes and also the the variation in the feldspar content. The picrites, like the other ultrabasic rocks, occur as bands within the gabbroic rocks. These bands, which range from 3 inches to several hundred feet, are best seen in the Ido Creek and Musia Creek areas. None has been seen on the south side of the valley. Less commonly on the north side troctolitic rocks composed of feldspar and serpentinized olivine occur, sometimes as bands within the gabbroic rocks, but also occasionally as a gradational rock between gabbro and thin bands of serpentinized peridotite. The latter rock, which may range to dunite, has been observed inter-banded with clinopyroxene on a small scale over thicknesses up to 20 feet. The contact between the two rocks is usually sharp.

Occasional bands of gabbro contain very little ferromagnesian mineral and approach anorthosites in composition. No outcrops of derived boulders of chromitite or inter-banded chromitite and peridotite have been observed in either the ultrabasic or the transitional rocks, though they have been found in other similar basic-ultrabasic belts.

The gabbroic group consists of gabbro with no ultrabasic layers. In some areas the rocks are banded owing to differing percentages of feldspathic and ferromagnesian minerals. In places the banding is rhythmic, but more commonly the rock is uniform. It is usually fine to medium-grained and equigranular, and consists largely of feldspar and pyroxene with perhaps some olivine. In Afaiee Creek medium-grained gabbro grades into fine-grained leucogabbro towards the Urere Metamorphics to the south. Considerable difficulty was experienced in distinguishing between the hornfels and doleritic rocks of the Urere Metamorphics and the fine-grained gabbros in the Sisiworo Creek-Boborobo and Foasi River areas.

Coarse-grained pegmatitic gabbro occurs on a minor scale throughout the basic-ultrabasic suite and may be a late stage differentiate. Very irregular in form, it occurs mainly as small dykes, sometimes occupying joint planes, and as patches. These bodies are best exposed at the eastern end of the Didana Range, where they are entirely confined to the peridotite and occur only as small lensing dykes. In Ucku Creek, on the other hand, they are confined to the gabbroic rocks but are very irregularly-shaped small bodies rather than dyke-like in form. The rock consists of feldspar, amphibolite, and pyroxene; the pyroxene is usually euhedral with crystals up to 1 1/2 inches - 2 inches long in a feldspathic mass.

Serpentinization. - Serpentinization is common in some of the basic and ultrabasic rocks in the area. Most of the basic and ultrabasic rocks containing olivine (peridotite, dunite, troctolite, and picrite) are partly or completely serpentinized. Orthopyroxene appears also to be affected. No regular pattern of serpentinization has been observed in the field. Unserpentinized dunites and peridotites occur at the eastern end of the Didana Range, but elsewhere these rocks are usually at least partly serpentinized.

No talc or antigorite has been found in the main ultrabasic belt, although talc schist occurs on the contact with the Goropu Metamorphics in Unido Creek. Small cross-fibre chrysotile veinlets, generally no more than 1 cm. wide, occur sparsely in the serpentinite. Serpentine schist is locally developed by shearing along fault zones.

Structure of Basic-Ultrabasic Belt. - Normal contacts between the basic-ultrabasic belt and the older metamorphics are rarely seen. In two places, however, possible intrusive contacts have been observed. In Unido Creek on the north side of the Goropu Mountains there is a well exposed contact between peridotite and banded biotite schist. The contact is rolling and irregular and marked by strong shearing. The adjacent peridotite is converted to talc schist and the biotite schist to chlorite schist. A few yards upstream there is a 2-foot dyke of sheared talc in the metamorphics. Farther upstream but still along the strike of the main contact another contact is seen between altered basic and ultrabasic rocks and contorted metasediments. A small dyke of basic rock branches from the contact, but is itself very irregular. Nearby, a small composite dyke of microperidotite with a more gabbroic core intrudes the biotite-chlorite schist.

At the head of the Foasi River small ultrabasic dykes intrude the Foasi River Limestone. Most are micaceous, possibly a mica peridotite or lamprophyre. One dyke about 3 feet thick is composite, with a central core of pyroxenite? within micaperidotite. Smaller mica-rich rocks also intrude the Urere Metamorphics near Deune and Namudi. Large bodies of lamprophyre, which are surrounded by the Domara River Beds and probably intrude them, are seen in the Domara River at the southern edge of the area. These mica-rich rocks may be a late lamprophyric stage which post-dates the main ultrabasic intrusives.

The distribution of the rock types of the basic-ultrabasic belt does not conform to any simple pattern. Generally speaking the north side of the valley, i.e. the Sibium and Didana Ranges, is mainly composed of rocks of the gabbroic and transitional groups. The basic rocks are very much more common than the ultrabasic rocks, but nowhere are the latter completely absent. The eastern end of the Didana Range is mainly composed of peridotite and dunite, and at the western end of the Sibium Range there appears to be more ultrabasic rock than basic: in Afaiee and Ido Creeks ultrabasic rocks are overlain by gabbroic rocks which become finer southwards.

On the south side of the valley in the Silimidi area ultrabasic rock crops out, but southwards it is overlain by medium-grained gabbro with occasional ultrabasic bands. West of this, mainly ultrabasics (usually serpentinite) occur in fault contact with the Domara River Beds or the Urere Metamorphics. In the middle and upper reaches of the Foasi River, basic, ultrabasic, and Urere Metamorphic rocks occur together, which suggests that the transitional group intrudes the Metamorphics.

Banding is common in the rocks and is quite regular in some areas. This applies to the southern flank of the eastern end of the Didana Range, where the strike of the banding is consistently north-east with the dip to the south-east. Similarly the southern flank of the Sibium Range in the Afaiee Creek-Musia Creek areas also shows good banding striking eastwards and with a fairly shallow southerly dip. In the extreme west of the area the strike is more north-east, and here the rock relationships seem to be a straightforward transition from ultrabasic rocks above. However, in the eastern Didana Range the reverse relationship is true and gabbroic rocks are overlain by ultrabasic rocks, then by a further zone of transitional rocks with common gabbro, and these in turn are overlain by massive ultrabasics. South of Silimidi the ultrabasics are very well banded with dips ranging up to 60° and striking west to south-west. In Ucku Creek these ultrabasics are overlain by gabbroic rocks, some of which are poorly banded. Elsewhere on the south side banding is absent or very poorly developed. Occasionally the banding is extremely irregular, as for instance south of Mamama, where the dip is usually to the north, but the strike varies through nearly 180° , indicating strong local folding of the banding. This is the only place, apart from just north of Deune, at which northerly dips have been recorded. Elsewhere the dip is south-west to south-east with an average angle of about 30° .

In summary it can be said that there is no simple pattern of distribution of rock types and attitudes of the compositional banding. There is no simple gradation from basal ultrabasic layers to upper gabbroic, but rather several alternations of ultrabasic, transitional, and gabbroic groups. The attitude of the banding, which from its nature must have developed in a sub-horizontal or horizontal attitude from a differentiating primary magma, shows that the rocks must have been considerably tilted and folded since their original accumulation. Much faulting has probably accompanied the movements but lack of marker horizons in the sequence prevents its detection.

Petrography of the Basic-Ultrabasic Suite. - The variation in composition of the rocks of the basic-ultrabasic suite is apparent in hand-specimen examination, and representative rock types have been examined in thin section.

Specimen 96281 (slide no. 2645) is typical of the gabbro group of the suite; it is a microgabbro which in thin section consists of similar proportions of bytownite ($Ab_{20}An_{80}$) and diallage in eutectic intergrowth. A little intergranular yellowish ?serpentine in some

places forms a radiating corona on clinopyroxene grains. The average grain-size of the rock is 0.5 - 1 mm. and opaque oxides are absent. The primary minerals have been altered next to a prehnite veinlet. The texture of the rock is not ophitic.

Another medium to coarse-grained typical gabbro (specimen 96242a, slide no. 2701) consists of about 40% bytownite ($Ab_{25}An_{75}$), 40% pyroxene (augite or diopside), and 20% magnesian olivine, in a eutectic intergrowth of anhedral and subhedral crystals. Some crystals have developed slight strain shadows and some olivine crystals show slight alteration to a green serpentine mineral. The rock is an olivine gabbro.

Specimen 96282 (slide no. 2652) is a gabbroic rock collected from a band within the transitional group of rocks. It consists of an anhedral eutectic intergrowth of about 40% bytownite (a more acid variety, $Ab_{28}An_{72}$), 30% diallage, 20% magnetite, and 10% hypersthene. The diallage is faintly green and the hypersthene pleochroic from pale pink to very pale green. Magnetite occurs as large anhedral crystals, clearly of early magmatic crystallization and containing diallage and bytownite inclusions. The hypersthene occurs as narrow rims around magnetite and clinopyroxene crystals, especially when these two minerals are adjacent, and is clearly of late magmatic crystallization. The rock is a magnetite-hypersthene gabbro; the enrichment in iron in this layer is very striking and points to the operation of the iron-enrichment trend of differentiation in the consolidation of the layered series.

Specimen 96294 (slide no. 2639) is a melanocratic rock occurring with poorly banded, dominantly gabbroic rocks. It is medium to coarse-grained and consists of 45% hypersthene (pleochroic), 25% plagioclase, 15% olivine, and 15% clinopyroxene (?diallage). The texture is anhedral, but the plagioclase tends to occur in the interstices of the ferromagnesian minerals and is probably of later crystallization. Strain effects are common in the crystals and the primary minerals may have been somewhat granulated. The rock is an olivine and diallage-bearing hypersthene norite.

The specimens described above are gabbroic rock types collected from the gabbroic and transitional groups. Within the transitional group a common rock type was classed in the field as picrite and consisted of dominant ferromagnesian minerals with smaller amounts of feldspar. Specimens of this rock type have been examined in thin section. Specimen 96225 (slide no. 2700) consisted of dominant orthopyroxene with subordinate olivine and interstitial plagioclase and amphibole. The orthopyroxene crystals (magnesian variety, not hypersthene) are subhedral and form a crystal aggregate suggestive of settling and accumulation of orthopyroxene and olivine crystals followed by crystallization of interstitial feldspar and amphibolite. The orthopyroxene and olivine are largely serpentinized and the feldspar has altered to very fine-grained material including fine isotropic garnet. The rock may be classed as melanocratic olivine norite approaching a picrite.

Specimen 96293 (slide no. 2642), collected from the southern slopes of the Sibium Range, is medium-grained and although serpentinization has partly obscured primary features, consisted originally of about 65% olivine and orthopyroxene (olivine dominant), about 20% feldspar (bytownite), and 15% diallage in anhedral intergrowth. The minerals tend to cluster: diallage usually is associated with bytownite and both occur in smaller crystals than the olivine and orthopyroxene. Serpentinization is accompanied by part or complete replacement of the feldspar by fine-grained ?vesuvianite. The rock may be classed as a feldspathic peridotite or a picrite.

Specimen 96247 (slide no. 2693) from the southern slopes of the Didana Range is about 40% serpentinized, but primarily consisted of about 40% orthopyroxene, 30% olivine, 20% diallage, and 10% bytownite ($Ab_{15}An_{85}$). The diallage and particularly the bytownite occur interstitially to the orthopyroxene and olivine, and form anhedral irregular plates. The alteration products of the bytownite include, in different cases, prehnite, zoisite, and isotropic garnet. The rock may be classed as a partly serpentinized picrite or feldspathic peridotite.

Specimen 96242b (slide no. 2709) from the north-eastern end of the Didana Range consists of about 50% orthopyroxene, 30% olivine, 15% amphibole, and 5% plagioclase. The orthopyroxene and olivine are partly serpentinized, the amphibole is locally altered, and the feldspar altered to a fine aggregate of secondary minerals. The amphibole is slightly pleochroic and is probably a calcic hornblende. The orthopyroxene and olivine occur as subhedral crystals partly surrounded by and separated by large anhedral plates of amphibole and feldspar - the texture appears to be caused by accumulation of early-formed olivine and orthopyroxene and crystallization of late interstitial fluids to yield hornblende and plagioclase. The rock is a plagioclase and hornblende-bearing peridotite in which orthopyroxene, olivine, hornblende, and plagioclase are of primary crystallization.

Specimen 96291 (slide no. 2653), collected from the southern slopes of the Didana Range, is a typical pyroxenite from the transitional group. The rock is coarse-grained and consists of interlocking crystals of clinopyroxene (diallage) with minor olivine (about 10%) as interstitial crystals and several inclusions within the diallage. The diallage contains many small birefringent lamellae which may be exsolution lamellae of orthopyroxene. Strain effects, particularly in olivine, are locally present. The rock may be classed as an olivine diallagite.

Rocks of the peridotite-dunite group of the basic-ultrabasic belt occur as fragments in the ultrabasic breccias. From thin sections of these breccias it is apparent that the peridotite group consists of magnesian olivine and magnesian orthopyroxene in varying proportions and with local serpentinization of varying extent. Many of the rocks are medium to coarse-grained, but a striking feature of all specimens examined is that strain effects such as undulose extinction, strain banding and lamellae, and bent crystals are well developed in olivine and orthopyroxene. In extreme cases granulation has occurred and elongate, parallel, relict larger crystals become surrounded by granulated, equi-dimensional crystals of the same mineral.

Specimen 200 from Wowo Gap area is typical of these peridotites. The rock is composed of orthopyroxene and olivine crystals in two distinct size ranges: large primary crystals averaging about 2.5 mm. and up to 5 mm. and small secondary crystals from 0.05 to 0.15 mm. forming an equigranular aggregate enclosing the larger crystals. Enstatite, occurring as large primary crystals, has a well developed parting and tiny lamellae which are possibly exsolution lamellae of clinopyroxene. Magnesian olivine occurs in anhedral partly serpentinized grains, which in some areas are strongly granulated. Colourless amphibole and red-brown chrome spinel are uncommon accessories. The rock is an orthopyroxene-rich peridotite (saxonite) which has suffered strong stress; the primary minerals are deformed and granulated.

The above descriptions illustrate the variation in the rock types of the basic-ultrabasic suite. Several thin sections illustrate the mineralogical variation giving rise to the large and small scale banding characteristic of the suite. Specimens 96283, 96245, and

96226 are from the transitional group. Specimen 96283 (slide no. 2646) is a peridotite rock showing bands due to concentrations of pyroxene and olivine varying from 1 cm. to 4 cm. in thickness. The rock consists of serpentinized and partly serpentinized olivine, diallage, minor turbid interstitial material (probably replacing plagioclase), and rare orthopyroxene. In thin section the individual bands vary from diallage olivine (75% olivine, 25% diallage) to olivine diallagite (5% olivine, 90% diallage, 5% interstitial feldspathic material).

Specimen 96245 (slide no. 2695) is an example of interbanded peridotite and gabbroic rock types. The gabbroic rock is a troctolite consisting of about 70% bytownite ($Ab_{23}An_{77}$), 25% olivine partly serpentinized, and 5% diallage. The gabbro layer consists entirely of bytownite with rare pleochroic green hornblende, for 0.5 cm. at the top of the layer (i.e. below the sharp contact with the peridotite) and at the base of this layer is a thin layer of olivine (0.1 cm.). It appears that the topmost part of the troctolite has locally differentiated so that instead of troctolite there is a bytownite layer with a basal thin layer of olivine. The peridotite layer rests very sharply on the feldspar layer, although the contact is irregular and there is no clear evidence of settled euhedral olivine crystals on the gabbroic layer. The basal 1 cm. of the peridotite layer is completely composed of mesh serpentine (after olivine), and the rock was probably a dunite. This passes upwards into serpentinized peridotite consisting of very common bastite pseudomorphs after orthopyroxene and mesh-texture pseudomorphs after olivine. A feature of the bastites is that they contain parallel lamellae and a few larger inclusions of exsolved clinopyroxene.

Specimen 96226 (slide no. 2706) is a very finely banded rock consisting of varying proportions of olivine, diallage, and bytownite ($Ab_{20}An_{80}$). The ferromagnesian-rich bands are from 1 to 5 mm. thick and the feldspathic bands up to 10 mm. thick. No regular, repeated pattern of rock types is evident in the bands. The grain size averages about 0.5 mm. but in some bands is finer, around 0.1 to 0.2 mm. The variation in rock type is shown below:-

| | O - olivine | C - clinopyroxene | B - bytownite. |
|-------------|-------------|-------------------|--|
| Band 1 | 20% O, | 75%C, | 5%B; bytownite - diallage peridotite. |
| Band 2 | 15% O, | 50%C, | 35%B; olivine gabbro. |
| Band 3 | 35% O, | 15%C, | 50%B; diallage troctolite. |
| Band 4 | 15% O, | 15%C, | 70%B; olivine leucogabbro. |
| Band 5 | 5% O, | 10%C, | 85%B; leucogabbro, approaching bytownite rock. |
| Band 6(1mm) | 40% O, | 60%C, | 0%B; diallage peridotite. |
| Band 7 | 17% O, | 40%C, | 45%B; olivine gabbro. |
| Band 8 | 80% O, | 20%C, | 0%B, serpentinized diallage olivine. |

The overall rock composition is probably that of an olivine gabbro.

In summary, the thin-section examinations have shown that the layered rocks of the basic-ultrabasic suite consist of the major constituents olivine, orthopyroxene (enstatite and hypersthene), bytownite, and diallage, with minor primary accessories chromite, magnetite, and amphibole. Stress effects, post-dating crystallization, are well developed and serpentinization has affected the olivine and orthopyroxene-bearing rocks to a varying extent. It is very significant that in all these rocks the serpentinization has produced mesh-texture pseudomorphs after olivine, and bauxite pseudomorphs after orthopyroxene. Random-textured antigorite serpentine has not been observed in any of the rocks described above.

Specimens 96251 (slide no. 2644) from north of Sivia and 96260 (slide no. 2647) are from the pegmatitic gabbro and pyroxenite which occur within the basic-ultrabasic belt, but do not apparently form part of the layered sequence and intrude this sequence in dykes and irregular bodies. Specimen 96251 is an extremely coarse pyroxenite (average grain-size 1.5 - 2 cm.) consisting of anhedral intergrown pyroxene crystals with rare interstitial amphibolite plates and patches of fibrous chlorite. The pyroxene is probably enstatite and the rock a pegmatite enstatolite.

Specimen 96260 was collected from a pegmatitic gabbro dyke intruding peridotite near Wowo Gap. The rock has a pegmatitic grain-size and texture, and crystal outlines of feldspar are common. The feldspar has a large central core of unzoned calcic plagioclase (probably bytownite) surrounded by a very thin rim of strongly zoned sodic plagioclase (probably acid andesine to oligoclase). The sodic feldspar has also veined and partly replaced the calcic feldspar in some crystals. The ferromagnesian minerals include probably at least four types of amphibole, one type surrounding and possibly partially replacing another; they represent successive crystallizations from and reactions with a changing magma. The types include a deep brown pleochroic hornblende and a colourless hornblende (?edenite). The rock probably shows two distinct stages of crystallization:- (1) Magmatic - bytownite + brown hornblende + ?edenite (probably), (2) Hydrothermal (deuteric or late magmatic) - crystallization of oligoclase-andesine and secondary tremolitic amphiboles from interstitial volatile and soda-rich fluids.

Two specimens of the serpentized peridotite intruding the Goropu Metamorphics in Unido and Kovai Creeks have been examined in thin section. Specimen 96238 (slide no 268A) consists predominantly of antigorite in the typical random flake-texture, and lacks included magnetite grains such as generally occur with mesh-textured serpentine. Talc is present along irregular veins and appears to be a later replacement of the antigorite. Small amounts of carbonate are present.

Specimen 96295 (slide no. 2688) also consists dominantly of antigorite, much of which had grown perpendicular to small magnesite-filled cracks. Carbonate also occurs along several shears and forms about 20% of the rock. Anhedral relict chromite occurs but is not common.

These rocks are peridotites which have undergone low-grade metamorphism (usually equivalent to that producing rocks of the albite-epidote amphibolite facies), resulting in replacement of the rocks by antigorite serpentine. The rocks in this respect are sharply distinct from the serpentized peridotites of the basic-ultrabasic suite described previously. From the petrographic evidence it is suggested that these serpentized peridotite bodies within the Goropu Metamorphics are older intrusions, intruded prior to the metamorphism of the Goropu Metamorphics and unrelated to the much later basic-ultrabasic suite of the Papuan Basic-Ultrabasic Belt. If so, serpentized peridotite which makes a sheared intrusive contact with Goropu Metamorphics in Unido Creek (see p.) is the metamorphosed older serpentinite and not the younger layered series. Thus the two suggested intrusive contacts of the basic-ultrabasic suite described above are probably irrelevant to the problem of emplacement of the layered suite, one being a contact of an older unrelated serpentinite and the other a younger biotite-augite lamprophyre (see section on 'lamprophyres') and not a peridotite.

ULTRABASIC BRECCIA

Lithology. A fairly common rock-type within the ultrabasic suite, particularly in the Wowo Gap area, is a breccia consisting of angular fragments of peridotite or dunite or both, in a variable matrix. The breccia shows a continuous gradation. At one extreme it consists of scattered angular fragments of dunite or peridotite (generally 1-3 inches diameter) in a matrix of yellow-green sand-sized olivine crystals; in the matrix, which may form up to 65% of the rock, are scattered larger olivine crystals, rare chromite and possibly pyroxene crystals. At the other extreme the breccia contains much less matrix and size of the fragments varies greatly (up to 3 feet in diameter). Commonly the matrix is formed of yellow-green olivine crystals, but in many places it is a green or pale green-blue amorphous serpentine. There is usually no sign of shearing or directed texture in the serpentine.

Related to the serpentine breccias and probably transitional from them is a breccia, usually with less than 30% matrix, in which the matrix contains a considerable proportion of a white soft mineral, usually amorphous and possibly a carbonate, associated with a pale green serpentinuous mineral. In outcrop this is generally transitional from shattered serpentinized peridotite in which the fragments are generally separated by a thin film of hyalite, much of which has a colloform texture and forms an encrustation on both sides of the creek, leaving a narrow opening between.

Commonly in outcrops there is a complete transition from massive coarsely-jointed ultrabasic through fine-jointed and shattered rock with thin silica films along shatter joints, to a breccia consisting of angular peridotite fragments in a serpentinous matrix. Elsewhere olivine breccia has been serpentinized patchily to serpentine breccia.

In the Wowo Gap area there is a breccia with ultrabasic fragments in a dark-grey, very fine matrix, suggestive of a very fine-grained basic igneous rock. Some of this breccia contains basalt fragments. It forms a body at least 150 feet thick and of considerable extent. Another possibly related type has a brown, rather hard and glassy matrix, apparently non-crystalline and non-granular, which may be chalcedonic silica. In the headwaters of Sivia Creek and elsewhere on the south side of the Didana Range a breccia consisting of gabbro fragments has a grey-white matrix apparently consisting of disaggregated gabbro. The country rock is also gabbro. This breccia, like the ultrabasic breccia, is not sheared, and both may have been formed in the same way.

Distribution. The ultrabasic breccia is most extensive on the slopes of the Didana Range north of Wowo Gap, and at the head of Darumu Creek. It is also found, mostly as the olivine matrix type, as a narrow zone of discontinuous bodies on the southern side of the fault near Silimidi Creek. Serpentine breccia was also observed around Mioki. Between Mioki and Imuruwake small bodies of breccia occur within serpentine, but some of the breccia is probably spread as a sheet similar to the Sivia Breccia. Small bodies have also been observed in Ido Creek in the north-east of the area and in Ucku Creek. Both occur within peridotite.

In detail the outcrops of the breccia are quite irregular. A very few bodies appear linear and dyke-like, and several of these strike at about 20° in the Wowo Gap area. The boundaries are generally gradational. Serpentine schist is not associated with the breccia. Although the bodies may be broadly controlled by major fault-lines, they are not tectonic fault breccias, as shown by their variation in strike, their gradational contacts, and the lack of tectonic deformation effects.

The belt of breccia bodies south of Silimidi could possibly be related to the east-striking late Tertiary or Quaternary fault that downthrows the Domara River Beds against the ultrabasic rocks.

Petrography. The ultrabasic breccias therefore have the two contrasting modes of occurrence - the pipelike occurrence and the sheet breccia of the Sivai Breccia member of the Silimidi Beds. There is considerable variation in lithological character, particularly in the pipe-like type of occurrence. The breccia has been divided into several types; but there is probably no sharp division between them, and all represent varying intensities of the same process.

The percentage of matrix to fragments in these rocks is very variable, and in thin section it is evident that much of the matrix of the hand specimens is actually very fine fragmental material. In all examples the fragments are angular, although in the basalt-peridotite type (see below) some of the larger fragments are slightly rounded and smoothed. Fragments are unsorted and quite clearly there are no shearing effects within the matrix, even when this is of serpentinous material, which is characteristically very susceptible to shearing. On the other hand the deformational effects in the peridotites of the basic-ultrabasic belt are strongly developed in the peridotite fragments of the breccia; this deformation antedated the brecciation and is unrelated to it. Serpentinization, to mesh-texture serpentine or to antigorite, has accompanied brecciation in some places.

(a) Chalcedony type.- Specimens 196 and 201 from the east Didana Range are examples of the chalcedony type of ultrabasic breccia. The rocks are transitional from finely jointed peridotite and contain inter-fragmental dull white material, usually forming less than 30% of the rock. In thin section the fragments are of peridotite in which serpentinization to mesh-texture serpentine is well advanced and, in the smaller fragments, commonly complete. The matrix consists in some areas of extremely fine aggregate chalcedony (0.001 - 0.005 mm.) with wisps, rhombs, and irregular grains (0.001 - 0.02 mm.) of carbonate and accessory flakes and small grains of serpentine. In other cases well developed colloform chalcedony encrusts the fragments.

(b) Serpentine type.- Specimens 4317, 191 and 192 from the east Didana Range are typical of the ultrabasic breccias classed as serpentine breccias. The rocks consist of green-brown peridotite fragments in a blue-green matrix of dull serpentinous material. They are transitional from finely jointed serpentine, and some examples (e.g. specimen 192) appear clearly to be the result of penetration of the serpentinous material along irregular cracks in the peridotite. The fragments are angular, but some larger fragments have smooth margins. Serpentinization of the fragments is very variable and usually results in the formation of yellow-brown mesh-texture serpentine, but locally small fragments are some larger fragments have been altered to antigorite.

The matrix is variable. In some areas it is pale yellow-green and consists of small irregular mesh-texture serpentine fragments (80%) with small patches and irregular veinlets of extremely fine aggregate chalcedony. The aggregate chalcedony also occupies the cores of colloform vugs. In other areas the matrix is a turbid yellow serpentinous material, partly colloform, which seems to be an early stage in invasion and separation of the peridotite fragments. In some cases this material lacks fragments or has 'ghost' fragments, where angular, serpentinized fragments merge into the serpentinous matrix. The material in these matrix area has very low birefringence and a filmy or platy form, and is probably a serpentine mineral.

(c) Quartz type.— Specimen 188b is the only example of this type. The rock consists of about 35% angular fragments in a very fine-grained, hard, grey-white matrix. The fragments are of two main types; firstly, antigorite serpentinite, in clear, colourless fragments containing clustered magnetite grains, and secondly very turbid, semi-opaque serpentinous material, probably of mesh-texture type but partly altered. The matrix consists of a very fine (0.01 - 0.02 mm), very uniform granular aggregate of quartz with small flakes (?fragments) of antigorite and mesh-texture serpentine and granules of magnetite. Small veinlets of quartz with comb-structure, and also vugs, occur commonly marginal to fragments or 'channels' of clear very slightly coarser quartz and probably represent the final channels of the siliceous fluids through the rock.

In the larger antigorite serpentinite fragments the antigorite commonly grows in flakes perpendicular to and centred on the margin of the fragments; the original ultrabasic rock, therefore, must have been first brecciated and then antigoritized.

(d) Peridotite type.— The peridotite type breccia is probably the most common and is found in the centre of many bodies which have serpentine-type and chalcedony-type breccia near the country rock. Specimens 4318 and 212 are typical of this type of breccia.

In specimen 4318 the fragments consist of medium and coarse-grained dunite and peridotite in which the olivine usually shows a slight serpentinization to mesh-texture serpentine along irregular cracks. The growth of antigorite, both as a direct replacement of olivine and, more commonly, as an alteration from mesh-texture serpentine, is very variable and the completeness of antigoritization bears no relation to fragment size. The growth of antigorite post-dates the brecciation, as shown by the flakes of antigorite perpendicular to the margins of the fragments. In specimen 212 the fragments are largely of dunite mylonite and there has been very little serpentinization (to antigorite).

In specimen 4318 the matrix forms about 70% of the rock and contains ?antigorite fragments ranging from 0.1 mm. to sub-microscopic. Interstitially to this very fine material there is cryptocrystalline aggregate material with a refractive index of below 1.54, which is probably chalcedonic silica. Within this also are a few very small carbonate grains. In specimen 212 the olivine fragments range from medium grained to sub-microscopic and the matrix to these fragments varies from turbid-brown, indeterminate material to yellow-brown and colourless, extremely finely granular? chalcedony and serpentine. Small antigorite laths and magnetite grains also occur. In some places the matrix has a colloform habit around fragments and on the margins of the fairly common vugs and veinlets (this colloform material includes the blue-green garnierite observable in hand-specimen lining the vugs.).

(e) Basalt-peridotite type.— This type of breccia is of local occurrence near the bend in the Ibinambo River north of Mapu and possibly marks the centre of most intense activity of the brecciating process. Specimen 188 (1a) is typical of this breccia and specimen 194 is a related type.

Specimen 188 (1a) consists of about 50% matrix (1 mm. or less grain-size) and 50% fragments, among which ultramafic and basalt fragments are dominant. The ultrabasic fragments include the following types:

- (1) Peridotite (rare) showing strain effects and generally partly antigoritized, the antigorite having formed directly from the olivine.
- (2) Very common antigorite serpentinite.
- (3) Common mesh-texture serpentinite showing partial antigoritization.
- (4) Few talc or talc-serpentine fragments.

Basalt constitutes about 35% of the fragments; it is an olivine basalt containing common olivine phenocrysts and smaller clinopyroxene (probably augite, possibly pigeonite) phenocrysts in a groundmass of aligned plagioclase laths (zoned from bytownite $Ab_{21}An_{79}$ to labradorite $Ab_{38}An_{62}$), granular clinopyroxene, magnetite, and areas of colourless isotropic glass. The olivine is more rich in iron than that in the dunites and is partially or completely altered to bowlingite rather than serpentine. Some basalt fragments have a slightly different groundmass: in some this is an opaque or translucent brown ?glass; others contain pyroxene and magnetite microlites. In almost all fragments the feldspar has altered to an extremely fine aggregate material which is also produced by devitrification of the glass - this material is probably a very fine-grained clay mineral.

Other uncommon fragments in the rock include hornblende-feldspar porphyry (the feldspar is andesine, $Ab_{65}An_{35}$) and a related microdiorite. Also there is a fragment of epidote-quartz-tremolite hornfels and a slightly schistose rock consisting of a quartz-sericite-chlorite band in an epidote-chlorite-quartz rock. There are several smaller fragments of finely granular quartz and single crystal fragments of bowlingite (after olivine), clinopyroxene, quartz, magnetite, feldspar, and one crystal of apatite (probably derived from a nearby microdiorite fragment). Single crystal fragments of olivine are common and are unstressed, biaxial (-)ve with a large 2V, and unserpentinized, and commonly have bowlingite rims. They are derived from the basalt and not the peridotite.

Even under 800:1 magnification the matrix is largely fragmental, with bowlingite-olivine, magnetite, and tiny serpentine fragments most common. Areas of fragments of fine aggregate material appear to be the same as the secondary alteration from the feldspar in the basalt fragments and were therefore probably feldspar fragments originally. Colloform chalcedony forms rims to vugs and several veinlets in the rock and several of the vugs are filled with limonite. A small amount of interstitial material throughout the matrix is probably colloform silica.

In specimen 194, 95% of the fragments consist of ultramafic rocks and mainly of antigorite serpentinite. Some fragments were originally of hornblende-feldspar porphyry (as in 188 (1a)), but the feldspar has largely been replaced by a very fine aggregate mineral, considered to be a clay. These hornblende-feldspar porphyry fragments are probably derived from small porphyritic dykes such as intrude the basic-ultrabasic belt in other parts of the area. The matrix of specimen 194 includes very common yellow-orange translucent grains which are probably bowlingite after olivine as in 188 (1a). The breccia occurs as a small irregular body within the ultramafic rocks north of Wowo Gap. It is not part of, but occurs close to, the postulated centre of main activity from which specimen 188 (1a) was collected.

(f) Sheet peridotite breccia. - The specimens described above were all collected from the irregular bodies of breccia occurring within the ultrabasic rocks near Wowo Gap. The contrasting mode of occurrence of the breccia is as conformable sheets (the Sivai Breccia) within the Silimidi Beds. Specimen 96201 was collected from the Sivai Breccia near Silimidi and specimen 96246 from the Sivai Breccia between Sivai and Darumu Creeks.

Specimen 96201 (slide no. 2681) is fairly typical of the sheet breccias and consists of green to green-brown peridotite fragments in a pale yellow-green medium-grained matrix, mainly of olivine crystals. In thin section the rock consists of angular fragments of dunite, peridotite, olivine, orthopyroxene, and rare chromite. Strain shadows are common in the peridotite and several fragments contain shears, antedating brecciation, along which

there has been slight serpentinization. A distinctive feature is the tendency for fragments of the one mineral species to cluster together; this apparent with orthopyroxene and particularly with chromite, both of which are much less abundant in the peridotite fragments than olivine; yet they both occur in clusters of fragments in the matrix. This appears to be the result of local brecciation, wherein one large chromite or orthopyroxene grain has been fragmented, and the fragments have scarcely moved or mixed with surrounding fragments. This feature is inconsistent with sedimentary deposition of the angular fragments, but is consistent with either tectonic or volcanic brecciation.

The matrix of the breccia is variable. Commonly it consists of small serpentine fragments (mesh-texture and bastite) in an extremely fine aggregate of chalcedony. In other areas the fragments are largely unserpentinized olivine, and the matrix (of which there is very little) is turbid yellow-brown material with some patches of aggregate chalcedony. Carbonate (?magnesite) occurs as a crystalline cement and matrix to some areas; its distribution is very patchy. There is no evidence of shearing within the matrix of the rock.

In hand specimen irregular darker 'channels' are evident through the rock. In thin section these are channels and irregular patches in which the chalcedonic intergranular material is a little more common and in which the smaller olivine and orthopyroxene grains have been serpentinized.

Specimen 96246 (slide no. 2705) is very similar to 96201 but differs in that the matrix contains a high proportion of carbonate (?magnesite) as anhedral crystals and patches. In some areas carbonate forms the whole of the matrix, but in others olivine and serpentine fragments and sub-isotropic chalcedony are dominant. The fragments are very slightly serpentinized, to mesh-texture serpentine rather than antigorite.

It is apparent that the sheet breccias are almost identical with the peridotite breccias described previously and the same process of brecciation must explain both types of occurrence. The thin section examination confirms that the sheet breccias are not clastic sediments nor are they produced by tectonic brecciation.

Origin. In all types of the ultrabasic breccia except the basalt-peridotite type, and in both modes of occurrence of the peridotite type, the breccias consist entirely of ultramafic rocks to which have been added water (causing serpentinization), silica (quartz and chalcedony), and carbon dioxide (forming carbonate minerals). The ultramafic rocks are the country rock to the pipe-bodies and their emplacement (before the Domara River Beds) considerably antedates and is unconnected with the formation of the breccia pipes and sheets (after the Domara River Beds, within the Silimidi Beds). The brecciation is not tectonic and not due to erosion and sedimentary deposition, as has been shown by both field and thin section examinations, but rather an invasion and brecciation of the ultramafic country rock by igneous and siliceous fluids.

The irregular breccia pipes and bodies are considered to be of volcanic origin, formed by the passage of volcanic gases (mainly gas-phase water-bearing silica and carbon dioxide) along cracks and joints in peridotite: the cracks were widened and the country rock brecciated to yield the irregular bodies of ultrabasic breccia. The different types of breccia are considered to be due to varying velocities, pressure, and temperature of the gas flow, the basalt-peridotite and peridotite types being due to the most and the chalcedony type to the least intensive activity. Serpentinization to mesh-texture and bastite serpentine accompanied the

less intense phases of activity; antigoritization probably occurred under higher temperature and pressure conditions, and under the most intense activity olivine was stable (e.g., the sheet breccias); but in waning phases, and particularly as the pipes cooled, it was locally altered to talc, antigorite, and mesh-texture serpentine.

The peridotite sheet breccias are considered to represent the overflow and extrusion from one or more centres of moderate to high temperature fluidized ultrabasic breccia formed in the volcanic vents and channels described above. They are thus considered to be a nuee ardente type of deposit. This activity is unconnected with the emplacement of the basic-ultrabasic belt. The occurrence of the basalt-peridotite type of breccia in which the matrix is largely single crystal fragments of basaltic origin indicates that in all probability the gaseous activity was derived from subjacent basaltic magma. The activity probably occurred in Pleistocene to Recent times and may be penecontemporaneous with the activity of the Sesara volcano, from which olivine basalts were extruded.

DIORITE-GRANODIORITE INTRUSIONS.

Small bodies of diorite and granodiorite, intruding the Urere Metamorphics in the Amora Range area, are common and are best seen along the Awala River. The rock types vary considerably, but are mostly medium-grained microdiorites rather than diorites. The rocks consist of hornblende, feldspar, and variable amounts of quartz. Commonly they are porphyritic, the phenocrysts being generally of plagioclase, occasionally of hornblende. In the Awala River the rocks range to a very leucocratic quartz-feldspar-epidote microgranodiorite: the epidote forms 15-25% of the rock. The intrusions are generally small dykes and seem to have no constant trend. In the Liamo area granodiorite dykes become noticeably more dioritic near their contacts, possibly owing to assimilation of the country rock.

Petrography. Specimen 96252 (slide no. 2702) was collected near Liamo as typical of the pyritiferous microdiorite intruding the Urere Metamorphics. The rock is medium-grained, and consists of about 65% plagioclase, 10% biotite, 10% green hornblende, 10% quartz, and accessory magnetite and pyrite. The plagioclase occurs as large tabular crystals with interstitial quartz and is strongly zoned from andesine cores ($Ab_{60}An_{40}$) to oligoclase ($Ab_{82}An_{18}$) rims. The rock is crossed by a vein of anhedral quartz. The rock is an unmetamorphosed quartz microdiorite containing hornblende and biotite.

Specimen 96264 (b) (slide no. 2691) was collected from a very leucocratic epidote-bearing dyke intruding the Amora Conglomerate. The rock is porphyritic, consisting of about 65% feldspar (albite) phenocrysts, 10-15% quartz, 15% patches of fine-grained epidote and chlorite, and 5% euhedral and subhedral pyrite. The minerals are considerably sericitized and altered to fine-grained material. The rock is an epidote-chlorite sodic microgranite approaching an albite microsyenite.

Specimen 96264 (c) (slide no. 2690) was collected from the Awala River as an intrusion of porphyritic microdiorite within the Urere Metamorphics. The rock contains ferromagnesian phenocrysts, probably originally calcic clinopyroxene, pseudomorphed by aggregates of epidote, chlorite, and carbonate. The feldspar phenocrysts are labradorite ($Ab_{35}An_{65}$), although secondary albite also appears to be present, and locally the feldspar is replaced by carbonate. The groundmass (about 40% of the rock) is a granular mosaic of feldspar, quartz, chlorite, and magnetite. The original rock was probably a porphyritic dolerite and in its composition and degree of alteration resembles the porphyritic andesites and the dolerites of the Urere Metamorphics rather than the unmetamorphosed intrusive microdiorite.

A similar rock (specimen 96279, slide no. 2683) collected from a feldspar porphyry within the Urere Metamorphics at the head of the Domara River contains acid labradorite (Ab, An₄₅) and deep green hornblende phenocrysts (partly chloritized), with less common smaller crystals of apatite, sphene, and magnetite. The groundmass consists of anhedral quartz, small feldspar laths, and common chlorite and calcite. The feldspar porphyry seems to be generally andesitic, although the feldspar composition approaches that of the porphyritic dolerite described above; and like it this porphyry may be part of the early phase of andesitic and basaltic intrusives and extrusives of the Urere Metamorphics rather than related to the later, unaltered, microdiorite and related rocks.

HORNBLENDE-FELDSPAR PORPHYRY INTRUSIONS.

Porphyry bodies closely resembling the andesite flows and agglomerate intrude the Urere Metamorphics, the ultrabasic belt, and the Goropu Metamorphics. The intrusions, mostly dykes, commonly occur close to faults. They are found on both sides of the fault between the Goropu and the Urere Metamorphics west of Namudi, and are unsheared and post-date the faulting. They occur in the fault-zone south of Musia, in the fault-zone between the Domara River Beds and the Urere Metamorphics near Miokodi, and similarly between these rock types in the Foasi River. Variation from hornblende-feldspar porphyry to feldspar porphyry occurs quite sharply in the dykes seen in the Moikodi and Foasi River areas.

Small dykes, mostly hornblende porphyry, occur sporadically, intruding the older rocks, but do not appear to be associated with faults.

The porphyry is usually rich in xenoliths, many of which are gabbroic and ultrabasic, the latter apparently being usually recrystallized to hornblendite.

BIOTITE LAMPROPHYRE INTRUSIONS.

Small dykes of a dark porphyritic rock, apparently ultrabasic in composition and containing biotite phenocrysts, occur on the edge of the area in the Domara River. The rocks appear in the hand specimen to be biotite lamprophyres or biotite peridotites. They are unserpentinized. Lamprophyric dykes have also been observed north of Bubudi, in Ikumi Creek, and on the north side of the Amora Range south of Namudi. In the dyke north of Bubudi, however, the phenocrysts are olivine or pyroxene and not biotite. The rocks have been observed to intrude the Urere Metamorphics and the Foasi River Limestone, the basic-ultrabasic belt, and the Domara River Beds: so they are apparently much later than the rocks of the ultrabasic suite.

Petrography. The petrographic examination of the rocks mapped in the field as biotite lamprophyres and biotite peridotites has shown that the two are the same, and quite distinct from the rocks of the basic-ultrabasic suite. Thus the contact between 'biotite peridotite' and the Foasi River Limestone in which the limestone is invaded by a series of thin irregular dykes bears no relation to the basic-ultrabasic belt, and can in no sense be regarded as an intrusive contact between peridotite of the basic-ultrabasic suite and the sediments of the Urere Metamorphics.

Specimen 96285 (slide no. 2682) was collected from a lamprophyric dyke intruding the Urere Metamorphics in Ikumu Creek. The rock is fine-grained (average about 0.1 mm.), and consists of about 35% euhedral augite, 25% of euhedral biotite, and 15% euhedral magnetite, with about 20% euhedral interstitial plagioclase (largely saussuritized) and access-

ory chlorite and ?prehnite. The rock has no directed texture and is not metamorphosed.

Specimen 96280 (slide no. 2651) was collected from the 'biotite peridotite' bodies intruding the Domara River Beds on the southern edge of the area mapped. The rock is very similar to 96285, but contains less biotite, and the augite is less commonly euhedral. Quartz is common as irregular patches enclosing the biotite and augite. Also very common are patches of a green pleochroic fibrous mineral with moderate to high birefringence. This is probably a mica, although its form is more typical of chlorite.

Specimen 96255 (slide no. 2689) was collected from a lamprophyric dyke intruding serpentine. The rock contains about 25% brown biotite laths and 30% subhedral to euhedral clinopyroxene within a mosaic of anhedral albite (35%) with sphene (5%) and interstitial chlorite. The texture and mineral composition suggest two distinct phases of crystallization, the first involving augite and biotite and the second albite and chlorite. Like the specimens described above, the rock is unsheared and unaltered.

STRUCTURE

Folding

The regional structure of eastern Papua and New Guinea broadly appears to consist of a central core of 'Owen Stanley Series' flanked by younger metamorphics - the 'Kaindi Series', 'Urere Metamorphics', etc. Upper Tertiary to Recent rocks overlie these metamorphics. The rocks in the Musa River area generally conform to the west-north-west regional strike. The only exceptions are the Goropu Mountains, which are offset a considerable distance to the north from the Owen Stanley Range, and they appear to form an isolated structure. Mapping of the north and the west sides of the Mountains has revealed this to be either a dome or possibly a broad anticline plunging westwards. Strikes are constant and dips vary from 10° to 75° .

South of Deune the Goropu Metamorphics are highly folded, and the Amora Range is probably an anticline plunging south-east, with the Urere Metamorphics overlying a folded core of Goropu Metamorphics. Elsewhere, structures in the Urere Metamorphics are not obvious owing to the absence of marker horizons and the rarity of reliable dips in the hornfelsed rocks. The occurrence of limestone at the head of the Foasi and Ikumu Rivers and on the north flank of the Amora Range near Moikodi indicates that the anticlinal axis may extend farther south-east. The irregularity of strike and dip on the north side of the Goropu Mountains in the Urere Metamorphics may indicate minor folding against the Goropu block.

The Domara River Beds strike north-west, with dips ranging from horizontal to 65° . On the north side of the valley the beds dip very shallowly south. This may be in part a depositional dip, but is probably mainly due to down-warping and downfaulting of the Musa Valley. On the south side dips are steeper and more varied, and in the Domara River a broad anticline and a syncline are present; but farther west and east the anticline, at least, is faulted. The steeper dips are seen in the Domara River on the southern boundary of the area. Around Imurwake the Beds have a strike of north-west to north-north-west with dips up to 40° south-west.

Younger rocks such as the Silimidi Beds are horizontal. The Sesara Volcanics locally appear to have depositional dips up to $10-15^{\circ}$ and the Waiowa Volcanics have much shallower dips.

Faulting

The Musa Valley area is strongly faulted; most faults were active in recent times.

The faults generally trend west-north-west. Well-developed faulting on both sides of the valley, particularly on the north side, has led to the conclusion that the valley owes its existence in part, at least, to this faulting.

North of Safia on the northern edge of the valley is a well-defined fault trending east-south-east. This continues to approximately north of Obeia, where it may possibly be offset by a north-east-trending fault. It then continues east-south-east, dividing the Silimidi Beds from the Ubo Fonglomerate and Recent deposits. In this area it appears as if the Silimidi Beds have been faulted, in which case the fault is a very recent one; this conclusion may be supported by the excellence of the lineament north of Safia and the fact that on the slopes of the Didana Range there are several terrace levels probably representing rejuvenation of the erosion cycle north of the fault-line. Other faulting on the north side of the valley occurs west of Koira where a north-west-trending fault divides Recent deposits from the Domara River Beds. South of Musia a steeply dipping fault divides the Urere Metamorphics from the Domara River Beds.

On the south side of the Valley major faulting near Namudi separates the Goropu and the Urere Metamorphics. This fault, downthrowing to the north, almost certainly continues along strike and forms the steep front of the Amora Range. Immediately south-east of Moikodi in the Urere River and its tributary, the Urere Metamorphics are in contact with irregularly dipping Domara River Beds, and this contact too is probably faulted and is probably a continuation of the same fault. The fault probably continues in a curving line to the Ikumu and Foasi Rivers. In both these areas fault contacts exist between serpentine and Domara River Beds. In the Foasi River and Avikaro areas the fault appears to be offset to form the steep northern front to the hills at Avikaro. Farther east, south of Silimidi, a major fault exists between the ultra-basic rocks and the Domara River Beds, and has been observed in the Silimidi Gorge to be normal with a dip north of 60° . Smaller-scale faulting occurs in this area around the Adau Gorge; some of these faults are probably younger than the Silimidi Beds, faulting them against the conglomerates of the Domara River Beds.

In the eastern half of the area there are a number of faults trending north-north-east to north and downthrowing to the west. These occur west of Avikaro, between the Domara and Adau Rivers, and west of Silimidi on the south side of the Valley, and east of Fiobobo on the northern side.

Also trending approximately north is the major fault which bounds the Goropu Mountains on the west side. The evidence for this fault lies mainly in the abrupt topographic break and the distinct lineaments on the air photographs. It is not altogether impossible that the Goropu Mountains are displaced from the Owen Stanley Range to the south by a large transcurrent fault with east block moving north, and that this fault forms the western boundary of the Goropu Mountains. There is slight evidence for transcurrent movement in the strike of the banding in the ultrabasics, which appears to swing from east near the Musa Gorge to north-east towards the eastern end of the Didana Range. After slight displacement to the east in the Wowo Gap area this transcurrent fault may continue north to form the eastern boundary of the Didana Range. Strong shearing is developed locally in the ultrabasics in the area. There may be two separate faults since vertical displacement on the north and south sides of Wowo Gap is in opposite senses. If there is only one fault then it must hinge about Wowo Gap.

As mentioned before faulting probably occurs on the north side of the Goropu Mountains. The north side of the Didana Range also presents a steep face suggestive of a faulted front.

GEOLOGICAL HISTORY

The earliest geological event to occur in the Musa Valley area was the deposition of sediments which eventually were transformed to the Goropu Metamorphics. These sediments probably consisted of quartz siltstone, quartz greywacke, shale, and mudstone, with some calcareous quartz sandstone. Bedded calcareous siltstones and possibly marls were also probably deposited. The rocks were strongly folded to produce low-grade regionally metamorphosed quartz-mica phyllites, schists, and epidote metaquartzites. A distinct schistosity characterizes the rocks and complex incompetent folding occurs locally.

After a long period of erosion, more sediments were laid down in the area. They are more variable than those laid down previously, and consist of greywacke conglomerate, greywacke, greywacke siltstone, mudstone, probably some calcareous siltstone, and at least one limestone horizon. The presence of the greywacke conglomerate, with boulders up to 1 foot long, and the limestone suggests a shallow-water environment. Vulcanism was widespread throughout the deposition of the sediments, and vesicular basalts, in some places with pillow structure, are common. The sediments, together with the volcanics, now constitute the Urere Metamorphics. Small dolerite bodies common throughout the sediments are probably related to the basalts, but may represent a later intrusion of dolerite dykes. The rocks have been thermally metamorphosed and locally sheared. Folding along a north-west axis took place at the end of deposition, and though generally only moderately strong it has produced complex minor folding in the Foasi River Limestone. The intrusion of diorite and granodiorite bodies and rocks of the basic-ultrabasic suite followed the folding. The intermediate-acid intrusives may have been responsible for the thermal metamorphism, although the basic-ultrabasic rocks could have contributed. The basic-ultrabasic rocks are layered, and the features of the layering are considered to be due to differentiation in a horizontal position. Since the layering now dips at varying angles, folding followed differentiation. Minor hornblende porphyry intrusions possibly also occurred during the folding of the Urere Metamorphics.

A long period of erosion, which exposed the basic-ultrabasic rocks, followed. A trough, possibly assisted by faulting, was produced roughly along the site of the present Musa Valley but extending farther south. In this trough in Pleistocene times, the Domara River Beds, consisting, for the most part, of greywacke conglomerate and greywacke, were deposited. During the early part of the depositional phase vulcanism was common, and intermediate and basic agglomerates and tuffs were laid down in shallow water and are not interbedded with the conglomerate and greywacke. Andesitic lavas occur near the base in the Awala-Urere River junction area. Deposition of material derived from both north and south sides of the probable lake followed at a rapid rate. The boulder conglomerates suggest valley-fill rather than true lake sedimentation. Sporadic vulcanism, mainly agglomerate, continued throughout sedimentation, and towards the end of deposition several basaltic extrusions occurred.

Broad folding followed the deposition of the Domara River Beds. This was accompanied by strong faulting. Feldspar-hornblende porphyry dykes were in some places intruded, along the fault-zones. Biotite lamprophyres and occasional basic dykes were also intruded at this time or slightly later. The faulting probably produced the Musa Valley more or less as it is today. Shortly after the faulting the sub-horizontal deposits of the Silimidi Beds were laid down, accompanied by much explosive volcanic activity: at least two extrusive sheets of ultrabasic breccia were deposited.

Further faulting in Recent times affected the Silimidi Beds, and possibly about this time vulcanism occurred on the north side of the Sibium Range at Sesara. Very active erosion has continued from the end of deposition of the Silimidi Beds until the present day, as shown by the sequence of unconsolidated fanglomerate rocks deposited at the eastern end of the Musa Valley and on the north side of the Amora Range.

The area is still volcanically active, as shown by the eruptions of Waiowa Volcano in 1943 and 1944.

ECONOMIC GEOLOGY

It is well known that laterites and lateritic soils overlying peridotites and dunite rocks may become enriched in nickel in the lower parts of the soil profile. In Cuba and New Caledonia these soils have been successfully worked for nickel and recently similar deposits have been discovered on the ultrabasic rocks on islands off north-west Dutch New Guinea and in the Cyclops Mountains near Hollandia (Van Nes, 1954). In the Wowo Gap and Silimidi areas J.E. Thompson (1958) obtained positive but sub-economic nickel assays from soils overlying both the sheet peridotite breccia and breccias within the ultrabasic rocks as well as the peridotite-dunite rocks themselves. Garnierite has been observed locally in the matrix of these breccias in slightly weathered near-surface outcrops. As Thompson (1958) stated the soil profiles in this area and the high silica and low iron content do not indicate true laterites, e.g. Wakioko No. 2 at four feet:

| %SiO ₂ | %Fe | %Ni | * |
|-------------------|------|------|---|
| 51.60 | 9.23 | 0.81 | |

as opposed to a lateritic-type soil obtained from Kokoda, for example Kokoda B (3-7 feet):

| %SiO ₂ | %Fe | %Ni | * |
|-------------------|------|------|---|
| 16.54 | 33.9 | 0.45 | |

During the present survey 27 holes were sunk for a total of over 50 samples, a specimen being collected every 5 feet where possible. The holes were sunk by means of a Jarrett hand-auger on 5 feet rods of 3/4 inch pipe. The maximum depth reached was 15 feet, where the compactness of the clays prevented further penetration.

Sampling was confined to the eastern end of the Musa Valley, around Avikaro, Silimidi, Sivai-Darumu Creeks, and Wowo Gap. The hole gave the following figures:

| Depth (feet) | % Ni |
|-----------------|------|
| 1 | 0.82 |
| 5 | 0.96 |
| 10 | 1.06 |
| 13 | 0.92 |

*Both examples from "Report on a Geological Reconnaissance of the Middle Musa Area" by J.E. Thompson. Bur. Min. Resour. Aust. Rec. 1958/24 (unpublished).

In the Darumu Creek-Sivia Creek area the gently undulating sub-horizontal surface on the Silimidi Beds has a rather light vegetation on a soil rich, particularly on the surface, in iron-stone pisolites. In the pisolitic soils in the south-east of this area, the auger penetrated locally up to 8 feet on the sheet breccia and a maximum of 0.56% Ni was recorded. Holes in the Silimidi area gave a maximum of 0.44% Ni, and in the Avikaro area, where soil cover was exceptionally thin (average depth 2-3 feet), the maximum nickel percentage obtained was 0.24. The results obtained, together with the lack of mature surfaces with deep soil cover and the low percentage of dunites and peridotites compared with gabbros, etc., in the basic-ultrabasic belt, indicate the unsuitability of the area for nickeliferous lateritic deposits of economic importance.

All samples were tested by the Department of Lands, Surveys and Mines, Port Moresby.

Disseminated chromite occurs throughout the dunite and peridotite, but no bands or lenses of chromitite were found, although they were expected, particularly in the banded rocks, since bodies of chromite are found in similar layered ultrabasic belts in the Philippines and New Caledonia. Pyrite and minor chalcopyrite, mostly disseminated but occasionally in very small stringers, are common in the more massive rocks of the Goropu Metamorphics and particularly in the Urere Metamorphics. Pyrite is also common in the diorite and granodiorite bodies intruding the Urere Metamorphics, and in some it is introduced into, or concentrated along the contacts of, the Urere Metamorphics by the igneous bodies. In the Foasi River south of Awala, a shear-zone about 80 feet wide between serpentine and fine dolerite or hornfels contains irregular mineralization with pyrite, chalcopyrite, and possibly arsenopyrite, with secondary malachite. Smaller shear-zones with patchy sulphide-rich lenses, usually predominantly pyrite, occur within the Urere Metamorphics, particularly in the Awala River.

In the past small alluvial gold deposits have been worked in the Keveri valley, immediately south of the area mapped at the headwaters of the Adau River. Most of the production occurred between 1904 and 1926, and E.R. Stanley (1923) reports 5903 oz being mined up to 1922. Poor colours have been reported from streams in the Upper Musa and from Busi Creek on the south side of the Didana Range.

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ROCK SPECIMENS WITH MOLLUSCA FROM THE

MUSA VALLEY AREA, PAPUA.

by

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INTRODUCTION

Four rock specimens from the Domara River Beds, Musa River Area, Northern District, Papua (Namo Sheet, New Guinea 1-mile series) were submitted by the Bureau of Mineral Resources for determination of the age and nature of the specimens.

The Domara River Beds have hitherto been regarded as lacustrine and of probable Pleistocene age.

EXAMINATION OF THE SPECIMENS

F 30/59. NAMO Run 3, Photo. 5051, Pt.10.

Grey marl or calcareous mudstone boulder crowded with water-laid worn molluscan shells. These are, so far as can be determined from the poor state of preservation, gastropods of non-marine origin referable to the freshwater genus Cipangopaludina (Family Viviparidae, subfamily Bellamyinae). Cipangopaludina is a Recent genus recorded from South-East Asia, the East Indian archipelago, Philippines, and Japan. It is close to the Australian Notopala, one species of which, N. hanlevi (Frauenfeld), is commonly deposited in large numbers after flooding on the lower reaches of the River Murray.

The microscopic shell structure of the fragments in F 30/59 is close to that of Notopala hanlevi.

F 31/59. NAMO Run 3, Photo. 5051, Pt.10.

Grey marl or calcareous mudstone crowded with worn fragments of (?) Cipangopaludina. A few shells referable to Melanoides are also present.

F 32/59. NAMO Run 3, Photo. 5053, Pt.38.

Fine-grained soft greywacke with abundant small gastropods referable to Melanoides. Melanoides is a freshwater genus, range Paleocene-Recent. Recent distribution in warm waters of South-east Asia and neighbouring islands, North and East Africa.

One specimen of a probable Planorbis (s.l.) disintegrated in the attempt to separate it from the matrix.

F 33/59. NAMO Run 2, Photo. 5011, Pt.8.

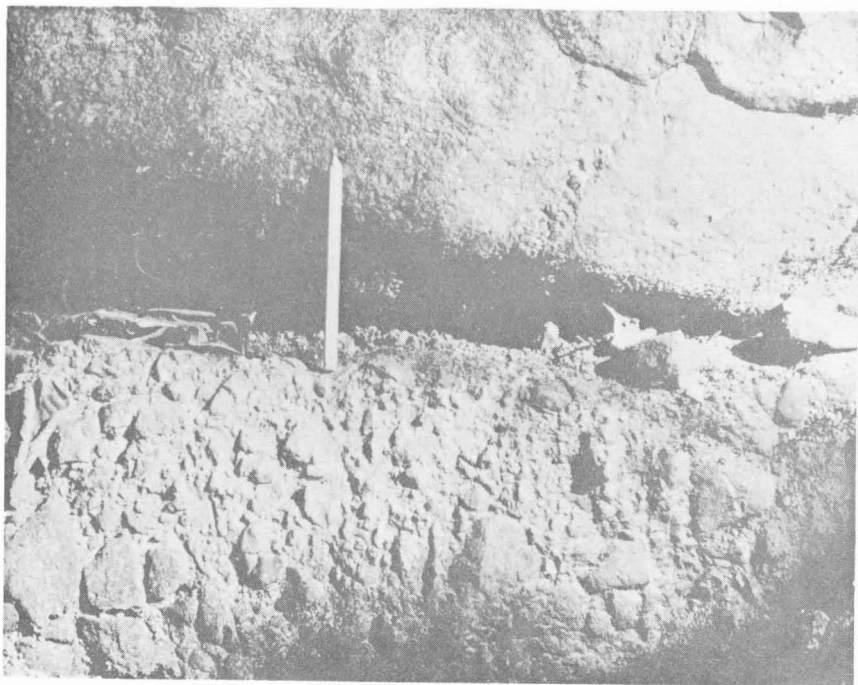
Soft greywacke with abundant remains of small gastropods identified as Melanoides sp.

CONDITIONS OF DEPOSITION

Sedimentation took place in a non-marine environment. this may have been lacustrine or piedmont, determinable by field observations. Greywackes have been recorded (see Twenhofel, 1932, Treatise on Sedimentation, 2nd edition, pp.802-803) as occurring in piedmont deposits. Deposition of the molluscs by flooding would be in accordance with either lacustrine or piedmont sedimentation. All three molluscan genera are found in rivers.

AGE OF THE MATERIAL

The writer has had no previous experience with material of this type from New Guinea, but suggests that the mollusca support the previous view that the deposits are non-marine and of Pleistocene age.



1.

Massive peridotite and peridotite breccia, Wowo Gap.



2.

Looking north into Musa Gorge. Ultrabasics cropping out on right.



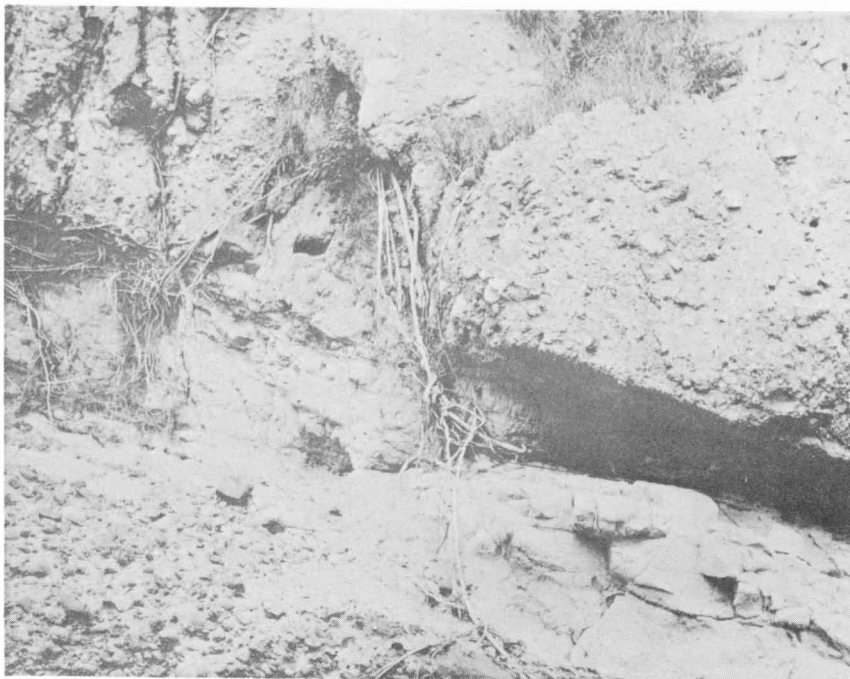
3.

Mt Suckling (11,226ft) from patrol post, Safia.



4.

Dip slopes, Domara River Beds, Musa Gorge.



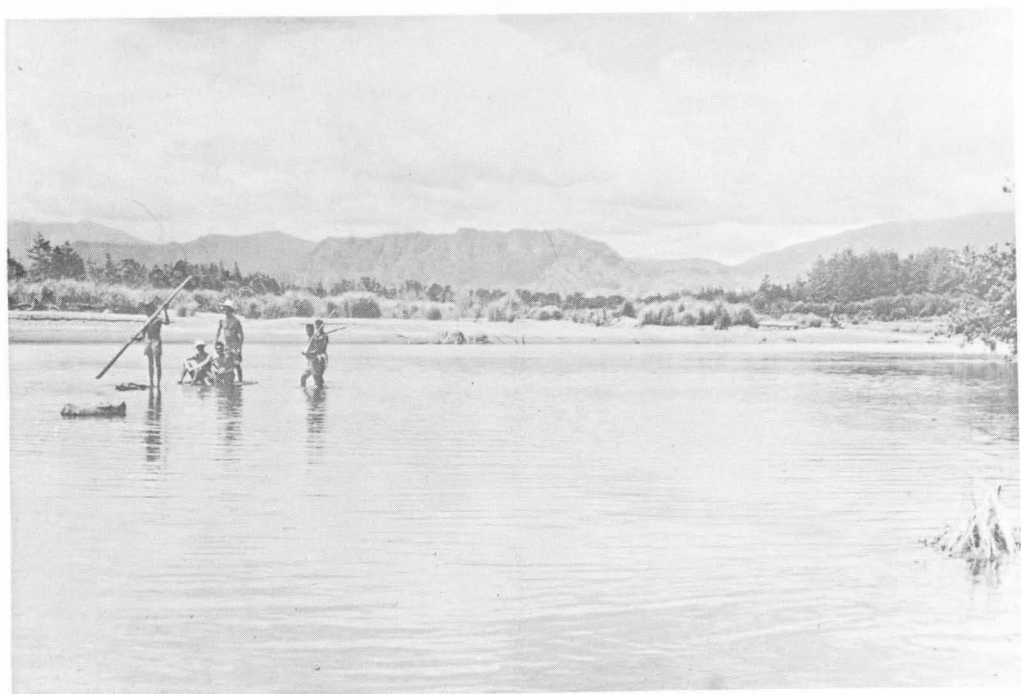
5.

Interbedded conglomerate, greywacke, agglomerate, Domara River Beds.



6.

Boroboro Gorge (Adau R.) area, South side of Musa Valley. Mt. Korioko and Mt. Avurum background.



7.

Adau River. In centre, hills surrounding Boroboro Gorge - composed of conglomerates of the Domara River Beds.

GEOLOGY OF
THE MUSA VALLEY, NORTHERN DISTRICT, PAPUA

Section E-F

Section A-B


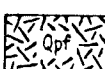
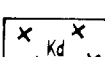
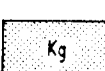
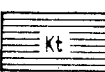

Section I-J

Section C-D

Section G-H

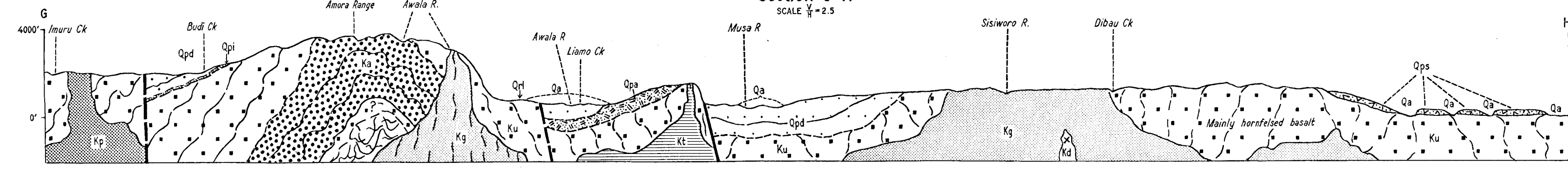
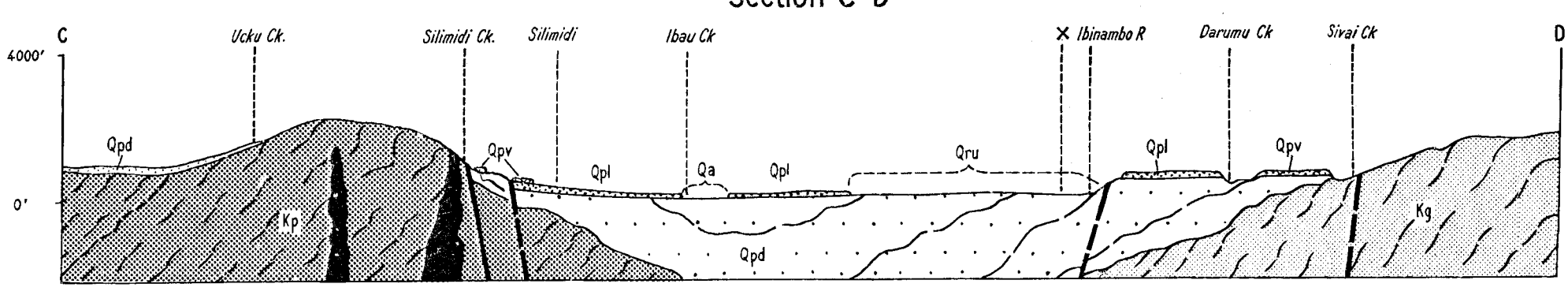
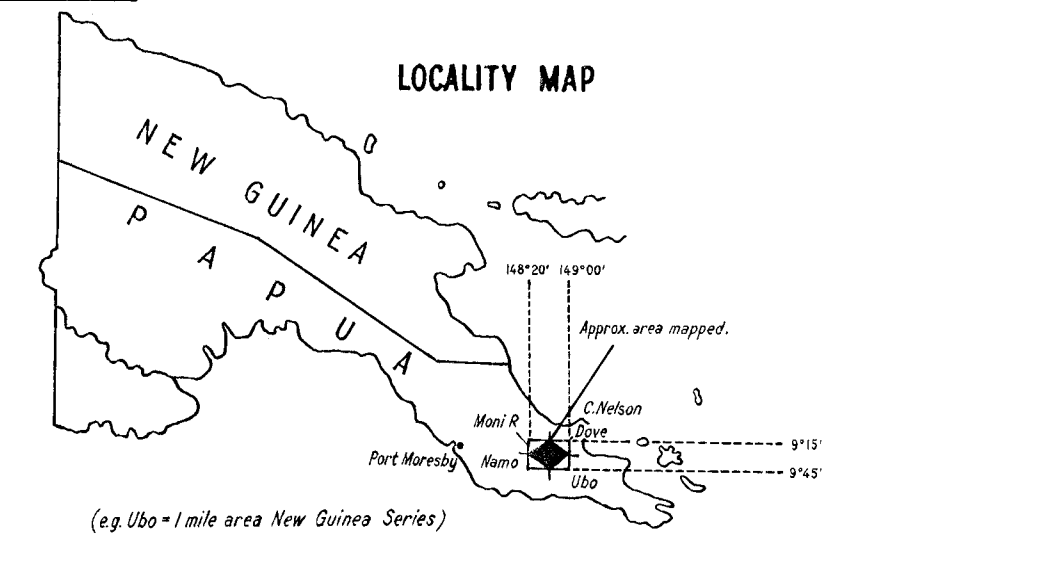
Reference

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|---------------------|-----------------------|--|--|
| CANOZOIC QUATERNARY | RECENT | | Sand, gravel, swamp, etc. |
| | | | Andesitic tuff, agglomerate |
| | | | Unconsolidated boulders |
| | PLEISTOCENE | | Basic lavas, tuff, agglomerate |
| | | | Conglomerate, greywacke, sedimentary breccia |
| | | | Ultrabasic breccia, conglomerate, sedimentary breccia |
| | | | Conglomerate, greywacke, mudstone, siltstone, agglomerate, basic lavas |
| | | | Intermediate-basic agglomerate, tuff, basic lavas, minor sediments |
| | MESOZOIC CRETACEOUS ? | | Horrefied basalt, dacite, agglomerate, siltstone, mudstone |
| | | | Limestone |
| | | | Horrefied conglomerate, minor greywacke, conglomerate |
| PALAEOZOIC ? | Gorapu Metamorphics | | Schist, phyllite |

| INTRUSIVE IGNEOUS ROCKS | | | |
|---------------------------|---|--|-------------------------------------|
| QUATERNARY PLEISTOCENE | { |  | <i>Ultrabasic breccia</i> |
| | |  | <i>Feldspar-hornblende porphyry</i> |
| LATE CRETACEOUS | { |  | <i>Diorite, Granodiorite</i> |
| | |  | <i>Gabbro</i> |
| | |  | <i>Transitional</i> |
| | |  | <i>Peridotite, Dunite</i> |

| | |
|--|---|
| | Strike and dip of bedding |
| | Strike and dip of igneous banding |
| | Strike and dip of jointing |
| | Strike vertical banding |
| | Strike and dip of dyke |
| | Strike and dip of shearing |
| | Strike and dip of bedding, with plunge |
| | Established boundary, position accurate |
| | Established boundary, position approximate |
| | Inferred, probable, or indefinite boundary |
| | Established fault - position accurate, with dip |
| | Established fault, position approximate |
| | Inferred, probable, or indefinite fault |
| | Inferred, probable, or indefinite fault, concealed |
| | Established fault, concealed |
| | Established anticlinal crest - position approximate |
| | Inferred anticlinal crest |
| | Established synclinal trough - position approximate |
| | Lineation |
| | Native track |
| | Native village |
| | Government Rest House |
| | Non-marine fossils |
| | Swamp |
| | Approximate heights (by officers of Department of Native Affairs) |

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