Chief Geologist

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THE GEOLOGY OF THE MUSA RIVER AREA, PAPUA

by

J.W. Smith and D.H. Green.

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CONTENTS

Contents (cont.) Page

SUMMARY

From May to October, 1958, a Bureau of Mineral Resources geological party mapped the Musa Valley area, Papua. This report presents the results of its work with special reference to the Papuan basic-ultrabasic belt and soils overlying the belt as a possible source for nickel.

The oldest rocks in the area, the Goropu Metamorphics, consist of low-grade regionally metamorphosed phyllites, schists, and quartzites. It is considered probable that they are equivalent to the "Owen Stanley Series"*. Unconformably overlying them are the Cretaceous(?) Urere Metamorphics which consist of siltstone, greywacke, greywacke-conglomerate, limestone, basalt, etc., all of which are thermally metamorphosed. Two members have been separated out from the Urere Metamorphics - the Amora Conglomerate and the Foasi River Limestone.

Gently-folded, non-marine Domara River Beds of Pleistocene age occupy very 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 which 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.

Basic-ultrabasic rocks intrude the Urere Metamorphics and represent the south-eastern end of the Papuan basic-ultrabasic belt. The basic-ultrabasic suite, which includes peridotite, dunite, pyroxenite, picrite and gabbro, is differentiated but presents no simple pattern of differentiation. Banding is commonly well-developed and dips up to vertical 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 generally trends east-south-east parallel to the strike of the rocks and the Musa Valley itself is in part a faulted trough. The Goropu Mountains are strongly faulted on the north and west sides.

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

* of (?) Palaeozoic age.

INTRODUCTION

During recent years increasing interest has been focused on laterites and lateritic soils overlying ultrabasic rocks in the Papuan basic-ultrabasic belt, as a possible source for nickel. 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. Subsequent samples collected 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 a Commonwealth Bureau of Mineral Resources party mapped the Musa River area on a regional scale with particular reference to the basic-ultrabasic belt and collected soil samples. The party, consisting of J.W. Smith and D.H. Green, was in the field for twenty weeks from the middle of May to the beginning of October. Initially, and throughout the season, the party was supplied by Anson aircraft of Papuan Air Transport Ltd. operating to a wartime grass-strip existing at Safia. This strip is approximately 800 yards in length and could be extended. A patrol post at Safia was occupied by a patrol officer of the Department of Native Affairs for the duration of the party's presence in the area and 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 labour is therefore not available on a casual basis.

An area of approximately 1200 square miles was mapped, access being mainly by way of the streams and Government or native tracks. The areas concerned - Dove, Ubo, Namo, and Moni River, sheets in the New Guinea 1-mile Series - are covered by vertical aerial photographs taken by Adastra Airways Pty. Ltd. at a scale of 1:48,000. No photo-mosaics were available at the time and the only maps were the 4-mile to 1 inch wartime series which were found to be very inaccurate. 1 mile to 1 inch uncontrolled photo-mosaics prepared by the National Mapping Division, Department of National Development for the plotting of geology, were ready for use early in 1959.

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 situated approximately one hundred miles east of Port Moresby on the northern slopes of the Owen Stanley Range - the central dividing range of Papua. It is possible to split the area 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.

a. 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 in a west-north-west direction 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 Liamo is fanglomerate-covered. 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. This southern fork trends west to west-north-west as a broad topographic low through Moikodi and Liamo to Namudi. Upstream from Deune the valley is no longer a distinct topographic unit. The valley is fault-bounded in a number of places and probably owes its existence primarily to down-faulting of a trough in late Pliocene or Pleistocene times.

b. The Goropu Mountains - the highest point of which is Mt. 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. It is probable that the mountain block is fault-bounded and that the Goropu Mountains owe their existence in part to fault activity. The mountains are precipitous and sharply dissected and the only points of entry are by streams, where waterfalls are quite common. Numerous large landslips have occurred at higher altitudes, especially on the northern faces of the Mountains.

c. 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. (Considerable variation is met with in spelling of these two names; the spelling used on the 40 mile:1 inch New Guinea map is therefore adopted.) The range varies from eight to ten miles in width. At the eastern end the maximum height is approximately 4,000 ft. and the country is sharply dissected. Farther west, near Fiobobo the range is about 1,000 ft. 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 7,164 ft. at Mt. Avinia and is in a youthful stage of dissection. 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, occur within the walls of a large volcanic crater. The crater floor is partly swamp and partly alluvium and is about 800 ft. above the level of the Coastal Plain to the north and east. The rim of the crater varies greatly in height, being highest east of Sesara and lowest west of Aurala and north of Sesara.

d. On the south side of the valley the Owen Stanley Range swings south through Mt. Clarence (6,330 ft) and Mt. Brown (7,950 ft) both of which are just off the area mapped. The foothills of the Owen Stanley Range include two prominent mountains of 3000-4000 ft in the east, Mt. Korioko and Mt. Uvaru, both composed of ultrabasic rocks. In the west the principal feature on the south side of the valley is the Amora Range, approximately 4000 ft high, which is composed of Urere Metamorphics. South of the Amora Range a topographic low near Bubudi and Imuruwake is caused by a downfaulted block of the Domara River Beds. The foothills area of the Owen Stanley generally has a rugged topography with streams and valleys in a youthful stage of erosion.

e. 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 Mts. Victory and Trafalgar. The plain appears to be clearly 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 area 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 to become 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 ft. 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 there is an approach to a local base-level, before the river enters a gorge near Adiobo and Musia. From near Uriobo the river flows E.S.E. through the Musa Valley before entering the Musa Gorge and flowing N.E. 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 200 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 with a deltaic mouth.

The major tributaries of the Musa River drain from the Owen Stanley foothills area into it in the Musa Valley proper. The northern streams are generally shorter and although the Sisiworo is approximately twenty miles long the stream lengths are commonly 4-10 miles long and the volume of water 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 shear faces of up to 1,000 ft. 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 Musa River may rise 3 or 4 ft. in a day. In the upper reaches severe flash floods are common and considerable care must be taken in selection of camp sites. The streams draining the Goropu Mountains are the most dangerous in this respect. Waterfalls and discordant junctions are common features and all the upper reaches of the streams show youthful characteristics.

CLIMATE

New Guinea lies within tropical latitudes and is subject to two seasons - the north-west monsoons which blow from November to April, and the south-east trade winds which blow 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 in. 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 area covering the East Didana Range and Wowo Gap receives a much heavier rainfall than elsewhere. From May to October in the valley itself strong northerly to north-westerly winds blow every afternoon.

It is expected that information on rainfall in the area will improve rapidly. Arrangements for the establishment of rain-gauges at several of the villages, e.g., Obeia and Namudi by Commonwealth Works Department in connection with their river-gauging programme were in hand when the party left the field.

FLORA AND FAUNA

Flora

Most of the area is covered by lowland and mid-mountain forest which varies considerably 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 some of the Domara River Beds. True grassland country occurs in the Musa Valley proper where kunai grass grows up to 10 ft. in height. 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 this could well be alpine environment.

Fauna

Mammal life though fairly common in the area is limited in variety. Wallabies are common in the grasslands where they are hunted by the natives with dogs, spears and nets. Pigs are more widespread but prefer the open forest. Several native possums - cus-cus - were observed. Bird life was more prolific and variable and all types were sought after by the natives for food and ornamentation. Amongst the commonest were cassowaries, hornbills, birds of paradise, (two varieties), parrots, pigeons, including the Gaura pigeon, hawks, ibises, and ducks.

Many snakes were seen during the season, the most common being the python. The largest of these was about 16 feet in length. Crocodiles have been seen and caught in the lower reaches of the Musa and Adau, and fish, principally mullet, bass and eel, are common in all the larger rivers.

PREVIOUS INVESTIGATIONS

Baker (1946) gives descriptions made by local observers of the volcanic activity in 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, Survey and Mines, Port Moresby, paid a brief visit to the Boroboro gorge and Waiowa areas. Subsequently in February 1958 he made a reconnaissance of the Didana Range and Silimidi areas covering approximately 400 square miles. These are the only previous known investigations.

GEOLOGY

METAMORPHIC ROCKS

It has long been recognised that the metamorphic rocks of New Guinea and Papua are capable of sub-division, and A.G. Maitland (1893) made the first attempt. Subsequently E.R. Stanley (1919) divided what he called "the Metamorphic Rocks" into four classes - the "Owen Stanley Series", the "Astrolabe-Kemp-Welch Series", "Crystalline Limestone" and the "Serpentine Series". In his report "The Geology of Papua" (1924) 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 of 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. It can be seen therefore that there is still doubt as to the age and relationships of the metamorphic rocks. In the Musa River area, where it is not possible to fix any definite age relationships, two separate groups of metamorphics exist. The older, the "Goropu Metamorphics", is related to the "Owen Stanley Series". The younger, the Urere Metamorphics, are very tentatively related to the "Kaindi Series" (Fisher 1939) of Cretaceous age. Ostracods were found in the Foasi River Limestone, a member of the Urere Metamorphics, but did not prove diagnostic in age.

GOROPU METAMORPHICS

The Goropu Metamorphics consist of quartz-mica phyllites, quartz-mica schists, chlorite schists, sericite schists and Metaquartzites containing epidote and chlorite. The metamorphics are low-grade regionally metamorphosed rocks possessing strong directed texture, minor folding, and often well-developed schistosity. The typical exposures of the Metamorphics occur in the Kovai 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 fault-bounded on the western and northern margins. Traverses conducted in the Goropu Mountains up the Kovai and Unido Creeks in the north and the Ibinambo R. 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 have the rocks been observed to be cleaved. 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 Deuno. In this area the rocks consist of laminated grey quartz-phyllites, blue grey to greenish calcareous quartz-phyllites with many veinlets of quartz and greenish chlorite, and sericite phyllites. The rocks, which are complexly minor folded, are characterised by their phyllitic nature. They are considered to be low grade regional metamorphics because of their low degree of recrystallisation and their directed texture. Crenulations are common, being especially intense in more calcareous bands. Strikes are extremely varied although minor folds generally plunge at low to moderate angles to the S.E. (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 their lithology, 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. Further 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. As deduced from boulders in the streams (inaccessible in their upper reaches) 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" are generally considered to be Palaeozoic in age.

Petrography

Three thin sections of the Goropu Metamorphics consistently show that these rocks have suffered 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 under these low temperature and strong stress conditions.

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, showing strong directed texture. The quartz occurs in part in comb-structure veinlets, some crystals showing growth stages by concentric hexagonal rows of inclusions. Magnetite is a rare accessory mineral. The rock has suffered low temperature recrystallization 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 but tends to be localized along subparallel movement planes. The distribution of the quartz, sericite and calcite is very patchy but there is no evidence whether this is 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 of 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 clino-pyroxene 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; $Z n c \approx 10^{\circ}$). There is a strong directed texture due to shearing of the rock and it 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 it is suggested was a basalt. The presence of glaucophane, apparently replacing a non-sodic pyroxene, may indicate 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. A hornfelsed greywacke-siltstone or quartz greywacke-siltstone is considered the most common rock type. Slightly coarser phases have the composition of a greywacke but certainly lack the graded bedding and sedimentary structures generally seen in greywackes. Basalt, basaltic agglomerate, greywacke breccia, blue grey and occasionally purple silts (some with slaty parting) are less common hornfelsed rock types. 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 Liamo 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 Metamorphism.

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 epidotised and chloritised, with dolerite and probable basalt are the major rock types in the Urere Metamorphics. Local shearing with the production of well-defined cleavage is common in this area and contacts with the bodies of serpentinite present are generally sheared.

The relationships of the numerous dolerite bodies in the Urere Metamorphics are rather problematical. In the field there is commonly great difficulty in distinguishing between the fine blue-green hornfels and fine blue-grey dolerite. Near Kakasa particularly, medium-grained dolerites are associated with fine basalts with scattered amygdales. The dolerites generally appear to have suffered the same metamorphism, jointing and shearing as the sediments and some are definitely intrusive probably penecontemporaneous 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 basic-ultrabasic suite. Disseminated pyrite occurs fairly commonly and chalcopyrite less commonly throughout the Metamorphics. The diorite and granodiorite also typically contain disseminated pyrite and in some cases sediments adjacent to dykes of these rocks contain small concentrations near the contacts. The pyrite is believed to have been introduced in part at least by the igneous rocks.

Little is known of the regional structure of the Urere Metamorphics due mainly to the scarcity of outcrops in which bedding is visible. As mentioned before 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 latter area the Urere Metamorphics to the north have a low northerly dip in contrast with the steeply-dipping, complexly folded, Goropu Metamorphics to the south. The structure in this area, i.e., the Amora Range, 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 Awala River-Musa River junction and north of Bubudi and Imuruwake. In other areas the contact with the Domara River Beds is faulted as near Moikodi and south of Musia.

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 as opposed to the regional metamorphism of the Goropu Metamorphics and therefore are almost certainly younger. It is possible that they may be related to the ?Cretaceous Kaindi Series which occur adjacent to the Papuan Basin-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 greywacke-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 3,000 ft.

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 Liamo Creek where it appears to have a N.E. 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 a S.E. plunging anticline 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 which shows considerable contortions. Numerous small calcite veins cut the Member. It crops out at the headwaters of the Foasi and Ikumu Rivers and in the latter 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 fact and the limestone's crumpled nature 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 termed hornfels. A number of rocks from the Metamorphics have been examined in thin section and the surprising feature evident from this examination is the high proportion of igneous extrusive and fine intrusive material and the comparative rarity of definite sediments.

Specimen 96269(b) (slide no.2703) was collected near Imuruwake and was unusual in apparently being a laminated phyllite of sedimentary origin amongst crystalline more massive 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 in quartz. The amphibole wisps do not lie in a plane of schistosity but have a tendency to form distinct crenulations. The rock is a greenschist and some stress has probably been active in its slight recrystallization. Its original composition may have been a greywacke-siltstone.

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; $ZnC \approx 23^{\circ}$) 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 (pyroxene + plagioclase → hornblende) and its original crystalline character explains the coarse grain size 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 most common being zoned and twinned plagioclase which is almost invariably pseudomorphed by calcite, sericite and chlorite aggregates. The second type of phenocrysts are 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. The rock could have either been intrusive or extrusive in origin.

Specimen 96265(c) (slide no.2694) was collected adjacent to 96265(b) and in outcrop the rock is distinctly fragmental appearing 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 plagioclase (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 96286 (section 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 comprise 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 there has been no extensive metamorphism of the rock. The rock 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 siltstones. 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 vughs and several small veinlets are filled with a zeolite considered to be chabazite. The groundmass contains small plagioclase (indeterminate) laths, small patches of matted ?sericite wisps, iron ore granules and much very fine, turbid, unidentifiable material (possibly devitrified glass). The hornblende phenocrysts are more abundant than the augite and the latter are generally smaller. Both minerals are definitely primary however and show typical euhedral pyroxene and hornblende crystal forms. The presence of both hornblende and augite phenocrysts is unusual in a volcanic especially as neither show evidence of resorption as 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 ores and 5% sphene. The texture is random but not clastic and feldspar occurs as laths whereas the amphibole, containing sphene inclusions, and associated with chlorite, probably is pseudomorphing pyroxene, possibly titan-augite. The rock has suffered low temperature retrogressive alteration but no extensive metamorphism. The rock thus can be classified as a non-porphyritic pyroxene andesite or microdiorite and the identification of this rock as primarily of igneous origin means in the Didana-Sibium Ranges no definite sediments have been found in the Urere Metamorphics and they 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 amygdales of epidote. The rock has a basaltic texture with albite laths (probably secondary after calcic feldspar) and interstitial epidote, chlorite, iron ore grains and quartz. There are no stress effects evident in the rock and it has suffered low temperature alteration. 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 amygdales 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 dolerite which has suffered only very slight retrogressive alteration.

In summary the thin section examination of the Urere Metamorphics has shown that a large percentage of these rocks consists of volcanic rocks most commonly of andesitic and basaltic character. These rocks have commonly suffered low grade retrogressive alteration under non-stress conditions resulting in breakdown of the 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 agglomerates and tuffs and outpourings of lava flows occurred at several different times during the sedimentation. The Beds crop out on either side of the Musa Valley, particularly on the south side. Outcrops also occur around Imuruwacke 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 5,000 ft. 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 of Pleistocene age and of non-marine environment (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 and often there is a lensing out of greywacke beds. 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 relationships were also observed in several places.

The arenites are poorly sorted and of greywacke to quartz greywacke composition but they do not show typical characteristics, e.g., slump structures, graded bedding, etc. of eugeosynclinal greywackes. Their composition is a reflection of rapid erosion. Carbonised wood fragments up to 3 ft in length have been found in conglomerate and greywacke and it is quite likely that the whole sequence is 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 faulting post-dating the Domara River Beds. Near the southern edge of the area in the Domara River are several basic dykes and medium-grained vesicular basalt 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 basal beds are coarse boulder conglomerate containing mainly basic and ultrabasic boulders. Near the Awala-Musa River junction the Domara River Beds unconformably overlie the Urere Metamorphics and this also occurs near Bubudi in the south-west. 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 with dips ranging up to 65° with an average of 20-25°.

<u>Musa Volcanics Member</u>

The Musa Volcanics consist of at least three beds of basaltic agglomerate, of 15-30 ft(+) thickness with interbedded greywacke, possibly tuffaceous, and greywacke-conglomerate. Below the lowest band of agglomerate is a conglomerate band and though the actual contact is not exposed it is probable that this conglomerate lies basally on the basic-ultrabasic rocks. The extent of the volcanics is not known accurately: westwards they lens out to the east of Beroma Creek; eastwards agglomerate was observed as boulders in a creek north of Obeia but none were seen in Lorupu Creek a little further 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 felspar porphyry with weathered-out ferromagnesian phenocrysts. This is probably an andesitic flow although contacts are not evident and it may be an intrusion. This is overlain by a coarse, poorly-bedded boulder conglomerate and above this are massive hornblende-felspar porphyritic andesitic volcanics consisting of lava and some agglomerate. This horizon is probably about 1,000 ft above the unconformity but the sediments below, for the most part, seem to have a volcanic influence from the base upwards 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 ft. and below it the conglomerate and sedimentary breccia is of similar thickness. The agglomerate is andesitic in composition and contains angular boulders up to 4 ft in diameter. The agglomerate is overlain by greywacke-conglomerate and sandstone (approximately 50 ft thick) and then by a bed of andesitic agglomerate (80 ft) and by pebbly sandstone and conglomerate.

South-east of this area and east of Bubudi andesitic agglomerate and hornblende-felspar 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 type 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 to a volcanic vent. The presence of a roughly circular topographic feature in the area may be the vent which supplied the Bubudi 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 Bubudi, and from the northern side of a circular body of andesitic volcanics (including lava blocks in lava) considered to be the vent for the lavas and agglomerates (Imuru Volcanics) at the base of the Domara River Beds in this area. In thin section it can be seen that the rock consisted of tabular plagioclase (andesine Ab_{65} An_{35}) 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 has suffered strong low temperature alteration with the feldspar being 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) and has suffered low temperature retrogressive alteration, possibly with metasomatism. These effects could be due to fumarolic activity since the rock is believed to be adjacent to the andesitic vent.

THE SILIMIDI BEDS

The Silimidi Beds consist of a horizontal to subhorizontal 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 Sivai 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 gently ($<4^{\circ}$) southwestwards towards the Musa Valley. It is dissected by Darumu 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. Originally the Beds probably covered the whole of the eastern part of the valley 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 contains both sedimentary and ultrabasic breccias.

The conglomerate consists largely of boulders of the basic-ultrabasic suite. This is particularly the case 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 directly 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 occurred causing 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, unserpentinised in some cases, in a matrix of fine to medium-grained yellow-green glassy olivine crystals with rare chromite and possible pyroxene crystals. The ratio of matrix to fragments is variable, some outcrops being 60-65% matrix and others only about 35% matrix. The size range of the fragments is variable but in these sheet breccias 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 ft thick and overlain by about 50 ft of conglomerate, mainly of ultrabasic and basic boulders, and lesser greywackes, and then by a further 30 ft of peridotite breccia. This lies very near to the sub-horizontal topographic surface but is overlain by patches of sedimentary conglomerate and sedimentary breccia which are in some cases 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 ft.

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 fact that the bottom-most beds of the Silimidi Beds and the topmost of the Domara River Beds are lithologically similar makes the unconformity hard to distinguish. South of Silimidi the lower peridotite breccia caps a prominent hill which is composed 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 about 80-120 ft thick and is overlain by 20 ft + of sedimentary breccia and greywacke conglomerate and then by a further peridotite breccia horizon about 15-20 ft 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 was well exposed and is gradational; at the top of the upper breccia horizon 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" 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 a sedimentary sequence with a greywacke conformably overlying it. Thin section descriptions of the Sivai Breccia are described under Igneous Rocks, Ultrabasic Breccia.

FANGLOMERATE DEPOSITS

Ubo Fanglomerate

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. The boulders range from 3-5 ft in length but may often exceed this. 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 conglomerates, 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 measures approximately 4 x 6 miles. 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 topographic high 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 basalts, agglomerates, tuffs 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 in overall composition the rock would approach being ultrabasic. The sediments crop out principally on the eastern side of the cone near Korala. In this area the rocks include a soft yellow-brown ?siltstone containing ellipsoidal and rounded bodies generally $\frac{1}{4}$" to $\frac{1}{2}$" long consisting of a white calcite rim and a core of green crystalline epidote. The enclosing rock has the appearance of a sediment though the ellipsoidal bodies are more suggestive of amygdales.

A small area of outcrop of agglomerate and some lava between Korala and Kakasa overlies the Urere Metamorphics and might be a separate vent. The rock types are identical to 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. An area of basaltic agglomerate crops out around Guara Creek. The latter 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 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 averaging about 0.3 mm. grain-size but occurring up to 1 cm. long, and also very common phenocrysts of clinopyroxene but averaging about 1 mm. up 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 $2V \gtrsim 90^\circ$; it is zoned in some crystals and invariably rimmed by or altered to bowlingite. The clinopyroxene is probably augite and it is colourless, biaxial (+)ve with $2V \gtrsim 45^\circ$. The rock is a typical olivine basalt and shows very great similarity in composition and texture to the olivine basalt fragments occurring in the peridotite-basalt breccia of Wowo Gap.

Specimen 96257(c) is unusual in containing a very 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 $2V \gtrsim 90^\circ$ but does not show any alteration to bowlingite. The clinopyroxene is pale green, faintly pleochroic, biaxial (+)ve, $2V \gtrsim 50^\circ$ and Z c$\gtrsim 48^\circ$, and is probably augite, possibly slightly sodic as suggested by the colour. Zoning is very common in the augite and shown 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 distinct from basalts of the Urere Metamorphics in their fresh, unaltered character and the percentage of olivine present.

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 occurs on the eastern edge of the area mapped. Waiowa volcano now has a crater-lake approximately 600 ft. across and the crater rim is about 75 ft. 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 agglomerates and occasional tuffs. The agglomerate boulders range up to 2 ft. in size but appear to be slightly smaller towards the edge of the area of main outcrop. Quartz fragments, occasionally found, are only of pebble size. Epidote-rich probable basaltic fragments were found near the vent: Baker (1946) reported the discovery, near the vent,   of two ejected pebbles of serpentinized pyroxenite indicating continuation east of the ultrabasic belt. The tuffs, which are normally very coarse-grained, are usually seen some distance from the cone. Both tuff and agglomerate contain occasional hornblende, biotite and augite phenocrysts. The area of devastation of vegetation, which can be clearly seen on the photographs, has a maximum spread of 3 miles. 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 aerial photographs just to the north of the present cone suggests that this 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 Mt. Trafalgar and Mt. Victory which form the high standing country of Cape Nelson to the north. The south-western slopes of these volcanoes occur within the D ve 1-mile sheet and may consist of flows.

Petrography. Specimen 96288 (slide no.2685) is a pale grey fine-grained rock containing a few ferromagnesian phenocrysts and scattered xenoliths and is a boulder collected from agglomerate approximately one 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 rock and this and the biotite phenocrysts particularly, show evidence of reaction with and reabsorption into the groundmass. The unstable biotite alters to clusters of magnetite crystals in some cases 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 and it is possible that a major control is the percentage of volatiles present.

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 in mineral composition it shows close affinities 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 since 1917 at least. 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 the fact that the ultrabasic rocks form a discontinuous belt. J.E. Thompson, Senior Geologist, Department of Lands, Surveys and Mines, has carried out reconnaissance mapping of the ultrabasic rocks in the Waria River Valley, Kokoda and Musa River valley areas. H.L. Davies also of the Department of Lands, Surveys and Mines, Port Moresby, has worked in the Ajura Kajura Mountains in the Kokoda area and more detailed work and soil sampling was done in this area by him in 1957 and 1958.

The Papuan basic-ultrabasic belt is approximately 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-west 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 further 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 due to 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 south side of the valley the basic-ultrabasic rocks are discontinuous due mainly to the covering Domara River Beds. No 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 rocks and, thirdly, 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, with some tendency for the pyroxene crystal to grow across the vein.

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" in length. In many cases the crystals have been observed to be bent, with distinctly curved cleavage faces. The crystals may be intergrown and cut across each other and there is usually a considerable size range of crystals 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. However, in Afaioe Creek the pyroxenite grades into a very coarse pegmatitic gabbro containing euhedral pyroxenes in a felspathic 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 group occur mainly on the north side of the valley in the Sibium and west Didana Ranges. Here they are very closely related and may in fact be equivalent due to the lensing out of ultrabasic bands.

The transitional group consists of a banded sequence of both basic and ultrabasic rocks in similar proportions. The banding is variable and in some cases is simply rhythmical banding in gabbro and olivine gabbro in which there is a concentration of ferromagnesian minerals at the base of each band (generally 6"-12" thick). Probably the next most common rock type is an ultrabasic picrite composed of pyroxene, some olivine and a little felspar. The pyroxene, probably orthopyroxene, occurs as very large crystals up to 1" in length poikilitically enclosing many small grains of olivine. The olivine, and probably also the pyroxene, are commonly serpentinised. Interstitial to the ferromagnesian minerals is a small though varying amount of white felspathic material. Though probably originally felspar this is now dull white in colour, the felspars having been saussuritized. Banding in the picrite is very variable and is due mainly to the variation in grain size of the orthopyroxenes and also to the variation in the felspar percentage. The picrites, as do the other ultrabasic rocks, occur as bands within the gabbroic rocks. These bands, which range from 3" to probably several hundred feet, are best seen in the Ido Creek-Musia Creek areas. None has been seen on the south side of the valley. Less commonly on the north side troctolitic rocks composed of felspar and serpentinised olivine occur, sometimes as bands within the gabbroic rocks but also occasionally as a gradational rock between gabbro and thin bands of serpentinised peridotite. The latter rock, which may range to dunite, has been observed interbanded with clinopyroxenite on a small scale over thicknesses up to 20 ft. The contact between the two rocks is usually sharp.

Occasional bands of gabbro contain very low percentages of ferromagnesian minerals and approach anorthosites in composition. No outcrops or derived boulders of chromitite or interbanded chromitite and peridotite have been observed in either the ultrabasic or transitional rocks though these 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 due to differing percentages of felspathic and ferromagnesian minerals and sometimes the banding is rhythmic. More commonly however the rock is uniform. It is usually fine to medium grained and equigranular, and consists largely of felspar and pyroxene with perhaps some olivine. In Afaice 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. However, in Ucku Creek they are confined to the gabbroic rocks but are very irregularly-shaped small bodies rather than dyke-like in form. The rock consists of felspar, amphibole and pyroxene, the latter usually being euhedral with crystals up to 1½"-2" long in a felspathic mass.

Serpentinisation

Serpentinisation is a common feature of 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 serpentinised. Orthopyroxene appears also to be affected. No regular pattern of serpentinisation has been observed in the field. Unserpentinised dunites and peridotites occur at the eastern end of the Didana Range but elsewhere these rocks are usually at least partly serpentinised.

No talc or crystalline, antigorite serpentinite 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 uncommonly 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. Adjacent to the contact the peridotite is converted to talc schist and the biotite schist to chlorite schist. A few yards upstream there is a 2 ft. dyke of sheared talc in the metamorphics. Further 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. In the vicinity of small composite dyke of mica peridotite 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. They are usually micaceous, possibly a mica peridotite or lamprophyre. One dyke of approximately 3 ft. thickness is composite with a central core of pyroxenite? within mica-peridotite. Smaller dykes of similar mica-rich rocks also occur intruding the Urere Metamorphics near Deune and Namudi. Larger 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 lamphophyric 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. This is so in Afaiee and Ido Creeks where 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 they are 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-upper reaches of the Foasi River basic, ultrabasic, and Urere Metamorphic rocks occur together suggesting that the transitional group intrudes the Metamorphics.

Banding is quite 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 on occasions striking eastwards and with 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 simple straightforward transition from ultrabasic rocks below to basic 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 which are sometimes 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 there appears to be 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 there must have been considerable tilting and folding of the rocks since their original accumulation. It is very probable that much faulting has accompanied this but with lack of marker horizons in the sequence this remains undetected.

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

Specimen 96281 (slide no.2645) is typical of the gabbro group of the suite and is a microgabbro which in thin section consists of similar proportions of bytownite (Ab_{20} An_{80}) and diallage in eutectic intergrowth. There is a small amount of intergranular yellowish ?serpentine and in some places this forms a radiating corona on clinopyroxene grains. The average grain-size of the rock is 0.5 - 1 mm. and opaque oxides are absent. Alteration of the primary minerals has occurred adjacent to a prehnite veinlet. The texture of the rock is not ophitic as in dolerites.

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 slight strain shadows developed 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 in colour 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 and 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 approximately of 45% hypersthene (pleochroic), 25% plagioclase, 15% olivine and 15% clinopyroxene (?diallage). The texture is anhedral but the plagioclase tends to occur interstitially to the ferromagnesian minerals and is probably of later crystallization than these. Strain effects are common in the crystals and there has possibly been some granulation of the primary minerals. 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) have subhedral form and form a crystal aggregate suggestive of settling and accumulation of orthopyroxene and olivine crystals followed by crystallizations of interstitial feldspar and amphibole. The orthopyroxene and olivine are largely serpentinized and accompanying this process the feldspar has altered to very fine-grained material including fine, isotropic garnet. The rock may be classed as a feldspar - poor, 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. There is a tendency for clustering of the minerals, diallage usually being associated with bytownite and both occurring in smaller crystals than the olivine and orthopyroxene. Accompanying serpentinisation the feldspar shows partial or complete replacement 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% serpentinised 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 serpentinised picrite or felspathic peridotite.

Specimen 96242 (b) (slide no.2709) from the north eastern end of the Didana Range consists of about 50% orthopyroxene, 30% olivine, 15% amphibole and 5% plagioclase. There is partial serpentinisation of the orthopyroxene and olivine, 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 in subhedral crystals partly surrounded by and separated by large anhedral interstitial 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 consisting of interlocking crystals of clinopyroxene (diallage) with minor (about 10%) olivine 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 an olivine diallagite.

Rocks of the peridotite-dunite group of the basic abasic 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 about 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, equidimensional 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 (biaxial (+)ve 2V .65°) occurring as large primary crystals has a well developed parting and tiny lamellae which are possibly exsolution lamellae of clinopyroxene. Magnesian olivine (biaxial (+)ve 2V large) 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 with deformation and granulation of the primary minerals.

The above descriptions illustrate the variation in the rock types of the basic ultra-basic suite. Several thin sections illustrate the mineralogical variation giving rise to the large and small scale banding characteristic of the suite. Specimen 96283 (slide no.2646) is a peridotite rock showing bands due to concentrations of pyroxene and olivine varying from 1 cm. to 4 cms. in thickness. The rock consists of serpentinised and partly serpentinised olivine, diallage, minor turbid interstitial material (probably replacing plagioclase) and rare orthopyroxene. In thin section the individual bands vary from diallage olivinite (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 serpentinised) 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 (0.1 cm.) layer of olivine. 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 texture serpentine (i.e. 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 - 5 mm. thick and the feldspathic bands up to 10 mm. thick. There is no regular, repeated pattern of rock types evident in the bands. The grain size averages about 0.5 mm. but in some bands is finer, around 0.1 - 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	15% O, 40%C, 45%B;	olivine gabbro.
Band 8	80% O, 20%C, 0%B;	serpentinized diallage olivinite.

The overall rock composition is probably that of an olivine gabbro but crystallization during gravitational differentiation has resulted in the separation into the layers of varying composition.

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. The layering is caused by rapidly varying differences in the percentages of the major constituents and has its origin in crystal settlings and accumulation during crystallization under gravity of a magma which may have been basaltic in composition or may have been even more basic. 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 serpentine pseudomorphs after olivine and bauxite pseudomorphs after orthopyroxene. Random-textured antigorite serpentinite has not been observed in any of the rocks described above.

Specimens 96251 (slide no.2644) 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 (average grainsize 1.5 - 2 cms.) pyroxenite consisting of anhedral intergrown pyroxene crystals with rare interstitial amphibole 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 4 types of amphibole, one type surrounding and possibly partially replacing the other, and representing 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 serpentinized 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 flare-texture and lacking included magnetite grains such as occur with mesh-texture serpentine usually. 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 which in many cases has grown perpendicular to small carbonate (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 serpentinized peridotites which have suffered 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 serpentinized peridotites of the ultrabasic-basic suite described previously. From the petrographic evidence it is suggested that these serpentinized 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. This observation has importance in that the sheared intrusive contact between serpentinized peridotite and Gorupu Metamorphics, in Unido Creek, which has been described above is between 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 and/or dunite in a variable matrix. The breccia shows a continuous gradation in type. 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 are scattered larger olivine crystals, rare chromite and possibly pyroxene crystals. The matrix in extreme cases forms up to 65% of the rock. At the other extreme the breccia contains much less matrix and the fragments are of very irregular size (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 appearing non-crystalline and possibly a carbonate, associated with a pale green serpentinous mineral. In outcrop this is usually transitional from shattered serpentinised peridotite in which the fragments are generally separated by a thin film of hyalite. In many cases the hyalite has a colloform texture and forms an encrustation on both sides of the crack 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 serpentine breccia occurs patchily in olivine breccia suggesting serpentinisation of this 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 ft. 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 Sivai 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. As with the ultrabasic breccia there is no shearing and the rock may have the same genesis as the ultrabasic breccia.

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 Sivai 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. Very occasionally the body appears linear and dyke-like and several of these strike at about 20° east of north in the Wowo Gap area. Usually the boundaries are gradational. Serpentine schist does not occur 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 deformational effects.

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

Petrography of the Ultrabasic Breccias. The ultrabasic breccias have two contrasting modes of occurrence as discussed previously and also show considerable variation in lithological character, particularly in the pipe-like type of occurrence.

The breccia has been divided into several types though it must be emphasized that there is probably no sharp division between these types 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 very angular although in the basalt-peridotite type (see below) there may be a low degree of rounding and smoothing of the larger fragments. There is no sorting of fragments 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 deformational effects as described previously in the peridotites of the basic-ultrabasic belt are strongly developed in the peridotite fragments of the breccia and quite clearly this deformation pre-dated the brecciation and is considered to be unrelated to it. Serpentinization, in some cases to mesh-texture serpentine and in other cases to antigorite, has accompanied brecciation in some examples.

(a) <u>Chalcedony-type</u>: Specimens 196 and 201 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 $<30\%$ 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- 0.002 mm.) of carbonate and accessory flakes and small grains of serpentine. In other cases colloform texture in chalcedony is well developed encrusting the fragments.

(b) <u>Serpentine-type</u>: Specimens 4317, 191 and 192 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. The rocks 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 very angular but larger fragments may 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 and some larger fragments have been altered to antigorite.

The matrix is variable. In some areas it is pale yellow-green in colour and consists of about 80% small, irregular mesh-texture serpentine fragments with small patches and irregular veinlets of extremely fine aggregate chalcedony. The aggregate chalcedony also occupies the cores of colloform vughs. In other areas the matrix is a turbid, yellow serpentinous material which may exhibit colloform structure and 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 areas has very low birefringence, 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. There are several small veinlets of quartz with comb-structure and also several vughs. These occurrences are commonly marginal to fragments or "channels" of clear, very slightly coarser quartz through the rock and probably represent the final channels of the siliceous fluids through the rock.

In the larger antigorite serpentinite fragments the antigorite commonly grows in flares perpendicular to and centred on the margin of the fragment. This shows that the antigoritization occurred after the brecciation of the original ultrabasic rock.

(d) Peridotite Type: The peridotite type breccia is probably the most common type and commonly is found in the centre of bodies which have serpentine-type and chalcedony-type breccia nearer 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 slight serpentinization to mesh-texture serpentine along irregular cracks. The growth of antigorite, both as a direct replacement of olivine or 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 growth of the flares 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 R.I. $<$ 1.54 and which is probably chalcedonic silica. Within this also are a few very small carbonate grains. In specimen 212 the olivine fragments range in size 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 vughs and veinlets (this colloform material includes the blue-green garnierite observable in hand specimen lining the vughs).

(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 dominent. The ultramafic 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 comprises about 35% of the fragments. The basalt 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 iron rich (biaxial (-)ve, 2V large) than that in the dunites and shows partial or complete alteration to bowlingite rather than serpentine. Some basalt fragments have slightly different groundmass, in some this is an opaque or translucent brown ?glass while others have 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 (feldspar 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 (derived from a nearby microdiorite fragment probably). Single crystal fragments of olivine are common and are unstressed, biaxial (-)ve with a large 2V, 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 being most common. Areas or fragments of fine aggregate material appear to be the same as the secondary alteration from the feldspar in the basalt fragments and these also were probably feldspar fragments originally. Colloform chalcedony forms rims to vughs and several veinlets in the rock and several of the vughs are limonite-filled. Colloform silica is probably present as a small amount of interstitial material throughout the matrix.

In specimen 194 95% of the fragments consist of ultramafic rocks and mainly of antigorite serpentinite. There are a number of fragments which originally were of hornblende-feldspar porphyry (as in 188(1a)) but in those the feldspar has largely been replaced by a very fine aggregate mineral, considered to be a clay mineral. These hornblende-feldspar porphyry fragments are probably derived from small porphyritic dykes such as occur intruding 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 occurrence of the breccia body is 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 extremely angular fragments of dunite, peridotite, olivine, orthopyroxene and rare chromite. Strain shadows are common in the peridotite and several fragments contain shears, pre-dating brecciation, and along these there has been slight serpentinization. A distinctive feature is the tendency for fragments of the one mineral species to cluster together; this is 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 and one large chromite or orthopyroxene grain has been fragmented and the fragments have undergone only limited movement and mixing 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 (mesh-texture and bastite) fragments 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 present within the matrix of the rock.

In hand specimen there are irregular darker "channels" evident through the rock. In thin section these are channels and irregular patches in which the chalcedonic intergranular material is a little more commom 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. There is very slight serpentinization of the fragments and this is to mesh-texture serpentine rather than antigorite.

In summary it is apparent that the sheet breccias are almost identical to 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.

Summary and Origin of the Ultrabasic Breccias

In all types of the ultrabasic breccia except the basalt-peridotite type and in both modes of occurrence of the peridotite breccia, 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 (pre-Domara River Beds) considerably pre-dates and is unconnected with the formation of the breccia pipes and sheets (post-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 with widening of the cracks and brecciation of the country rock 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 intense activity and the chalcedony type the least intense activity. Serpentinization to mesh texture and bastite serpentine accompanied the less intense phases of activity; antigoritization occurred under higher temperature and pressure conditions probably and under the most intense conditions olivine was stable (e.g., the sheet breccias) but in waning phases and cooling of the pipes particularly alteration to talc, antigorite and mesh-texture serpentine occurred locally.

It is considered that the peridotite sheet breccias 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 nuée ardente type of deposit. It is emphasized that 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 sub-jacent 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 show considerable variation but are mostly medium-grained microdiorites rather than diorites. The rocks consist of hornblende, felspar 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-felspar-epidote microgranodiorite, the epidote forming 15-25% of the rock. The intrusions are generally small dykes and no constancy of trend of these was observed. In the Liamo area granodiorite dykes become noticeably more dioritic near their contacts, possibly due 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 consisting 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 turbid 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_{45} An_{55}) and deep green, hornblende (partly chloritized) phenocrysts 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 in character although the feldspar composition approaches that of the porphyritic dolerite described. Similarly to the latter 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 latter, 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, usually dykes, commonly occur adjacent 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 also occur in the fault zone south of Musia, in the fault zone between the Domara River Beds and the Urere Metamorphics near Moikodi 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, usually hornblende porphyry, occur spasmodically, intruding the older rocks but do not appear to be associated with faults.

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

BIOTITE LAMPROPHYRE INTRUSIONS

Small dykes of a dark porphyritic rock apparently ultrabasic in composition and containing biotite phenocrysts occur on the southern edge of the area in the Domara River. The rocks appear in the hand specimen to be biotite lamprophyres or biotite peridotites. They are unserpentinised. Lamprophyric dykes have also been observed north of Bubudi, in Ikumi Ck and on the north side of the Amera 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 intruding the Urere Metamorphics and the Foasi River Limestone, the basic-ultrabasic belt, and the Domara River Beds also. The latter suggests that these rocks are 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 these rock types 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 former invades the limestone in a series of thin irregular dykes bears no relation to the basic-ultrabasic belt and this contact 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 c.a. 0.1 mm.) and consists of about 35% euhedral augite, 25% euhedral biotite, and 15% euhedral magnetite crystals with about 20% anhedral interstitial plagioclase (largely saussuritized) and accessory chlorite and ?prehnite. The rock has no directed texture and has suffered no metamorphism.

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 abundant biotite and the augite is less commonly euhedral. Quartz is common as irregular patches forming the enclosing mineral to 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 serpentinite. The rock contains about 25% brown biotite laths and 30% sub-hedral 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 involving albite and chlorite. As with 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 regional strike is west-north-west with which the rocks in the Musa Valley area generally conform. 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 structure or possibly a broad anticline plunging westwards. Strikes are constant and dips vary from 10° to 75°.

South of Deuno the Goropu Metamorphics are highly folded and the Amora Range is probably a south-east plunging anticline 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 further 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 also 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 further west and east the anticline, at least, is faulted. The steepest dips are seen in the Domara River on the southern boundary of the area. Around Imuruwake the Beds have a strike of north-west to north-north-west with dips up to 40° south-east.

Younger rocks such as the Silimidi Beds are horizontally or sub-horizontally bedded. The Sesara Volcanics locally appear to have depositional dips up to 10-15° and the Waiowa Volcanics have much shallower dips.

FAULTING

The Musa Valley area is strongly faulted and most of these faults were active in Late Tertiary to 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 Fanglomerate 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 and this 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 this 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 and 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 above fault. The fault probably continues in a curving line to the Ikumu and Foasi Rivers. In both these areas fault contacts exist between serpentinite 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. Further east, south of Silimidi, a major fault exists between the ultrabasic rocks and the Domara River Beds and the fault 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 and some of these faults are probably post-Silimidi Beds, faulting the latter 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 aerial 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 it is this fault which 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-/the east towards the eastern end of/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. It is possible that 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 hinging must be 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, mudstone with some calcareous quartz sandstone. Bedded calcareous siltstones and possibly marls were also probably deposited. Following deposition the rocks were strongly folded to produce low-grade regionally metamorphosed quartz mica phyllites, schists and epidote meta-quartzites. A distinct schistosity characterises the rocks and complex incompetent folding occurs locally.

Subsequent to a long period of erosion, sedimentation again occurred in the area. The sediments 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 ft. in length, and the limestone suggest a shallow water environment. Vulcanism was widespread throughout the deposition of the sediments and vesicular basalts, in some places with pillow structure, commonly occur. The sediments together with the volcanics now comprise 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 took place subsequent to 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 further 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 now interbedded with the conglomerate and greywacke. Andesitic lavas occur near the base in the Awala River-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 agglomeratic, continued throughout sedimentation and towards the end of deposition several basaltic extrusions occurred.

Following the deposition of the Domara River Beds broad folding took place. 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. Following shortly after the faulting the sub-horizontal deposits of the Silimidi Beds were laid down. This was accompanied by much explosive volcanic activity and 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 peridotite 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. 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 stated by Thompson (1958) the soils in this area do not appear to be true laterites as indicated by their soil profiles and their high silica and low iron content. e.g. Wakioki No.2 at 4 ft.

% SiO_2	% Fe	% Ni *
51.60	9.23	0.81

as opposed to a lateritic type soil obtained from Kokoda for example

Kokoda B	% SiO_2	% Fe	% Ni *
(3-7 ft)	16.54	33.9	0.45

During the present survey 27 auger holes were sunk for a total of over 50 samples, a specimen being collected every 5 ft where possible. The holes were sunk by means of a Jarrett hand-auger on 5 ft rods of ¾" pipe. The maximum depth reached was 15 ft 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 maximum nickel percentage was 1.06 from Wowo Gap and this was considerably above average. No.2 hole, Wowo Gap, gave the following figures:

Depth	% Ni
1 ft	0.82
5 ft	0.96
10 ft	1.06
13 ft	0.92

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

In the Darumu Creek-Sivai Creek area the gently folding sub-horizontal surface on the Silimidi Beds has a rather light vegetation on a soil rich, particularly on the surface, in ironstone pisolites. In the south-east pisolitic soils the auger penetrated locally up to 8 ft 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, the average depth being only 2-3 ft, 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 chromitite are found in similar layered ultrabasic belts in the Philippines and New Caledonia. Pyrite and minor chalcopyrite, usually 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 ft wide, between serpentine and fine dolerite or hornfels contains irregular mineralization with pyrite, chalcopyrite and possibly arsenopyrite with secondary malachite. Smaller shear zones in which 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 RIVER AREA, PAPUA

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ABSTRACT

4 specimens from the Domara River Beds, Papua, submitted by Bureau of Mineral Resources contained fresh water gastropods referable to Cipangopaludina and Melanoides. The rocks are regarded as of non-marine origin and probably Pleistocene age.

1. INTRODUCTION

Four rock specimens from the Domara River Beds, Musa River Area, Northern Districts, 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.

2. 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 fresh-water 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. hanleyi (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 hanleyi.

F31/59. 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 fresh-water genus, range Paleocene-Recent, Recent distribution in warm waters of South-east Asia and neighbouring islands, North and East Africa.

1 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.

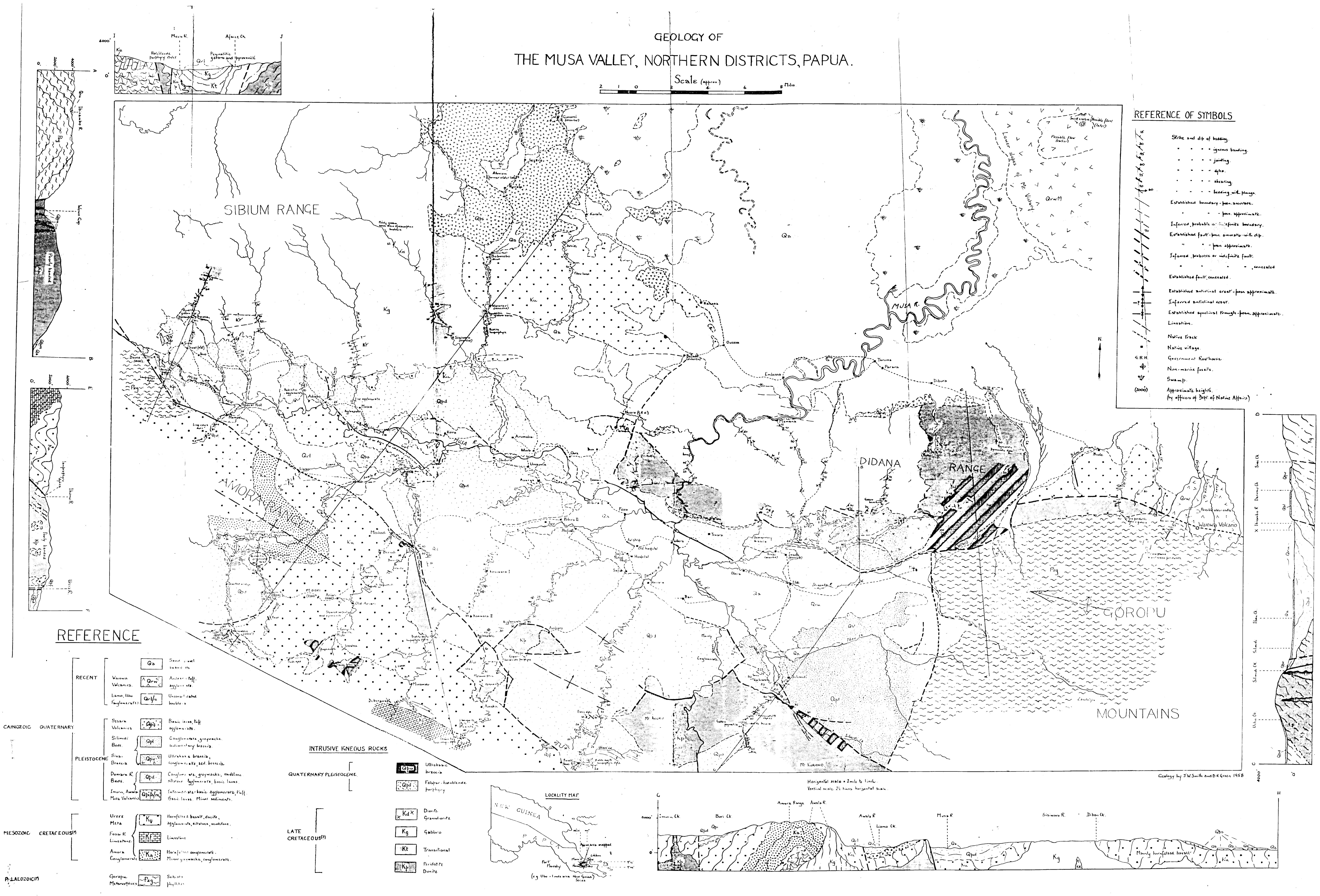
Soft greywacke with abundant remains of small gastropods identified as Melanoides sp.

3. 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.

4. 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.


GEOLOGY OF
THE MUSA VALLEY, NORTHERN DISTRICTS, PAPUA.
Scale (approx.)
SIBIUM RANGE
AMORA RANGE
DIDANA RANGE
GOROPU MOUNTAINS
MUSA R.
Mt. KORIOKO
Geology by J.W. Smith and D.H. Green 1958
REFERENCE
CAINOZOIC QUATERNARY
RECENT
Waiowa Volcanics. Qrw Andesitic tuff, agglomerate.
Liamo, Ubo Fanglomerates. Qrl/u Unconsolidated boulders
Qa Sand, gravel
PLEISTOCENE
Sesara Volcanics Qps Basic lavas, tuff agglomerate.
Silimidi Beds. Qpl Conglomerate, greywacke sedimentary breccia.
Sivai Breccia Qpv Ultrabasic breccia, conglomerate, sed. breccia.
Domara R. Beds. Qpd Conglomerate, greywacke, mudstone siltstone agglomerate, basic lavas.
Imuru, Awala Musa Volcanics Qpi/a/m Intermediate-basic agglomerate, tuff. Basic lavas. Minor sediments.
MESOZOIC CRETACEOUS(?)
Urere Meta Ku Hornfelsed basalt, dacite, agglomerate, siltstone, mudstone.
Foasi R. Limestone Kf Limestone
Amora Conglomerate Ka Hornfelsed conglomerate. Minor greywacke, conglomerate.
PALAEOZOIC(?)
Goropu Metamorphics Pzg Schists phyllites
INTRUSIVE IGNEOUS ROCKS
QUATERNARY PLEISTOCENE
Qpu Ultrabasic breccia
Qpf Felspar-hornblende porphyry
LATE CRETACEOUS(?)
Kd Diorite Granodiorite
Kg Gabbro
Kt Transitional
Kp Peridotite Dunite
REFERENCE OF SYMBOLS
Strike and dip of bedding.
" " " " igneous banding.
" " " " jointing.
" " " " dyke.
" " " " shearing.
" " " " bedding with plunge.
Established boundary - posn. accurate.
" " - posn. approximate.
Inferred, probable or indefinite boundary.
Established fault - posn. accurate - with dip.
" " - posn. approximate.
Inferred, probable or indefinite fault.
" " " " , concealed
Established fault, concealed.
Established anticlinal crest - posn. approximate.
Inferred anticlinal crest.
Established synclinal trough - posn. approximate.
Lineation.
Native track
Native village.
G.R.H. Government Resthouse
Non-marine fossils.
Swamp.
(2000') Approximate heights. (by officers of Dept. of Native Affairs)
N.
LOCALITY MAP
NEW GUINEA
Horizontal scale = 2 mile to 1 inch.
Vertical scale 2½ times horizontal scale.
Imuru Ck. Buri Ck. Amora Range Awala R. Awala R. Liamo Ck. Musa R. Sisiworo R. Dibou Ck.
Mainly hornfelsed basalt