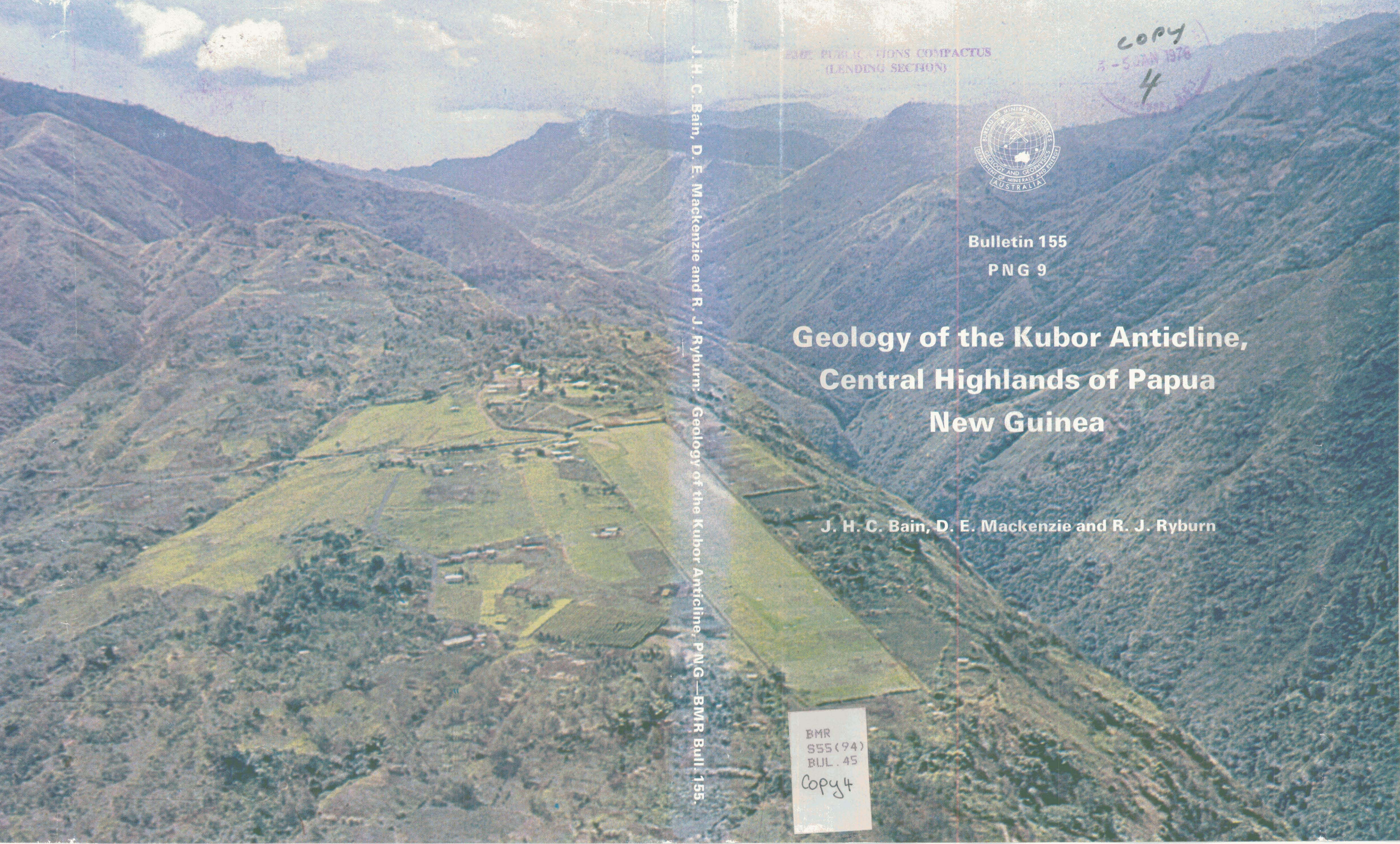

Bulletin 155
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DEPARTMENT OF MINERALS AND ENERGY
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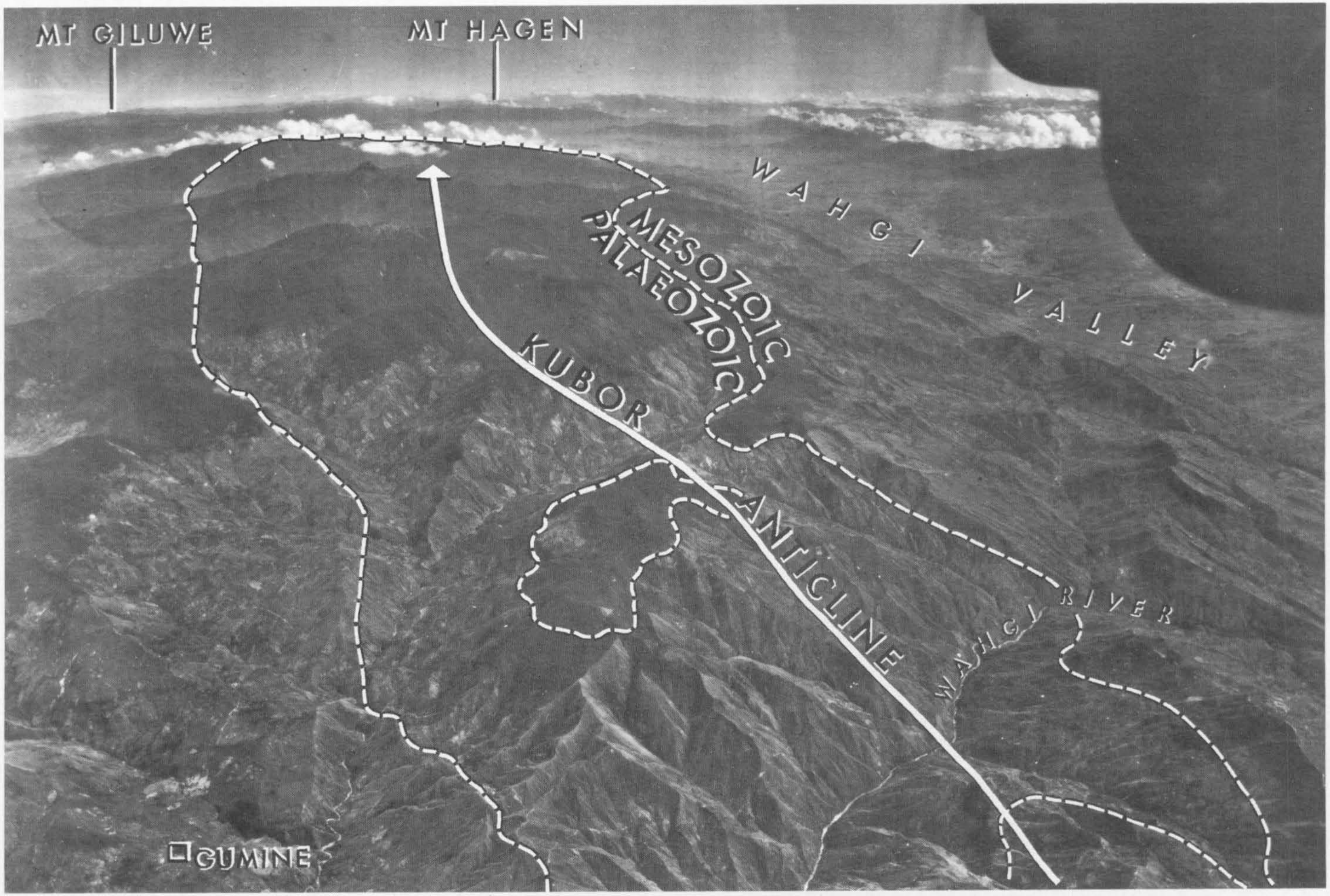

The Kubor Range and Wahgi valley from the east-southeast. Oblique aerial photograph.

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SUMMARY

The Kubor Anticline began as a basement fold on the northeast margin of the Australian continental block in Palaeozoic time. It is bounded in the north by the New Guinea Mobile Belt (Bain, 1973; Dow et al., 1973), a tectonically active zone within younger continental crust which accreted to the northern edge of the continent in Mesozoic time. Uplift of the northern edge of the older continental block resulted in gravity sliding, folding, and thrusting of the overlying Tertiary and uppermost Mesozoic rocks (Papuan Fold Belt), but the basement and the lower part of the cover rocks were only broadly folded and faulted (e.g. Kubor Anticline). Within the Mobile Belt the rocks are strongly deformed and intensely faulted.

The oldest rocks exposed are low-grade greenschists formed by regional metamorphism of sedimentary and volcanic rocks of probable Palaeozoic age (Omung Metamorphics). They crop out only in the core of the Kubor Anticline, where they are intruded by acid to basic large plutons and small stocks (Kubor Granodiorite) of probable Late Permian age.

In the west and northeast, the Kubor Granodiorite is conformably overlain by small patches of Upper Permian or Triassic limestone and arkose (Kuta Formation). Upper Triassic dacites and basalts (Kana Volcanics) are also unconformable on the metamorphic and plutonic rocks, but are not in contact with the Kuta Formation. They form outliers on the crest of the Kubor Range and overturned fault wedges on the southern and western slopes of Mount Wilhelm.

The basement, Kuta Formation, and Kana Volcanics are overlain unconformably by the upper part of the Wahgi Group (about 7000 m of Upper Jurassic to Upper Cretaceous clastic and volcanic rocks), and the same sequence forms the limbs of the anticline. The sequence consists of the Upper Jurassic Maril Shale, composed predominantly of shale, the Lower Cretaceous Kondaku Tuff, composed mainly of volcanolithic sandstone, shale, and basic volcanics, and the Upper Cretaceous Chim Formation, composed largely of shale. The lowermost beds in the Maril Shale contain a high proportion of clasts derived from the underlying rocks, and constitute a distinctive stratigraphic marker. The volcanolithic sediments, where they have been buried to depths of 4500 m or more, contain prehnite, pumpellyite, and zoisite. The lower part of the Wahgi Group (Lower Jurassic Balimbu Greywacke and Middle Jurassic basic Mongum Volcanics) is absent from the Kubor Anticline but present in the Jimi-Wahgi divide to the north.

The southern and western limbs of the Kubor Anticline are overlain with paraconformity by upper Palaeocene? mudstone and sandstone (Pima Sandstone) and Eocene-Oligocene limestone (Nebilyer Limestone) respectively. At the east end of the northern limb, the Upper Cretaceous rocks are overlain with slight unconformity by about 300 m of Eocene-Oligocene foraminiferal limestone (Chimbu Limestone), which forms the base of the sequence in the Yaveufa Syncline. The Eocene-Oligocene limestones are everywhere overlain by Miocene limestone or clastics. The Nebilyer Limestone at the western closure of the Kubor Anticline is overlain by fine clastics with interbedded limestone, marl, and mudstone (Aure Beds) which grade southwards into massive shelf limestone (Darai Limestone). The Miocene limestone has slid southwards off the flank of the Kubor Range and now rests with marked unconformity on highly disturbed Upper Cretaceous shale.

In the Yaveufa Syncline the Chimbu Limestone is overlain unconformably by a sequence of siltstone, tuffaceous sandstone, conglomerate, and limestone (Movi Beds) and volcanics and volcanolithic rocks (Yaveufa Formation) that thicken to the southeast.

The Mesozoic formations in the Jimi-Wahgi divide and Bismarck Mountains are intruded by large composite plutons and small stocks of middle Miocene age (Kimil Diorite and Bismarck Intrusive Complex). The large hypabyssal diorite stock (Michael Diorite) forming Mount Michael is of upper Miocene age. The numerous small intrusive bodies (Kenangi Gabbro) in the vicinity of the Yaveufa Formation, and a small stock (Benembi Diorite) near Kuta, were probably also emplaced in the Miocene.

The northern limb of the Kubor Anticline is cut by the Bismarck Fault Zone along the southern margin of the New Guinea Mobile Belt. The Bismarck Fault Zone is 20 km wide and consists of a disturbed zone of subparallel anastomosing faults, thrusts, and tight overturned folds. There is at least 3000 m of vertical displacement (north side up) spread over the width of the fault zone in the vicinity of Mount Wilhelm.

No economic mineral deposits are known in the Kubor area. The Bismarck Intrusive Complex, the Jimi-Wahgi divide, and Mount Michael appear to be the most prospective areas for disseminated copper-gold-molybdenum deposits. The small alluvial deposits along the Wahgi River probably contain some gold. Large quantities of stone, suitable for use as road metal, aggregate, or building stone, and unconsolidated gravel, suitable for road construction, are present in the Kubor area.

INTRODUCTION

The Kubor Anticline forms the rugged Kubor Range in the central highlands of New Guinea between longitudes 144°E and 145°E. The range is 75 km long and almost uninhabited. Most of the range is heavily forested (Fig. 1), but some of the peaks over 3000 m have been glaciated and now support an alpine type of vegetation. The surrounding country is part of a high deeply dissected plateau (Purari Plateau) sloping to the south. The grasslands in the northern part of the plateau support over a quarter of a million people and are served by numerous roads, tracks, and airstrips (Fig. 2), but the southern part is heavily forested and sparsely populated.

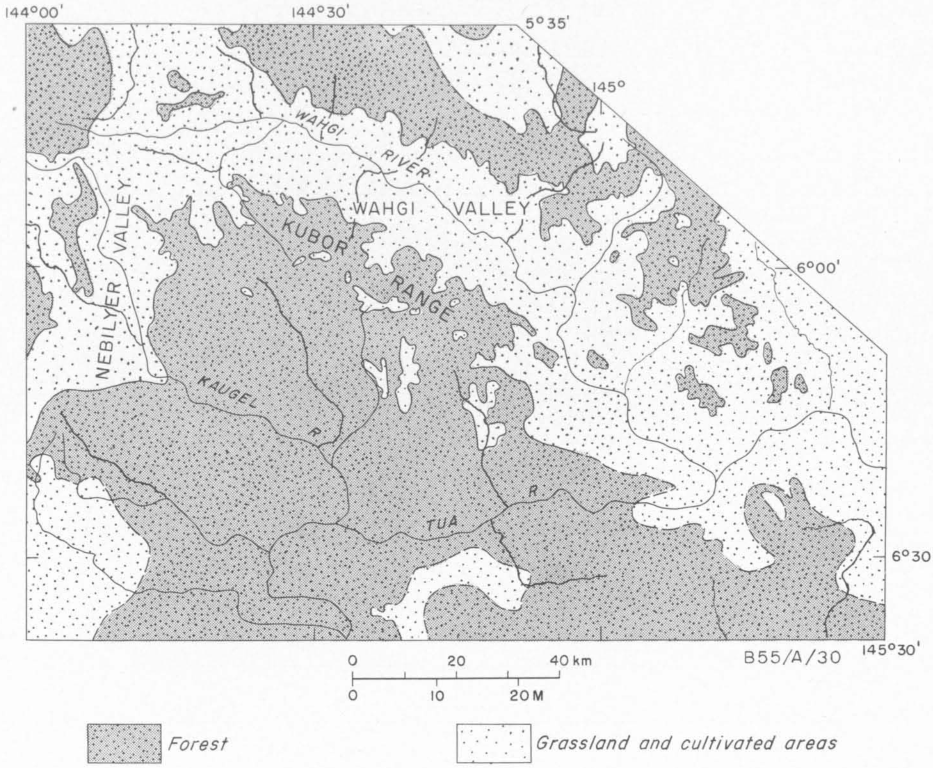


Figure 1. Distribution of vegetation.

The area described in this Bulletin is outlined on the accompanying Ramu and Karimui Sheets, which were mapped by the Bureau of Mineral Resources as part of a program of regional mapping at 1:250 000 scale in Papua New Guinea. The regional geology of the Ramu and Karimui Sheet areas is outlined in the Explanatory Notes accompanying the maps.

The field work from June to October 1968 was carried out by J. H. C. Bain, D. E. Mackenzie, and R. J. Ryburn, with the assistance of D. B. Dow, R. J. Tingey, I. E. Smith, G. Cifali, and R. W. Page during the helicopter traverses. The detailed follow-up work was carried out by Bain, Mackenzie, and D. J. Belford in June and July 1970.

The area mapped covers the Purari Plateau from the Nebilyer valley in the west to the Asaro-Wahgi divide in the east. In the north it is bounded by the Jimi-Wahgi divide and to the south by the Poru River and the Karimui and Crater volcanoes.

This Bulletin deals with the geology of the Kubor Range and the adjacent country, and incorporates the unpublished results of some traverses by D. B. Dow and F. E. Dekker in 1964.

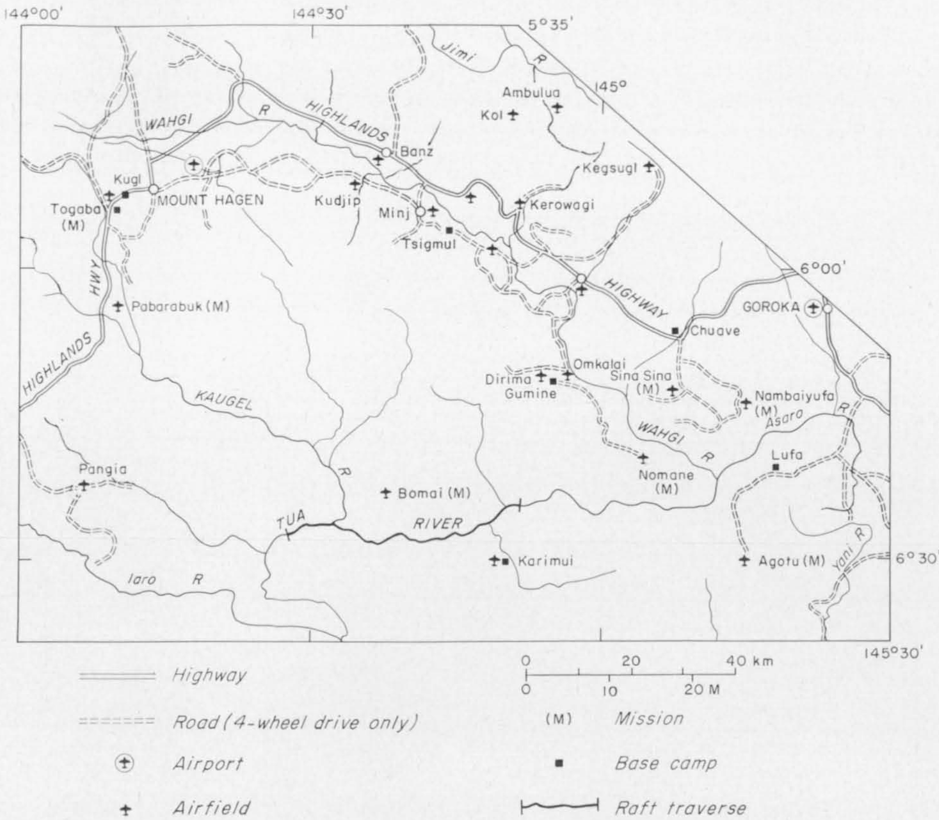


Figure 2. Roads and airstrips.

Physiography

The Purari Plateau (Spinks, 1935) is a rugged area with mountain peaks up to 4500 m, deeply incised gorges, and spectacular limestone cliffs. The plateau slopes gently to the south from an average elevation of about 2000 m near Mount Hagen town to about 800 m in the southwest (Fig. 3). The area is encircled by mountain ranges and divides, except for a gap in the southwest through which pass the main streams draining the plateau. The bordering ranges in the north and east culminate in Mount Wilhelm (4509 m), which rises some 3000 m above the Wahgi valley (Fig. 4).

The Kubor Range (Frontispiece) rises to over 3500 m above sea level at several places along its 75 km length. The range consists of a core of Palaeozoic rocks flanked by foothills of Mesozoic rocks. In the west, where the range is 35 km wide and composed largely of granitic rocks, the topography is rugged and the drainage complex. The highest points on the range are capped by deeply eroded outliers of flat-lying volcanic rocks (Fig. 5), which commonly form rugged rocky peaks such as Mount Sigul Mugal (Fig. 6). Elsewhere the range is covered by forest, and is uninhabited.

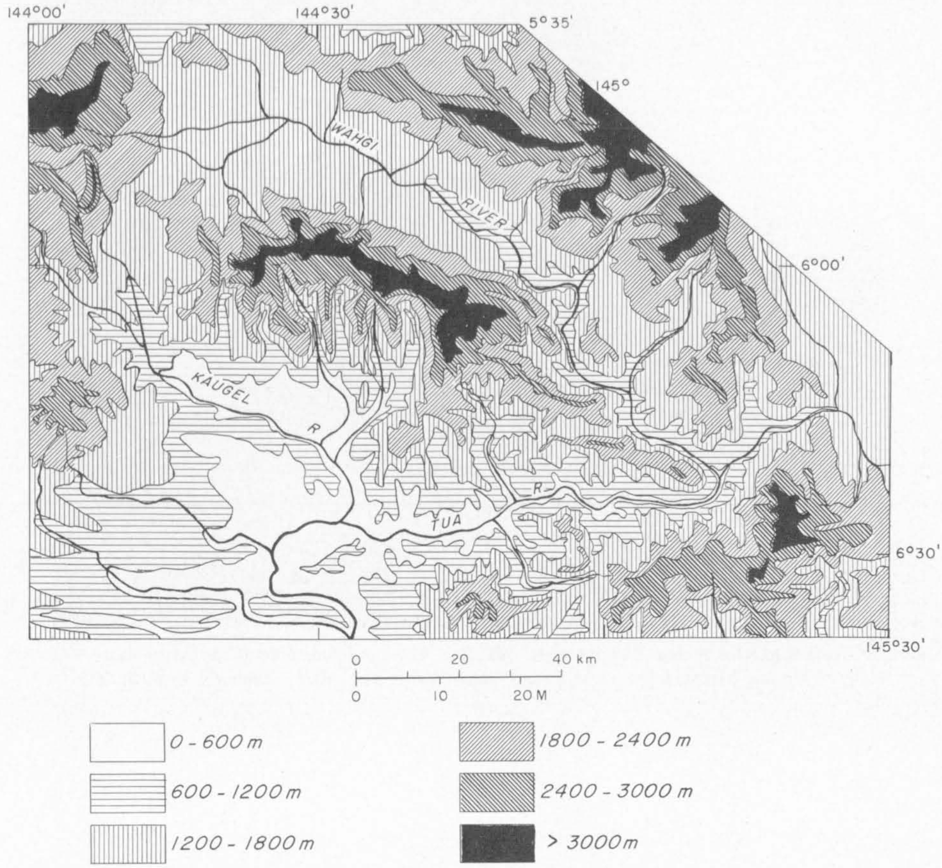


Figure 3. Topography.

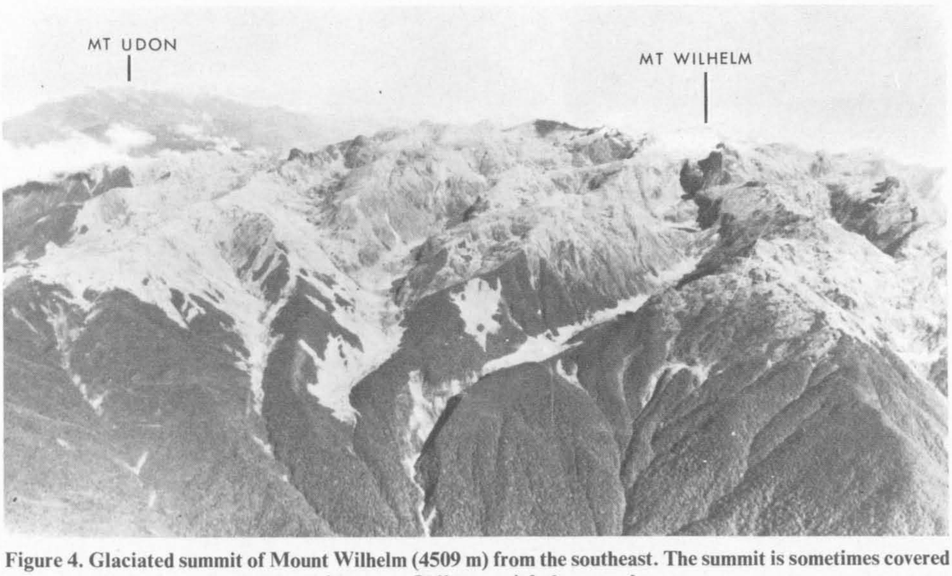


Figure 4. Glaciated summit of Mount Wilhelm (4509 m) from the southeast. The summit is sometimes covered with snow. Oblique aerial photograph.

Figure 5. Central part of Kubor Range (about 4000 m). The range consists of flat-lying Kana Volcanics resting on Omung Metamorphics and Kubor Granodiorite. The relief in this area is about 2000 m.

Figure 6. Mount Sigul Mugal (about 4000 m) from the northwest. The mountain is composed by granodiorite capped by Kana Volcanics.

The landscape above 3200 m has been modified by late Pleistocene glaciation. Cirques were developed at a number of places on the Kubor Range and on Mounts Giluwe (west of the Kubor area), Hagen, Michael, and Wilhelm (Löffler, 1970).

Remnants of moraines are preserved on Mount Giluwe and on the flanks of Mount Wilhelm, and the floor of the central Wahgi valley is covered by alluvial fans that are partly of fluvioglacial origin.

A prominent limestone cuesta (the Chimbu Limestone) extends for 60 km southeast of Kerowagi. The cliffs are up to 300 m high and present an almost impenetrable barrier to east-west travel, except where they are cut by the southwesterly flowing Chimbu and Mai Rivers. The Chimbu River flows east from a small tarn high on the slopes of Mount Wilhelm, and then swings southwest past Gembogl and flows through a series of straight-walled gorges cut in the more resistant rocks at the bottom of a deep valley, and finally breaks through a deep V-shaped notch in the Chimbu Limestone dip-slope near Kundiawa. Much of its energy is dissipated in a short broad valley before it joins the Wahgi River.

The Wahgi River starts on the steep eastern slope of Mount Hagen, and in a short distance it becomes a mature river meandering along the flat floor of the upper Wahgi valley (Figs. 7, 8). The flat area was probably formed when the ancestral westerly flowing Wahgi River was dammed by the Mount Hagen volcano and the infilling of the shallow lake formed behind the barrier (Haantjens, 1970). The direction of flow of the Wahgi River was then reversed by river capture. About 12 km due south of Kerowagi the river drops into a gorge (Figs. 9, 10), at least 600 m deep, which extends beyond the confluence of the Wahgi and Asaro Rivers.

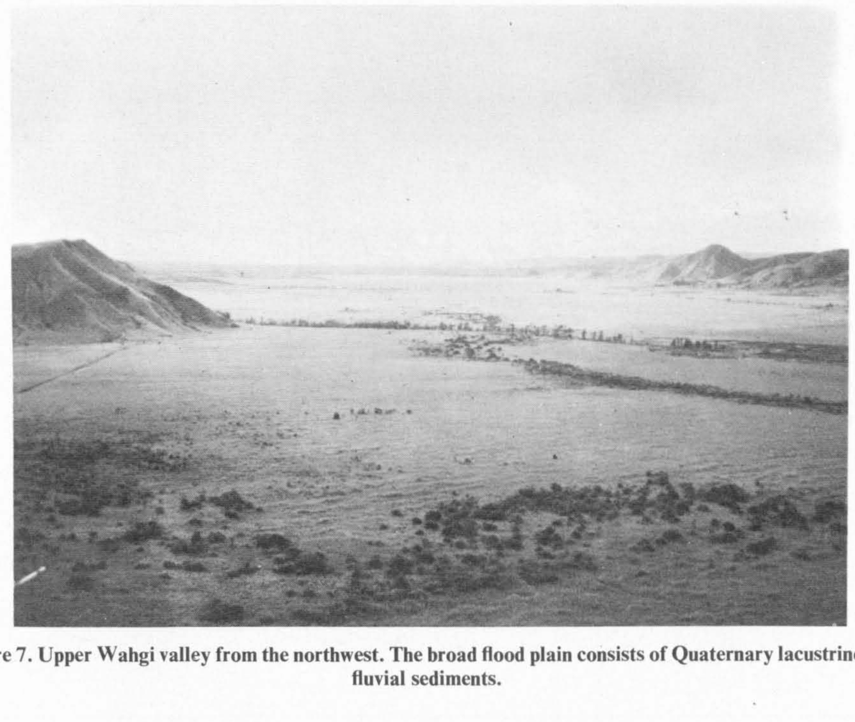


Figure 7. Upper Wahgi valley from the northwest. The broad flood plain consists of Quaternary lacustrine and fluvial sediments.

A number of terraces can be distinguished in the Wahgi gorge: the main terrace is at the base of the Kondaku Tuff and the next is near the base of the Maril Shale, a third has been cut in the Maril Shale and Omung Metamorphics, and, finally, there is a small terrace at the base of the gorge. Numerous deeply incised tributaries enter the gorge by waterfalls, as most of the valleys have been left 'hanging' by the rapid lowering of the stream.

Figure 8. Broad flood plain of the Wahgi valley near Banz, viewed from the southwest. The flood plain is flanked by alluvial fans.

Figure 9. Wahgi River gorge between Kundiawa and Gumine, viewed from the north. Omung Metamorphics and small stocks and dykes of Kubor Granodiorite crop out along this section of the gorge.

The Kaugel River enters the westerly flowing Tua (Wahgi) River southwest of Mount Suaru; to the south of the Kubor area the much swollen Tua is joined by the Erave River to form the Purari River.

A number of large stratovolcanoes have been superimposed on the deeply dissected land surface. They are surrounded by extensive gently sloping volcanic aprons, which have been deeply gullied by recent erosion. Some of the deep valleys (e.g. the Nebilyer) were filled with lava and lahars from Mount Hagen and other volcanoes, and many of the streams were diverted into new courses.

Figure 10. Omkalai airstrip is sited on a dip slope (13°) of Maril Shale. The Wahgi River flows from left to right through a gorge, 600 m deep, beyond the airstrip. The lower part of the scarp consists of Maril Shale, and the hills in the background, which are partly covered by clouds, are composed of Kondaku Tuff.

Climate

The mean annual rainfall on the Purari Plateau is about 2500 mm, with a relatively dry period in May to October when the southeasterly trade winds blow. The rainfall is lower in sheltered areas, and higher in the more exposed country. Up to 5000 mm of rain falls on the southern flanks of the Kubor Range and on the Crater and Karimui volcanoes, where the wet season is poorly defined.

In June to September 1968 the mean daily maximum and minimum temperatures recorded at Gumine base camp (1700 m a.s.l.) were 26.8°C and 12.8°C. During the remainder of the year the humidity is high, and the range in temperature is probably smaller. Occasional frosts occur down to an altitude of 2000 m.

Bik (1967) has described a similar climate for part of the western and southern highlands, and Brookfield & Hart (1966) have shown that there are considerable variations in the weather in different parts of the Wahgi valley at the same time of day. They contend that the climate of the enclosed highland valleys is controlled by local circulations that operate almost independently of the regional pattern.

Aerial photographs and base maps

Almost all the Kubor area is covered by aerial photographs, most of which were taken at a height of about 7600 m with a 152 mm focal-length lens, but some from 4500 m. The high local relief and elevation, wandering flight lines, variations in altitude and attitude of the aircraft, large areas of cloud and shadow, and poor quality of the prints make geological interpretation difficult. The Adastra and RAAF trimetrogon photographs were taken before 1960 and therefore do not show the recently made roads. Most of the recent Qasco photographs (taken in 1968) cover the trackless bush to the south of the Kubor Range.

Field and photo-interpretation data were plotted on topographic maps at about 1:50 000 scale. The base maps for the northern part of the area were made by enlarging the 1:63 360 Planimetric Series Preliminary Edition maps prepared by the Division of National Mapping. The base maps for the southern half of the area were prepared from uncontrolled photomosaics.

Access and method of working

In addition to the Highlands Highway from Lae to Mount Hagen, which runs through the area, there are numerous poorly formed roads in the Wahgi valley between Mount Hagen and Goroka, though many are impassable after heavy rain. There are also 19 airstrips within the area, most of which are open only to light aircraft (Fig. 2).

The 1968 base camp was established near Gumine and the Omkalai airstrip (Figs. 2, 10). Roads were traversed using four-wheel-drive vehicles, and the intervening country mapped by traverses along streams and tracks.

During the last five weeks of the 1968 survey a Bell 47G3B1 helicopter was used to extend the area mapped, and to position parties in the Okapa area and in the densely forested sparsely populated area to the south of the Kubor Range. An inflatable rubber raft was used during the mapping of a 65 km section of the Tua River.

In 1970 four-wheel-drive vehicles were again used to position ground parties for detailed mapping and collecting. A helicopter, working from a base at Baiyer River, was used during reconnaissance mapping in the Jimi valley (Mackenzie & Bain, 1973).

Helicopter operational methods in 1968 were based on experience obtained in the South Sepik region in 1967 (Dow et al., 1973; Davies & Dow, 1968). However, the Highlands survey encountered a number of new problems due to the nature of the country, and to the weather. As the geology of the area is complex, and photo-interpretation is unreliable, it was necessary to position traverse parties by helicopter to cover the more inaccessible areas. Most of the traverses lasted for 3 to 4 days with occasional traverses up to 8 days. Because of the paucity of landing sites it was found that the most economical use of the helicopter was obtained by a combination of the following practices: (i) spot observations made to plan traverses; (ii) geologist and native assistant placed in the field in the morning, and picked up the same afternoon (this method is economical only while working close to the helicopter base, that is, within 30 km); and (iii) geologist and 3 carriers positioned for traverses of 3 to 4 days' duration.

The helicopter base was moved twice to ensure that the machine operated only within its most economical range of 50 km. Light aircraft were used to move personnel and equipment between base camps. To make full use of the helicopter it was found that the party should consist of at least five or six geologists. The party leader generally co-ordinated the work, and made use of any free time on the helicopter with reconnaissance and 1-day traverses.

Previous geological investigations

N. H. Fisher, Government Geologist, made a brief visit to the Highlands in 1937, following the prospecting forays by the Leahy brothers and others, and the discovery of small alluvial gold deposits at Kuta and Bena Bena. In 1939 L. C. Noakes, Assistant Government Geologist, measured a section of the Mesozoic and Tertiary rocks in the Chimbu River and inspected the limestone at Kuta. His specimens from the Chimbu River were examined and described by Edwards & Glaessner (1953) and later by Crook (1961). In 1949 G. A. V. Stanley, K. M. Llewellyn, and M. F. Glaessner of the Australasian Petroleum Co. (APC) (Stanley, 1950) made a reconnaissance of the central highlands from Aiyura, east of Kainantu, to Mount Hagen. They described the Miocene rocks east of the Chimbu Limestone and re-examined the limestone at Kuta. Glaessner et al. (1950) subsequently established the age of the Kuta limestone as Permian. The underlying granitic and metamorphic rocks were considered to be Palaeozoic.

The first regional mapping in the Kubor area was undertaken by F. K. Rickwood (with assistance from the BMR) during the periods December 1950 to March 1951 and December 1952 to March 1953. The main purpose of Rickwood's surveys were to determine the relationship of the Kuta limestone to the Kubor granite and to determine the general structure and stratigraphy of the western highlands.

The lack of base maps and aerial photographs, except for the area near Kundiawa, necessitated pace and compass mapping. The resultant map and report (Rickwood, 1955) formed an excellent reconnaissance base for the more detailed mapping described in this Bulletin. Rickwood and other APC geologists (Rickwood & Kent, 1956) also mapped the area to the south of Mount Michael and the Tua River (Pio-Purari survey).

In 1956 the Bureau of Mineral Resources began regional mapping in the eastern part of the central highlands using aerial photographs and semi-controlled topographic base maps prepared by the Division of National Mapping (McMillan & Malone, 1960). In 1962 Dow & Dekker (1964) mapped the Bismarck Mountains immediately to the north of the area described in this Bulletin. Their base map was prepared from an uncontrolled photomosaic, and because of the extreme relief the rivers and geological boundaries on their map are as much as 8 km out of position.

Since 1962, J. R. Read and others of the Papua New Guinea Geological Survey have made geological observations along the line of the Highlands Highway in the course of road alignment investigations. Several mining companies, notably Kennecott Exploration (Australia) Pty Ltd, have made brief reconnaissances throughout the area, and collected stream sediments for analysis. A large number of specimens have been collected for isotopic age determination (Page, 1971; Page & McDougall, 1970a,b).

Acknowledgements

We gratefully acknowledge the assistance and hospitality extended to us by the officers of the Department of District Administration at Baiyer River, Bukapena, Chuave, Gembogl, Goroka, Gumine, Karimui, Kerowagi, Kotna, Kundiawa, Lufa, Minj, Mount Hagen, and Okapa. Special thanks are due to Messrs G. Reid and M. Bell (Gumine, 1968), P. Broadhurst (Okapa, 1968), R. Donovan (Lufa, 1970), R. Allen (Mount Hagen, 1970), and Mr and Mrs R. Cruikshank (Baiyer River, 1970). Mr L. Wilson, of the Stores and Supply Branch, Goroka, gave us valuable assistance in 1968.

The friendly assistance of local people who acted as carriers and guides and who allowed access to their land is much appreciated. Thanks are also due to the numerous mission stations throughout the highlands region for their hospitality, and to field assistants Messrs E. de Morsier (1968) and M. Gilfillan and G. Malafant (1970), who contributed greatly to the success of the field work.

Geological information and hospitality from Kennecott Exploration (Australia) Pty Ltd at Goroka, and discussions with Messrs I. Hughes (ANU) and E. Löffler (CSIRO) during the preparation of the Bulletin are acknowledged with thanks.

PRE-PERMIAN
(Fig. 11)

Omung Metamorphics
(Rickwood, 1955)

Name

The low-grade metasedimentary rocks in the core of the Kubor Anticline were named the Omung Metamorphics by Rickwood (1955, p. 68) after the Omung River on the northeast flank of the Kubor Range (6°00′S, 144°43′E).

Distribution

The metamorphics crop out mainly in the eastern half of the core of the Kubor Anticline where they are intruded by some small stocks of Kubor Granodiorite. In the west there are some enclaves of the metamorphics in a large pluton of Kubor Granodiorite. A small area of metamorphic and plutonic basement is exposed at the head of the Wahgi valley, 15 km northeast of Mount Hagen. The rocks in the Chimbu River, which Rickwood correlated with the Omung Metamorphics, are now assigned to the Kana Volcanics (Dow et al., 1973).

Lithology

The formation consists of meta-argillite, slate, phyllite, and sericite schist with subordinate metagreywacke and occasional metavolcanics. The most common rock type is dark grey massive indurated shale or siltstone with blocky jointing and poorly developed cleavage, but in places slate, phyllite, and sericite schist predominate. Segregation quartz veins are common. Spotted slate and hornfels are developed mainly in the narrow aureoles around the Kubor Granodiorite.

Less common are massive beds or thin interbeds of grey, bluish grey, or green metagreywacke with blocky jointing but no cleavage. Graded bedding and fine current-bedding are present in some thinly bedded sequences. A few intraformational breccias, composed of angular flakes of argillite set in a matrix of greywacke, are also present.

The boulders of green or red metavolcanic rocks found in many of the streams draining the Kubor Range were probably derived from thin flows and dykes within the metasediments. The metavolcanics are usually massive, and commonly contain relict amygdales and plagioclase phenocrysts.

Age

The Omung Metamorphics are pre-Permian. Around the west end and northeast flank of the Kubor Anticline, the Kubor Granodiorite and in places the Omung Metamorphics are unconformably overlain by limestones of the Kuta Formation. The microfossils in the limestone were originally dated as Permian (Rickwood, 1955), but the macrofossils collected in 1970 indicate an age close to the Permian-Triassic boundary (see p. 19). Elsewhere the metamorphics are overlain by the Upper Triassic Kana Volcanics or by the Upper Jurassic Maril Shale.

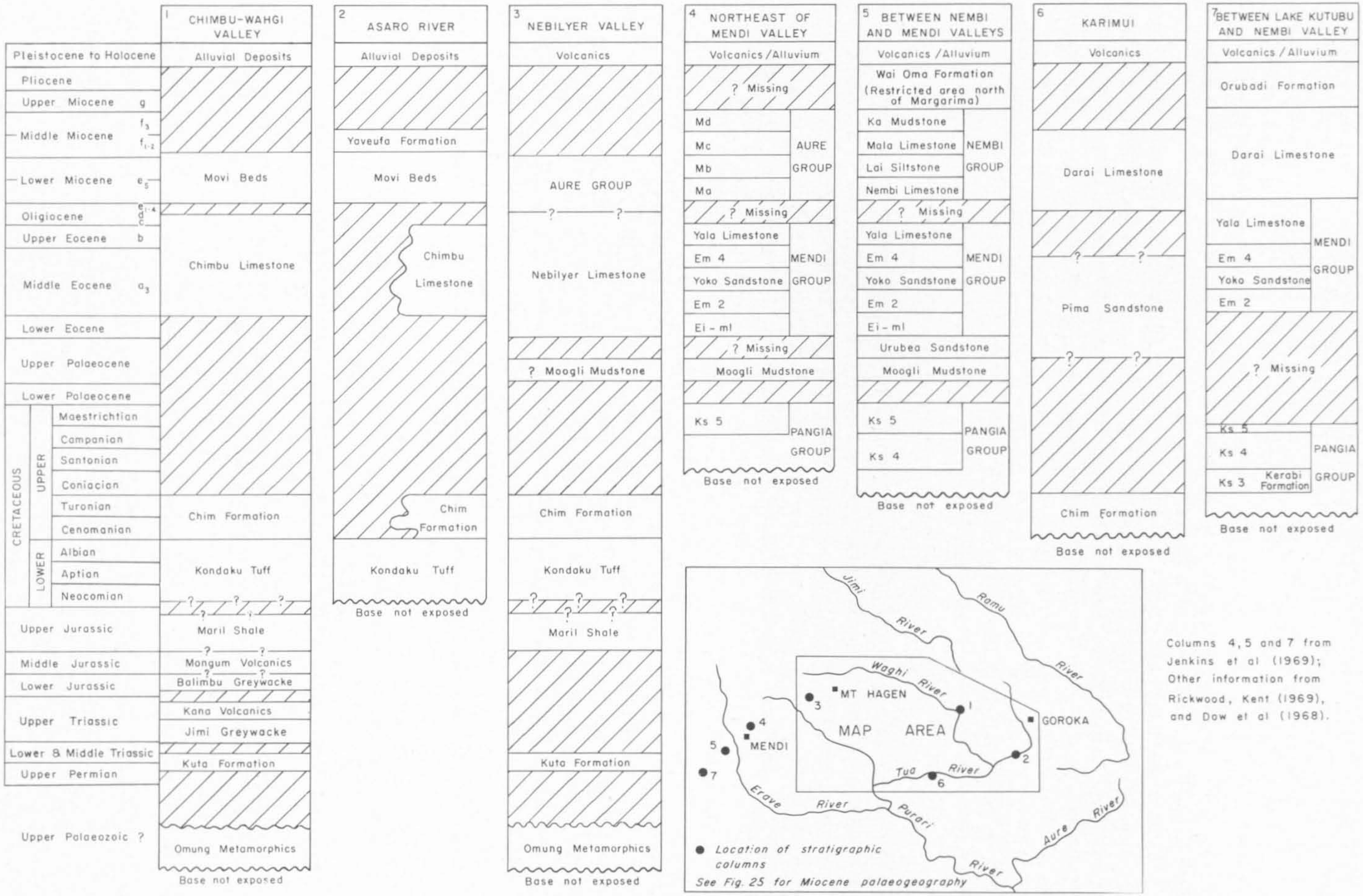


Figure 11. Stratigraphy.

Structure and thickness

In outcrop scale, the effects of the low-grade regional metamorphism vary from place to place and also according to rock type. Slaty or phyllitic cleavage is present only in the finer-grained rocks and is commonly parallel to the bedding where bedding can be observed. In some of the phyllites, notably on Mount Digini and in the Maril River, a later strain-slip cleavage (Fig. 12) gives rise to small folds and crenulation lineations on the main cleavage surfaces. Some of the slates and phyllites in the north branch of the Maril River are tightly folded and have an axial-plane cleavage. Post-metamorphic chevron folds and kink bands can also be seen in the phyllites on Mount Digini and in the Maril River.

On a regional scale, the bedding in the Omung Metamorphics strikes east-southeast and dips at moderate to steep angles in either direction, but predominantly towards the north. Overturned bedding was noted in the Omung River near Dek. The general parallelism of the cleavage and bedding suggests that the sequence is isoclinally folded. The broad anticlinal warping associated with the Kubor Anticline is superimposed on an earlier more complex structure. Allowing for the structure, the thickness of exposed sediments is probably over 2000 m.

Petrography

The fine-grained metasediments are poorly sorted quartzose silty shale and siltstone, metamorphosed to varying degrees. In the less altered rocks most of the clastic texture is preserved. The clastic grains consist predominantly of quartz and the following minerals arranged in decreasing order of abundance: albitized plagioclase, muscovite, chloritized and epidotized ferromagnesian minerals, biotite, sphene, epidote, and zircon. The fine-grained recrystallized matrix is composed of sericite, quartz, chlorite, albite?, and abundant disseminated opaque material. The cleavage is defined by a preferred orientation of micaceous minerals. In the more strongly metamorphosed rocks recrystallization and directional structures are more pronounced, but some relict detrital grains are always present. Fine-grained biotite has been developed in some of the phyllites, and many of the rocks are cut by veinlets of quartz, albite, and chlorite.

The metagreywackes consist of poorly sorted angular grains of quartz (about 60%), albitized plagioclase, muscovite, microcline, orthoclase, intermediate to basic volcanics, biotite, sphene, opaque minerals, epidote, apatite, and zircon set in a matrix similar to that of the finer metasediments. Shearing and cataclasis are common. As in the phyllites, biotite has been developed in some of the more strongly metamorphosed rocks.

Most of the metavolcanic rocks are altered basic or intermediate lavas. They are composed of greenschist assemblages of albite, chlorite, epidote, actinolite, quartz, calcite, and accessory sphene and opaque minerals. The subophitic texture and relict phenocrysts of plagioclase and augite are generally preserved. Some metamorphosed hypabyssal rocks with a relict porphyritic or doleritic texture are present. Two altered tuffs? consist of fine aggregates of albite, epidote, chlorite, and calcite.

In the contact-metamorphic aureoles around the Kubor Granodiorite intrusions the most common thermal metamorphic effect is the growth of biotite or andalusite porphyroblasts. For example, a hornfelsed siltstone (21NG2753) from within a few metres of the contact on Mount Digini contains spongy porphyroblasts of brown biotite and fine flakes of green biotite set in a recrystallized matrix, but the rock retains its clastic texture. Spotted slates have been noted in areas devoid of intrusions, as for example a spotted slate (21NG1355) from the Mogono River in which the spots consist of muscovite-biotite aggregates.

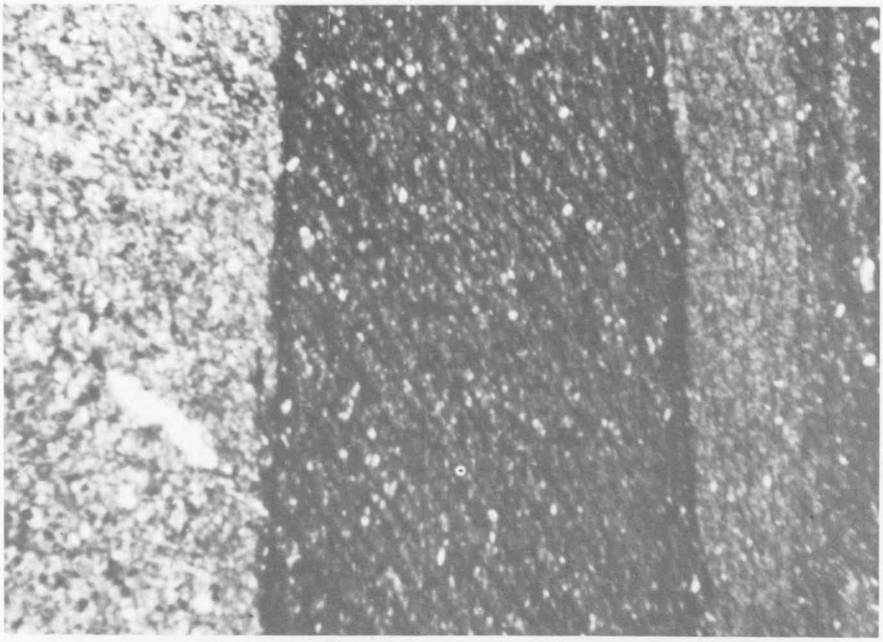


Figure 12. Strain-slip cleavage cutting obliquely across interbedded shale and siltstone (21NGO523) of the Omung Metamorphics along the Kundiawa-Gumine road. x 40. plane polarized light.

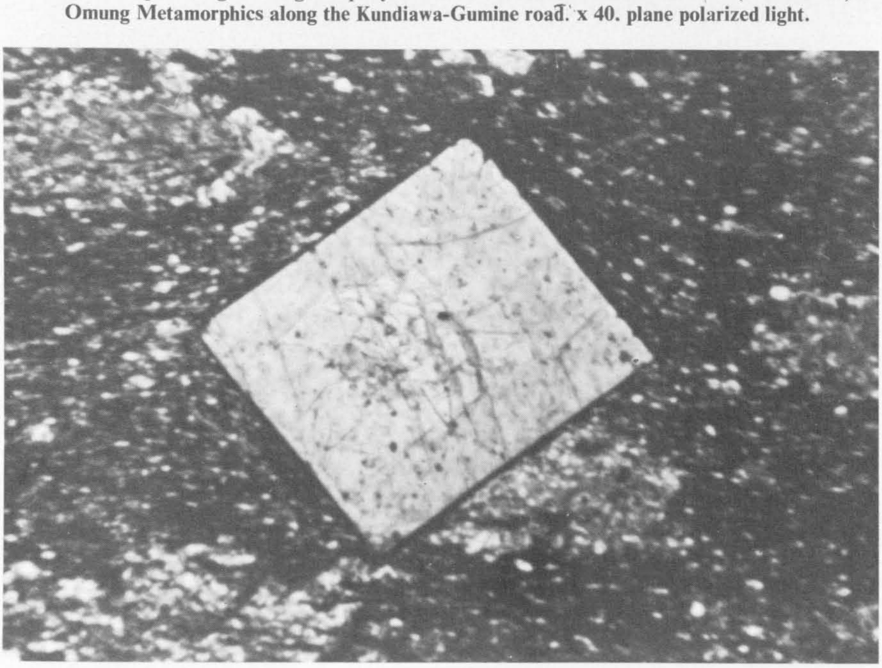


Figure 13. Sericitized andalusite crystal in hornfelsed siltstone (21NG1138) of the Omung Metamorphics along the Kundiawa-Gumine road. x 40, plane polarized light.

A hornfelsed siltstone (21NG1138) from the Gumine-Kundiawa road contains euhedral crystals of sericitized andalusite up to 2 cm long (Fig. 13). Smaller andalusite crystals with well developed chiastolite crosses occur in a similar rock (21NG2571) from a contact aureole on Mount Digini, and a spotted slate (21NG2805) from the Omung River contains porphyroblasts composed of radiating andalusite prisms and fine biotite.

A metadacite (20NG1287) beneath the Kuta Formation in Momai Creek near Kuta contains small stumpy prisms of scapolite in relict spherulites.

Other minerals of probable contact metamorphic or metasomatic origin include accessory garnet in a metavolcanic hornfels (21NG0520) from the Gumine-Kundiawa road, and tourmaline from a vein in a phyllite from Mount Digini (21NG2735).

Discussion

The core of the Kubor Anticline is the largest and easternmost of three known exposures of pre-Mesozoic basement in Papua New Guinea. Granitic basement rocks are exposed in the Strickland gorge (5°24′S, 142°08′E) and at Mabaduan on the coast of western Papua (9°40′S, 142°40′E) and has also been recorded in several petroleum exploration wells in western Papua. Pre-Mesozoic basement probably underlies much of western Papua from Torres Strait to the axis of the Central Ranges.

The Omung Metamorphics can possibly be correlated with the Goroka and Bena Bena Formations in the eastern highlands (McMillan & Malone, 1960), which also consist mainly of low grade metasediments. However, these formations probably include Mesozoic rocks, and the age of metamorphism may be considerably younger, possibly Early Tertiary.

The turbidite-type graded bedding, fine cross-lamination, and intraformational breccias preserved in the Omung Metamorphics suggest that at least some of the original sediments were laid down in an offshore marine environment. The predominance of fine-grained sediments, and the absence of conglomerate, limestone, and fossils indicate that nearshore shallow marine sediments are not represented. The detrital quartz, plagioclase, biotite, and muscovite were probably derived from the crystalline rocks on the Australian proto-continent to the southwest.

The metamorphism that resulted in the development of cleavage throughout much of the formation was probably coeval with the folding. The Kubor Granodiorite was emplaced at a later stage and does not seem to be connected with the regional metamorphism.

UPPER PERMIAN OR TRIASSIC

Kuta Formation
(Rickwood, 1955)

Nomenclature

Rickwood (1955, p. 69) used the name Kuta Group for the sequence of Permian? (Glåessner et al., 1950) calcareous arkose, limestone, and shale that rests unconformably on the Kubor Granodiorite and Omung Metamorphics. The formation is overlain by the Upper Jurassic Maril Shale or Lower Cretaceous Kondaku Tuff, or both. The type area is near Kuta village (5°55′00″S, 145°13′11″E) at the western closure of the Kubor Anticline. As the sequence has not been subdivided into formations the name is amended to Kuta Formation in accordance with the Australian Code of Stratigraphic Nomenclature.

Distribution and thickness

The Kuta Formation extends along the crest of the range from east of Kuta southwards to latitude 6°10′S, at the west end of the Kubor Anticline. Smaller exposures have been mapped on Mount Oga (Figs. 14, 15), and at three localities on the south side of the Wahgi valley, about 26 km east of Mount Hagen township. Limestones of the Kuta Formation are exposed in Numans Creek, near Dek (5°59′S, 144°45′E), and near Gurumugl in the upper Wahgi gorge, 13 km west of Kundiawa (Fig. 16).

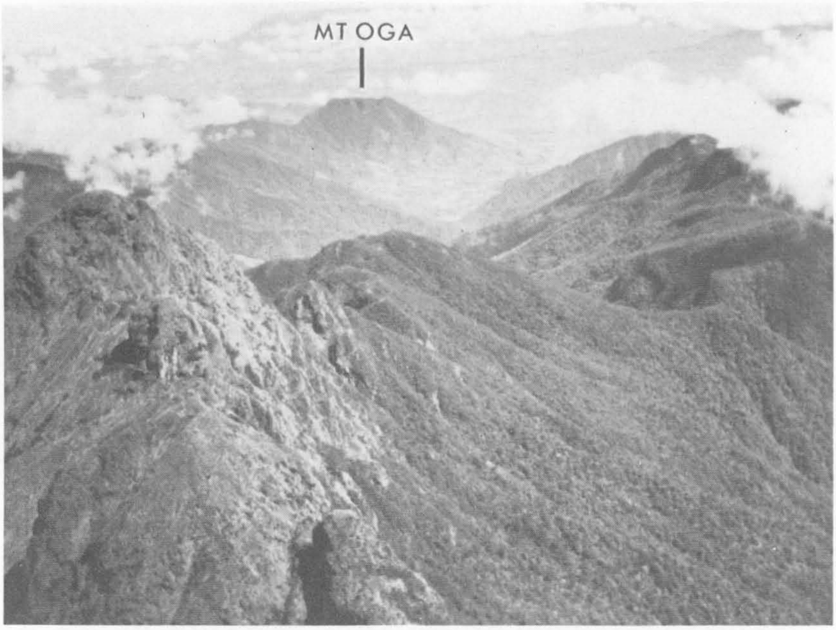


Figure 14. View to northwest from near the summit of Mount Sigul Mugal. The flat-topped hill in the centre background is Mount Oga.

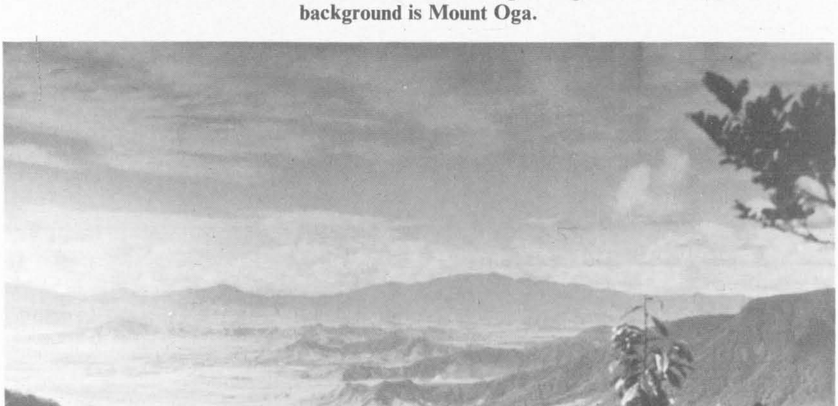


Figure 15. The Kaip valley and part of the upper Wahgi valley. The ridge in the background is the Wahgi-Jimi divide.

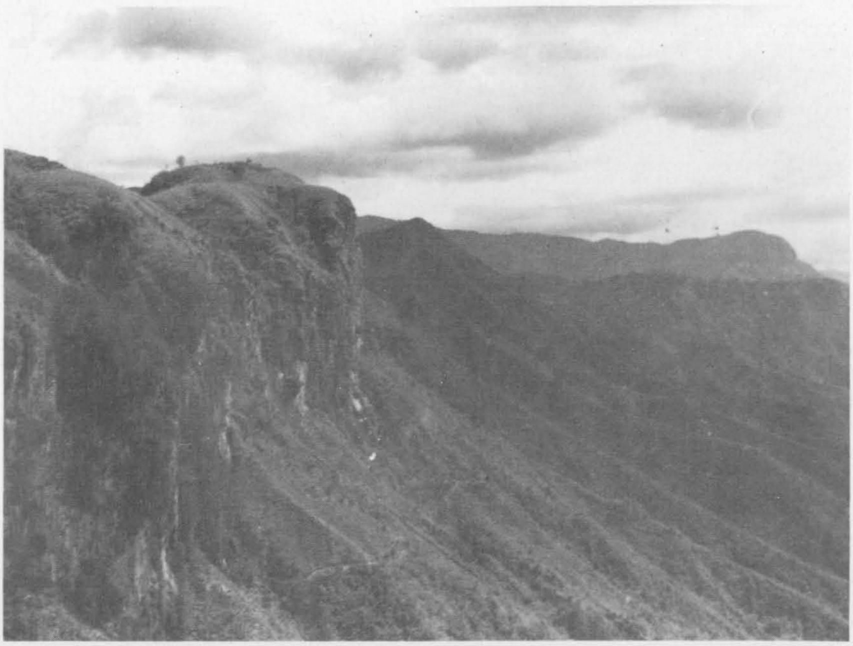


Figure 16. Outlier of reef limestone of the Kuta Formation overlying deeply weathered Kubor Granodiorite (right) near Gurumugl, 13 km west of Kundiawa.

The Kuta Formation attains a thickness of about 250 m southeast of Kuta; elsewhere it is 30 to 40 m near the Korman River and about 100 m in the Gurumugl area (west of Kundiawa).

Lithology

In the Kuta/Mount Oga area, the formation consists mainly of dense pale buff to light grey limestone resting on a basal arkose. At the type locality, Rickwood (1955) described a 'few feet of basalt' overlying the Kubor Granodiorite, then calcareous arkose which grades up into limestone; in other places the basal basalt is missing. At locality 20NG2688, 10.4 km south-southeast of Mount Hagen town, the sequence consists of massive pale grey crystalline limestone dipping west at about 5°. In Momai Creek, southeast of Kuta (about 13 km south-southeast of Mount Hagen), Kubor Granodiorite, hornfelsed Omung Metamorphics, and red to multicoloured volcanic rudites are unconformably overlain by coarse arkose grading up into gritty limestone. Farther south, in Tobe Creek east of Koibuga village, massive buff-coloured sandy crystalline limestone, about 200 m thick, directly overlies coarse granodiorite. The limestone dips west at 45°, and is overlain by Kondaku Tuff dipping at 38° to the southwest; this limestone bed was downfaulted into the granitic basement before the deposition of the Kondaku Tuff.

On the west side of the Kaip valley, 10 km east-southeast of Mount Hagen, a bed of massive dark grey limestone, which dips northwest, rests directly on the granodiorite, and is overlain by dark grey shale and siltstone (probably Maril Shale).

Across the valley, on Mount Oga (Figs. 14, 15), the Kubor Granodiorite and Omung Metamorphics are overlain by about 6 m of brown-grey sandy to gritty crystalline limestone containing sparse fossil fragments. The limestone is overlain by dark grey micaceous Maril Shale. A small outlier of Kuta limestone beside the main road and close to the Wahgi River consists of pale grey to buff coarse to fine-grained crystalline limestone containing scattered sandy granitic detritus. A larger exposure on the east side of the Wahgi River consists of fossiliferous pale grey to buff fine-grained limestone. Five kilometres farther east, also close to the main road, there is a small exposure of buff to grey medium to fine-grained crystalline limestone containing scattered granitic detritus and small fragments of brachiopods.

The prominent knobs of limestone (Fig. 16) on the northeast flank of the Kubor Anticline, between the Omung River and Neragaima Mission (6°02′S, 144°47′E), were mapped by Rickwood (1955) as part of the Maril Shale, but detailed mapping in 1968 revealed that they are biohermal reefs overlying a layer of arkose which rests unconformably on the Kubor Granodiorite; they are overlain by Maril Shale. The grey compact limestone is similar to that in the type locality.

Near Minj, calcareous arkose and limestone of the Kuta Formation grade laterally into calcareous breccias containing fragments of metamorphic rocks (Rickwood, 1955). The thin shale (or phyllite) breccia at the base of the Maril Shale, where it overlaps the Omung Metamorphics, was correlated with the Kuta Formation by Rickwood, but is more likely to be the basal part of the Maril Shale. The breccia is composed of material derived from the underlying Omung Metamorphics and Kubor Granodiorite, and crops out as an almost continuous bed beneath the Maril Shale.

Stratigraphic relationships

The Kuta Formation rests with marked angular unconformity on the Kubor Granodiorite and Omung Metamorphics. The base of the formation commonly contains abundant detritus derived from the underlying rocks. In places the Maril Shale overlies the Kuta Formation, but at Tobe Creek, 21 km southeast of Mount Hagen, and in the Wahgi River, 10 km west of Kundiawa, the Jurassic sequence is missing, and the Kuta Formation is overlain by or abuts against the Lower Cretaceous Kondaku Tuff.

Age

The foraminifera *Pachyphloia* and *Geinitzina* from the limestone near Kuta were considered to be of Permian age by Glaessner et al. (1950).

The fauna collected at various localities by Rickwood (1955) includes: *Dielasma* cf. *elongatum* (Schlotheim), *D.* cf. *itiatubense* Derby, *D.* sp., *Spiriferina* sp., *Rhynchonella* sp., *Streptorhynchus* cf. *pyramidalis* King, *Marginifera* sp., *Fistulotrypa* sp., *Pseudomonotis* sp., and an indeterminable gastropod. This assemblage was also considered to be Permian, but Rickwood states that it '. . . . . does not appear to have close affinities with either the Australian or Timor Permian.'

D. J. Belford (pers. comm.) has examined thin sections of samples of limestone from near Gurumugl Rest House, 6°03′S, 144°47′30″E, (specs 21NG0665 and 21NG2571). They contain nodosariid foraminifera that resemble the *Geinitzina/Geinitzinita* group and the genera *Frondinodosaria* and *Langella*, but definite identifications are not possible. A planispiral calcareous form lacking distinct pores in the outer wall and septa, but otherwise similar to the genus *Robuloides*, is also present.

Nodosariid genera similar to these have been recorded by Civrieux & Dessauvagie (1965) from the Permian and Mesozoic and by Crespin (1958) from the Permian of Australia. However, it is not possible at present to give a definite age to the foraminiferal fauna from the Kuta limestone.

A rhychonellid brachiopod from the same locality is considered by K. S. W. Campbell (pers. comm.) to be Triassic or Permian. Although he likens it to a New Zealand Triassic species, he does not consider it to be diagnostic. Preliminary examination by K. S. W. Campbell, J. M. Dickins, S. K. Skwarko, and D. L. Strusz of the brachiopods, ammonites, corals, polyzoans, and gastropods collected from the Kuta Formation in June 1970 led to further collections in 1971 by Skwarko and Brown with the main objective of obtaining datable ammonites. The ammonites obtained appear to be Triassic, but further work is required to refine this age estimate (J. M. Dickins, pers. comm.).

Limestone samples collected by Skwarko and Brown from near Gurumugl were examined for conodonts by R. S. Nicoll (pers. comm.): only two specimens were obtained, both of which have been identified as *Neospathodus hornsteini* (Mostler, 1967). In Australia *N. hornsteini* is restricted to conodont zone 22 (the *Epigondelella bidentata* Zone) which is equated with the *Rhabdoceras suessi* Ammonoid Zone (Sweet et al., 1971, p. 459). This would indicate that the Kuta limestone represents the upper Norian Substage of the Upper Triassic.

This last information postdated the preparation and production of the accompanying maps, which show the Kuta Formation as Upper Permian to Lower Triassic.

Structure

The Kuta Formation is generally gently dipping and only slightly folded. Near Kuta, on Mount Oga, and in the Gurumugl area, the dip is less than 10°; on the west side of the Kaip valley and farther south along the range the dip increases to as much as 45° owing to faulting.

Origin

The presence of coarse basal arkose, brachiopods, gastropods, corals, polyzoans, crinoids, foraminifera, and granitic detritus in the limestone indicates deposition on a shallow shelf. Near both Kuta and Gurumugl, the limestone covers an irregular granitic basement. The Kuta Formation does not occur above 2750 m in the Kubor Range, and it is concluded that the limestone was deposited as fringing reefs on granitic wash and breccia derived from the Palaeozoic basement.

TRIASSIC

Kana Volcanics
(Dow & Dekker, 1964)

Nomenclature

Dow & Dekker (1964, p. 12) proposed the name Kana Formation for a sequence of Upper Triassic volcanolithic sediments in the headwaters of the Jimi River to the north of the Kubor area. The sequence consists of at least 600 m of interbedded feldspathic arenite and tuffaceous siltstone with some beds of dacite-pebble conglomerate and minor quartz arenite and limestone. It conformably overlies the Jimi Greywacke, also of Late Triassic age, and is unconformably overlain by the Lower Jurassic Balimbu Greywacke. Macrofossils from the Kana River, a tributary of the Jimi River, have been assigned a Late Triassic age (Skwarko, 1967, p. 46).

The name was subsequently changed to Kana Volcanics by Dow et al. (1973) because of the high proportion of volcanic rocks outside the Jimi River area, notably in the Yuat River area and near Tabibuga in the Jimi valley.

Distribution and thickness

The Kana Volcanics crop out mainly in the Jimi valley and on the Jimi-Wahgi divide. The formation is exposed extensively but discontinuously from the headwaters of the Jimi River along the Jimi valley to the Yuat River in the South Sepik region. In the Bismarck Fault Zone/Jimi-Wahgi divide, the volcanics extend from the Chimbu River, 18 km northeast of Kundiawa, to the Lai River gap, northwest of the Kubor area. On the basis of the description by Dow & Dekker, (1964, p. 23) we have tentatively correlated the basic volcanics on Mount Udon at the east end of the Jimi-Wahgi divide with the Kana Volcanics.

The cappings of volcanic rocks on the summit ridges of the Kubor Range between Mounts Digini and Sigul Mugal (Figs. 5, 6) are almost certainly correlatives of the Kana Volcanics. Outliers have also been photo-interpreted on some of the southern spurs of the range.

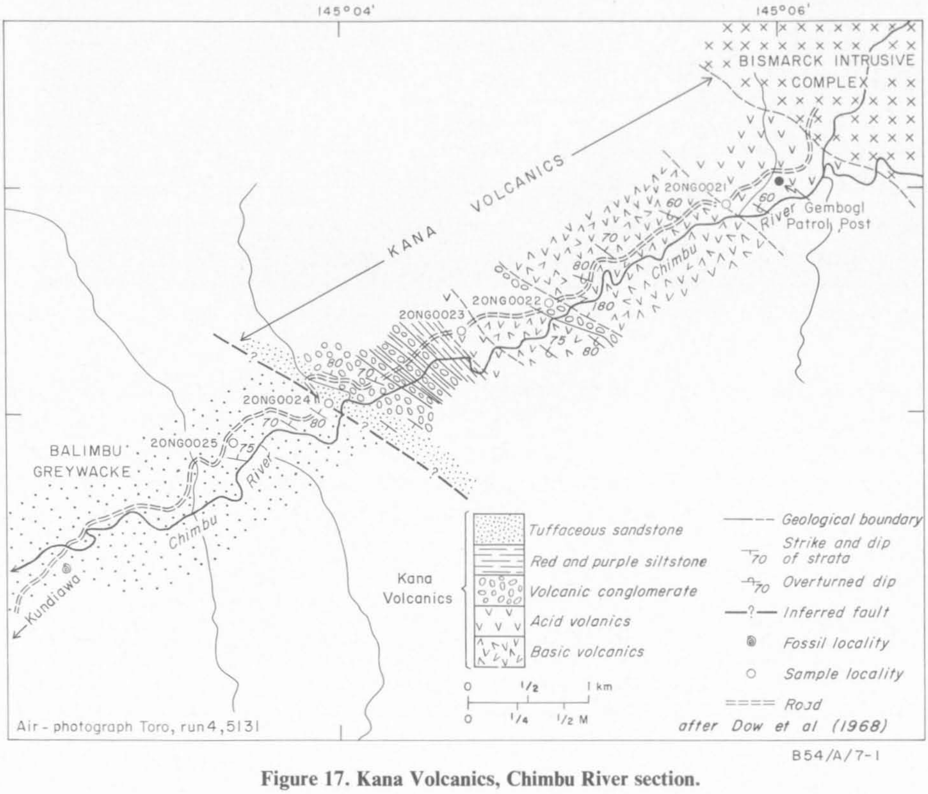


Figure 17. Kana Volcanics, Chimbu River section.

The formation is 3500 m thick in the Chimbu River type section (Fig. 17) and at least 2500 m thick in the area north of Banz. On the Kubor Range the thickness ranges from 200 to 700 m.

Lithology

The Kana Volcanics range from lavas and pyroclastics to epiclastic sediments of volcanic derivation. The lavas and pyroclastic rocks are mainly andesitic or dacitic with some basalts and rhyolites. The sediments are composed mainly of detritus derived from intermediate to acid volcanic rocks. The lavas and pyroclastic rocks (including breccia and agglomerate, Fig. 18) are subordinate to epiclastic rocks, but the proportions vary widely from place to place.

In many areas the Kana Volcanics can be recognized by the abundance of brick-red, maroon, purple, purplish red or pink, and green or greenish grey tuffs or fine-grained

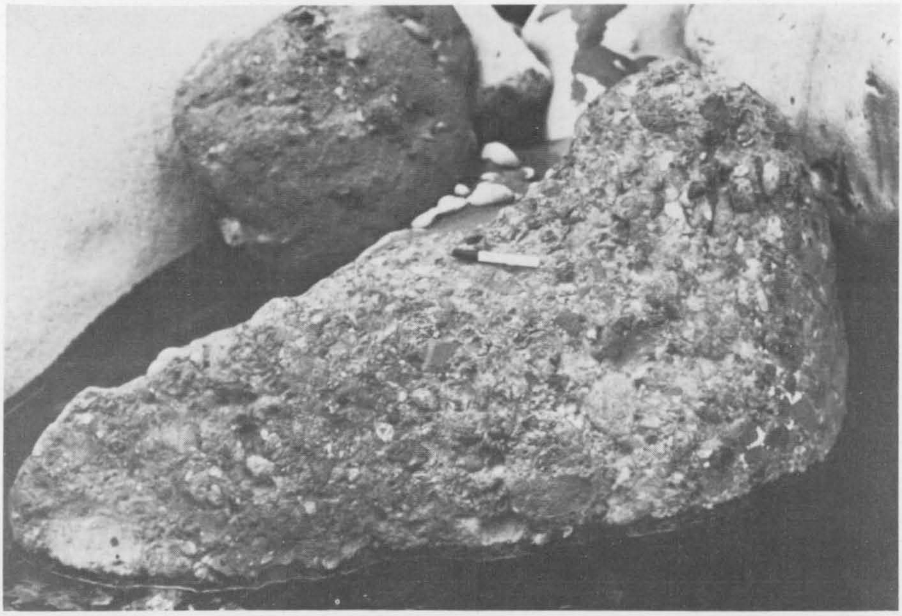


Figure 18. Boulder of purplish red agglomerate of the Kana Volcanics in the Jimi River, south of Mount Oipo.

tuffaceous sediments. The volcanic breccias and agglomerates are green or red, or contain a mixture of red and green clasts, and the volcanolithic conglomerates are characteristically red or brown. The lavas are commonly green owing to the abundance of chlorite and epidote, but red hematitic varieties are also present.

The sequence in the Chimbu River type section (Dow et al., 1973) is as follows:

Thickness (m)	*Top*
600	*Pebble conglomerate* beds up to 2.5 m thick interbedded with red *siltstone* and fine *tuffaceous sandstone*. The conglomerate consists of well rounded cobbles and pebbles and rare boulders of dacite set in a reddish purple tuffaceous matrix. Occasional basaltic pebbles are also present. The conglomerate grades up into green and reddish purple medium-bedded *feldspathic sandstone*, containing rounded pebbles of porphyritic andesite and some calcareous nodules, with some interbeds of red *tuffaceous siltstone* and *dacite-pebble conglomerate* similar to the underlying beds. The top of the sequence is probably faulted against the Balimbu Greywacke.
180	Red *tuffaceous siltstone and shale*. Small quartz and feldspar grains can generally be distinguished in the coarser varieties. There is a massive jointed unbedded band of dark grey sheared phyllite near the top.
180	Green *basaltic agglomerate* interbedded with *basalt-pebble and cobble conglomerate*. The basalt is green and highly epidotized in places.
1820	Mostly well bedded *crystal tuff* and *tuffaceous sandstone*, consisting of graded beds from 5 to 60 cm thick, grading up into light-coloured *shale* and *siltstone*. The volcanic material appears to be mainly acidic. Some *dacitic lavas and agglomerate*, and rare *dacite-pebble conglomerate*. The beds are intruded by dolerite and gabbro.
750	This part of the sequence is poorly exposed and intruded by many dykes of altered dolerite and gabbro. The sequence includes some green highly *altered* fine-grained *basic rocks*, which are probably basaltic lava flows, and bedded *andesite crystal tuff* similar to the overlying volcanics. The sequence is intruded by the Bismarck Intrusive Complex; the bottom of the sequence may be absent.

Volcanolithic, feldspathic, and tuffaceous sediments are exposed in a stream section through part of the formation 7 km southeast of the Chimbu River section. Much of the section consists of hard grey, green, or pink sandstone interbedded with red or grey tuffaceous siltstone and shale. The rocks range from massive to thinly interbedded, and the finer sediments exhibit graded bedding in places. Two of the rare calcareous interbeds, up to 10 cm thick, were found to contain poorly preserved bivalves, gastropods, and brachiopods. In places, the sequence contains massive beds of volcanolithic conglomerate composed of well rounded pebbles and cobbles of porphyritic andesite and dacite set in a grey or red tuffaceous matrix. Green massive andesite crops out near the top of the sequence, but no other lavas are present. The sequence also contains fine green volcanic breccia, dark grey foetid limestone, and a medium-grey limestone containing fragments of vesicular andesite.

Red and green volcanic breccias are abundant in the Jimi-Wahgi divide northeast of Banz; some red limestone and fossiliferous red shale were also seen. No outcrops were seen in the headwaters of the Koro River, but the presence of numerous boulders indicates that the formation is present. Green lavas of the Kana Volcanics crop out for a short distance farther downstream. On Mount Udon, Dow & Dekker (1964) reported 600 m of dolerite with some andesite grading up into 600 m of basalt, agglomerate, greywacke, and siltstone.

Intermediate lavas and pyroclastics predominate on the Kubor Range, but the outcrops on Mount Digini consist mainly of fine-grained grey or green lava and minor agglomerate. Near Mount Kubor the agglomerates and massive flow-banded or brecciated lavas are extensively chloritized and epidotized. One of the agglomerates appears to contain fractured remnants of pillow lava. Other rock types include epiclastic volcanic breccia, volcanolithic and feldspathic sandstone, and fine-grained grey or green tuff. Many of the lavas from the Kubor Range, which appear to be amygdaloidal in hand specimen, actually contain patches of an unidentified white mineral replacing plagioclase laths in the mesostasis.

Stratigraphic relationships and age

To the north, in the Jimi and Yuat Rivers, the Kana Volcanics conformably overlie slightly older Triassic sediments. In the headwaters of the Jimi River, Dow & Dekker (1964) found that the base was usually marked by a volcanolithic conglomerate, and that where the conglomerate was absent there was a downward transition into the Jimi Greywacke. In the Yuat River the Kana Volcanics overlie the Yuat Formation, which is, at least in part, equivalent to the Jimi Greywacke (Dow et al., 1968). In both areas the Kana Volcanics are overlain, probably unconformably, by the Lower Jurassic Balimbu Greywacke or its equivalent.

Within the Kubor area, similar stratigraphic relationships appear to hold north of the Wahgi valley, although the structure is complex. The Chimbu River section is overturned; the base is intruded by the Bismarck Intrusive Complex and the top appears to be faulted against overturned Balimbu Greywacke. In the Kubor Anticline, the volcanics rest unconformably on the Kubor Granodiorite and Omung Metamorphics, and are overlain by the Upper Jurassic Maril Shale 20 km north of Mount Hagen, and possibly on the south limb of the Kubor Anticline, west of the Mogono River.

The fossils collected from a few localities in the Bismarck Fault Zone are poorly preserved or otherwise unsuitable for precise dating. Skwarko (1967, p. 43) has recorded *Costatoria* cf. *melanesiana*, *Rhaphistomella? kumbrufensis*, and *Spiriferina* cf. *abichi* from locality H590 of Dow & Dekker (1964) in the Kana River. Because these forms were also found in the Jimi Greywacke which was dated as Carnian-Norian, Skwarko could not separate the two formations on palaeontological grounds, and thus the age of the Kana Volcanics is given as Late Triassic.

Petrography

The sequence in the Chimbu River type section includes lavas, agglomerates, tuffs, volcaniclastic sediments, and a microdiorite porphyry. The lavas range from basalt to rhyolite, but consist predominantly of dacite or rhyodacite. All the rocks have been altered by low-grade metamorphism. In the altered rocks the feldspar is albitized and chlorite and epidote are common, but calcite, actinolite, biotite, and muscovite are less abundant. The metamorphic grade decreases from the epidote-amphibolite facies close to the Bismarck Intrusive Complex to the lowermost greenschist facies at the downstream contact of the section and it therefore appears that the metamorphism was associated with the intrusion of the complex. A chloritized augite andesite pebble and a biotite dacite cobble from a volcanolithic conglomerate were identified from Geirinigl Creek.

The rocks north of Banz include volcanic breccia and arenite. The breccia is composed of poorly sorted angular fragments of vesicular lava ranging from fine sand-size material to clasts over 10 cm in diameter. The clastic volcanic material consists mainly of andesite and dacite. Most of the original textures are preserved, but the feldspars are albitized and chlorite, epidote, and calcite are common. Some of the clasts appear to have had glassy rims (e.g. spec. 20NG0608). In the rocks containing both red and green clasts, the red clasts are charged with fine-grained hematite, and the green clasts are chloritized. The volcanic arenites are essentially finer-grained equivalents of the breccias, and are similarly recrystallized. They commonly contain some feldspar and quartz detritus. One specimen (20NG0619) is a fine-grained recrystallized vitric tuff.

Owing to the extensive low-grade metamorphism the original composition of the lavas from the Kubor Range is uncertain. Most of them are probably altered andesites, but some altered basalt and dacite may be present. The albitized plagioclase laths commonly have a subophitic or trachytic texture. Quartz is abundant in the altered dacites or rhyodacites, and sericite is present where the rock originally contained potash feldspar. Olivine phenocrysts, altered to chlorite?, have been tentatively identified in altered basalts from Mount Digini (21NG2752) and Mount Kubor (21NG0024). The volcanolithic and tuffaceous sediments from the Kubor Range are similar to those already described, although some contain metasedimentary clasts derived from the Omung Metamorphics.

Provenance and depositional environment

The Kana Volcanics are composed almost entirely of the products of basic to acid volcanism, and include lavas and pyroclastic rocks and their transported derivatives. Most, if not all, of the epiclastic sediments were laid down in a marine environment, but some of the lavas and pyroclastics are subaerial. The presence of massive beds of volcanolithic conglomerate points to subaerial erosion, although the beds may have been laid down offshore.

The Kana Volcanics were probably laid down on and around volcanic islands that were formed along the northern margin of the Australian continent in Late Triassic time.

LOWER JURASSIC/UPPER CRETACEOUS

Wahgi Group

Up to 7300 m of shale, siltstone, sandstone, and subordinate volcanics and limestone were deposited in the Kubor Range area after erosion of the Kana Volcanics.

These rocks have been divided into five formations each of which thickens outwards from the core of the Kubor Anticline, which was probably emergent from Triassic time onwards.

Nowhere is the group seen in its entirety, owing to the structural complexity of the area. Observable sequences above the Triassic/Jurassic unconformity are shown below:

	Kol Syncline	*Kubor Anticline*	*Lower Jimi Valley*
Upper Cretaceous		Chim Formation	
Lower Cretaceous	Kondaku Tuff	Kondaku Tuff	
Upper Jurassic	Maril Shale	Maril Shale	Maril Shale
Middle Jurassic	Mongum Volcanics		
Lower Jurassic	Balimbu Greywacke		Balimbu Greywacke

Correlatives of the Wahgi Group are the Feing and Kuabgen Groups (Blucher Range Sheet area) and the Om and Lagaip Beds (Wabag and Blucher Range Sheet area).

Balimbu Greywacke
(Dow & Dekker, 1964)

Definition

The Balimbu Greywacke (Dow & Dekker, 1964, p. 14) is a Lower Jurassic sequence of interbedded greywacke and siltstone (Fig. 19) which crops out in the headwaters of the Jimi River 50 km northeast of the Kubor Range. The type section in Balimbu Creek on the north limb of the Kol Syncline is about 300 m thick. The Balimbu Greywacke rests unconformably on the Upper Triassic Kana Formation, and is conformably overlain by the Mongum Volcanics of probable Middle Jurassic age. Ammonites from the type area indicate a Sinemurian-Pleinsbachian age (Skwarko, 1967, p. 46; 1973).

Figure 19. Fossiliferous Balimbu Greywacke in the Jimi River, 3 km north of Mongum. The sequence consists of greywacke with interbeds of shale.

Distribution

Rocks correlated with the Balimbu Greywacke have been mapped in three areas in the Bismarck Fault Zone: in the Chimbu River, in the Koro (Kworu) River, and along the southern fall of the Jimi-Wahgi divide between Banz and Nondugl. The formation also crops out above the Kana Volcanics and directly beneath the Maril Shale between the Tsau and Gai Rivers to the north of the Kubor area. The presence of Early Jurassic fossils on the divide between the Yuat and Muramuni Rivers suggests that the Balimbu Greywacke may extend for 140 km to the northwest of the type area (Skwarko, 1973; Dow et al., 1973).

Koro River. In the Koro River, northeast of Kerowagi, Dow & Dekker (1964) mapped a sequence of greywacke, siltstone, and shale, which they correlated with the Balimbu Greywacke on the basis of lithology and an ammonite of probable Early Jurassic age (Skwarko, 1967; 1973). They pointed out that although the apparent thickness was over 1300 m, repetition by faulting was likely.

The Koro River sequence was re-examined in 1968. The sequence consists mainly of dark blue-grey sandstone*, dark grey siltstone, and shale. The sandstone is well bedded, indurated, and moderately well jointed. The detritus consists mainly of fragments of rock and feldspar, and appears to be mainly of volcanic origin; the grainsize ranges from fine sand to grit. Carbonaceous fragments are common, if not characteristic. Thinly bedded to massive shale and siltstone interbedded with sandstone form less than half the sequence. Some of the finer sediments have a tuffaceous appearance.

A large, but poorly preserved, belemnite about 20 cm long was found in shale near Bogo Rest House (20NG2635), close to the Koro River ammonite locality (H549) of Dow & Dekker (1964). G. R. Stevens (pers. comm.) of the Geological Survey of New Zealand has been unable to provide a positive identification, but he pointed out that similar large belemnites are known in the Lower Jurassic in other parts of the world. Also noted were sinuous worm trails on a bedding plane in sandstone.

The Koro River sequence appears to overlie the Kana Volcanics to the southwest and to directly underlie the Maril Shale to the northeast, but one or both of the contacts may be faulted. The sequence has been disturbed by numerous faults and divergent dips are common. The Koro River sequence is probably a southeasterly extension of the Balimbu Greywacke on the southern limb of the Kol Syncline, and has a minimum thickness of about 1500 m.

Other occurrences

Rocks correlated with the Balimbu Greywacke crop out in the Chimbu River 15 km northeast of Kundiawa (Dow et al., 1968, p. 25). The sequence of greywacke, siltstone, and shale is 1500 m thick, and is overturned steeply to the northeast. It is faulted against overturned Kana Volcanics to the northeast, and overlies overturned Maril Shale to the southwest. Apart from incipient metamorphism, the sequence is similar to that in the Koro River. The siltstone and shale are strongly cleaved, and in places the beds are cut by dolerite dykes up to several metres wide. Indeterminate bivalves and a poorly preserved ammonite were collected from within 200 m of the contact with the Maril Shale (20NG0561).

South of the Jimi-Wahgi divide, the Balimbu Greywacke appears to occupy a fault-bounded strip trending southeast from north of Banz towards Kerowagi. The lithology is similar to that of the Balimbu Greywacke elsewhere, but as the strati-

* The term sandstone is used in preference to greywacke as the rocks contain relatively little matrix, and do not display turbidite structures.

graphic relationships are uncertain, correlation is tentative only. The strip is faulted against Cretaceous rocks to the south and the Kana Volcanics to the north. The beds dip moderately to steeply northeast, and the thickness is about the same as the estimated thickness of the Koro and Chimbu River sequences.

The formation is absent in the Kubor Anticline, probably because of the emergence of the anticline in the Early Jurassic; the emergence corresponds with the unconformity between the Maril Shale and Kana Volcanics and the older rocks. Alternatively, it is possible that the unfossiliferous lower part of the Maril Shale may be equivalent to the Balimbu Greywacke.

Provenance and environment of deposition

The distribution and thickness of the formation suggest that it was deposited in an elongate trough extending 170 km northwest from the Chimbu River to the Yuat-Maramuni divide. The detritus was derived mainly from pre-existing volcanic rocks (Kana Volcanics?) and possibly from contemporary volcanism, as some of the rocks appear to be tuffaceous.

Mongum Volcanics
(Dow & Dekker, 1964)

Definition

In the Kol Syncline, in the headwaters of the Jimi River, the Mongum Volcanics (Dow & Dekker, 1964, p. 15) overlie the Lower Jurassic Balimbu Greywacke and underlie the Upper Jurassic Maril Shale. The type section, on the north limb of the Kol Syncline 2 km north of Mongum village, consists of 250 m of basaltic agglomerate and pillow lava interbedded with pebble-cobble conglomerate and tuffaceous greywacke. From its stratigraphic position, Dow & Dekker inferred a Middle Jurassic age, but Early or Late Jurassic ages are also possible.* The fossils from the type area are too poorly preserved to be identified.

Distribution

The Mongum Volcanics crop out on both limbs of the northwesterly trending Kol Syncline. The boundaries have been interpreted from the aerial photographs and from field observations by Dow & Dekker in 1962; the area was not revisited in 1968 or 1970.

In the Koro River sequence, which is a southerly extension of the Kol Syncline, the Mongum Volcanics are not present probably because of thinning or faulting east of Mount Udon. Elsewhere in the Jimi valley/Bismarck Fault Zone area, the Maril Shale rests directly, and probably unconformably, on the Balimbu Greywacke. With the possible exception of the basic volcanics underlying the Maril Shale in the Maramuni River (Dow et al., 1973) the Mongum Volcanics appear to be restricted to the Kol Syncline.

Maril Shale
(Edwards & Glaessner, 1953)

Nomenclature

Following Noakes' (1939) tentative subdivision of the Chimbu River/Wahgi gorge sequence, Edwards & Glaessner (1953, p. 97) proposed the name Maril Shales for the

* The Balimbu Greywacke fauna has been dated as Sinemurian-Pliensbachian, and the Maril Shale fauna as Kimmeridgian (Skwarko, 1967; 1973). The interval between includes the late Lower, Middle, and early Upper Jurassic.

basal unit of 'siliceous and calcareous shales'. In 1945 Glaessner identified the Late Jurassic bivalve *'Buchia' malayomaorica* among the fossils collected by Noakes. Rickwood (1955) subsequently mapped the Maril Shales around the east end and north flank of the Kubor Anticline. Dow & Dekker (1964) amended the name to Maril Shale in accordance with the Australian Code of Stratigraphic Nomenclature.

In the earlier descriptions, the upper and lower boundaries are not specifically defined, but in the Wahgi gorge type section we place the bottom at the unconformity with the Omung Metamorphics and the top at the incoming of volcanolithic sediments of the Kondaku Tuff.

Distribution and thickness

More recent mapping (e.g. Dow & Dekker, 1964, Dow et al., 1973, Mackenzie & Bain, 1972) has shown that the Maril Shale extends for 220 km from the Kubor Anticline in the southeast to the Muramuni River in the South Sepik region. Within the map area, the formation is exposed mainly around the basement core of the Kubor Anticline and in the Bismarck Fault Zone.

The thickest sequence is at the east end of the Kubor Anticline. Along the northern limb, the thickness diminishes to the west from 1200 m in the Wahgi gorge to about 400 m in the Omung River; it is about the same in the Minj, Tuman, and Korman (Komun) Rivers and lenses out beneath the Kondaku Tuff 8 km southeast of Mount Hagen. On the southern limb, the formation is about 1500 m thick in Olefa Creek, 7 km west of Gumine; it thins to about 1000 m in the Mogono River and pinches out 30 km farther west. It reappears around a small window of Kubor Granodiorite in the Wembo River, 25 km south of Mount Hagen, at the west end of the anticline. The summits of Mount Oga and Mount Mani at the northwest end of the Kubor Range are capped by small outliers of Maril Shale.

The formation also crops out in the Kuni and Muga Rivers (the 'Keleng Hill' area of Rickwood, 1955) at the northwest end of the Wahgi valley, where it is at least 1200 m thick.

In the Bismarck Fault Zone, a belt of Maril Shale extends from Gorgme, in the Chimbu River, to the Kol Syncline north of Mount Udon. The stratigraphic thickness is uncertain owing to extensive faulting, but Dow & Dekker (1964) give an estimate of 1000 m in the nose of the Kol Syncline, to the north of the Kubor area. In the Bismarck Fault Zone, the formation is repeated by reverse faulting and reappears in the Chimbu and Koro Rivers to the southwest of the main exposures.

The largest exposures lie to the north and northwest of the Kubor area, where a broad and almost continuous belt extends for 180 km from the Tsau River to the Maramuni River. In the Tsau River the thickness exceeds 2000 m, and a similar thickness has been reported in the Maramuni area (Dow et al., 1973).

Topography

The Maril Shale generally crops out in well developed strike ridges. Dip-slopes are particularly prominent on the north flank of the Kubor Anticline where a resistant arkose member is present.

Lithology

The formation consists of massive or well bedded moderately indurated grey shale and siltstone with variable proportions of mica and carbonate. There are commonly two well developed sets of joints and a flaggy parting parallel to the bedding. The calcareous shale and siltstone tend to disintegrate into small blocky fragments.

Pyritic and carbonaceous shale and siltstone are common 8 km west of Gumine and 2 km south of Neragaima. The pyrite occurs as concretions up to 30 cm across, or as thin lenses or finely disseminated grains. Where pyritic, the sediments are usually dark grey and carbonaceous. A thin lens of schungite?, a vitreous carbon mineraloid with a high titanium content, was collected from the Maril River by inhabitants of the Gumine area.

The formation contains interbeds of fine to medium-grained sandstone ranging from 10 cm to 2 m thick. Thin beds of grey to dark grey calcilutite are widely distributed, and red or green shale have also been noted in various localities.

In the Kubor Anticline, the base of the Maril Shale is generally defined by a bed of breccia-conglomerate up to 20 m thick (see also p. 00). The conglomerate is composed of poorly sorted angular to subrounded clasts of slate, phyllite, metagreywacke, and granodiorite derived from the underlying basement, and fragments of shale, greywacke, quartz, sandstone, chert, limestone, and volcanic rocks. The matrix consists of siltstone, sandstone, grit, or limestone. The basal rudite grades locally into coarse arkosic sandstone where the formation overlies the Kubor Granodiorite.

On the northern limb, between the Wahgi gorge and Omung River, the middle of the formation consists of up to 200 m of resistant arkose interbedded with minor shale, calcareous sandstone, and calcarenite.

In the north, the sequence also contains a few thin flows of green or grey amygdaloidal lava. Pillow lavas were noted on the road between Gurumugl and Neragaima Mission. In a few places thin beds of volcanic breccia and fine tuff are associated with the lava flows. Some dykes were also noted.

In the Wahgi gorge, the formation is intruded by a sill of diorite up to 15 m thick (Kera Sill p. 00); similar sills are common 20 km northeast of Mount Hagen and in the Tsau River to the north of the Kubor area. The sills may be related to the interbedded lava flows.

The basal part of the sequence at the east end of the Kubor Anticline includes lenses of limestone up to 70 m thick. The boulders of dark grey fine-grained limestone from one of the lenses west of the Gumine-Kundiawa road contain conspicuous echinoid plates. Some of the boulders are crowded with phyllite clasts derived from the underlying metamorphic rocks.

Stratigraphic relationships and age

In the Kubor Anticline, the Maril Shale generally rests unconformably on the Omung Metamorphics or Kubor Granodiorite. At the northwest end, the formation locally overlies Permian-Triassic limestone of the Kuta Formation, and in the Gurumugl area, 15 km south of Kerowagi, it abuts against partly exhumed biohermal reefs of the Kuta Formation. It rests unconformably on the Upper Triassic Kana Volcanics 20 km northeast of Mount Hagen town and probably also on the southern flank of the anticline, west of the Mogono River. In the Kubor Anticline, the formation is everywhere overlain by the Lower Cretaceous Kondaku Tuff. The contact in some areas is apparently conformable, but in places there is a slight angular unconformity.

In the Kol Syncline, the Maril Shale conformably overlies the Mongum Volcanics and is overlain, possibly unconformably, by the Kondaku Tuff (Dow & Dekker, 1964, p. 16). To the southeast in the Koro and Chimbu Rivers, the Mongum Volcanics are absent, and the Maril Shale rests, probably unconformably, on the Lower Jurassic Balimbu Greywacke.

A Late Jurassic age is indicated by the widespread occurrence of *Malayomaorica malayomaorica* and to a lesser extent *Inoceramus* cf. *haasti* (Fig. 20). The fauna is considered to be Kimmeridgian (Skwarko, 1967, p. 46).

Figure 20. *Inoceramus* **cf.** *haasti* **(large ribbed shells) and** *Malayomaorica malayomaorica* **(small bivalves at top left) in the Maril Shale.**

Rickwood (1955) recognized *'Buchia'* (= *Malayomaorica*) *malayomaorica* at a number of localities along the north flank of the Kubor Anticline. He concluded that the fossils occur in a single horizon within the formation, but this was not supported by our observations, although many of them do occur in a distinctive red calcareous siltstone in the middle of the sequence (cf. Edwards & Glaessner, 1953, p. 98). The fauna occurs in the middle and upper parts of the formation, but not in the lower. Thus it is possible that the base of the formation may be Middle Jurassic or even older.

Petrography

The shale and siltstone consist of poorly sorted angular to subrounded grains of quartz, feldspar, muscovite, biotite, fine-grained volcanic rocks, and chert set in a matrix of calcite, sericite, clay minerals, and opaque matter. Carbonate mud, bioclastic debris, and calcareous microfossils are also present, and with an increase in the carbonate content the rocks grade into impure calcilutite.

The arenites are typically quartzofeldspathic or arkosic. The compact arkoses on the north limb of the Kubor Anticline consist of angular to rounded clasts of quartz and feldspar in about equal proportions (60-80% of total), with subordinate muscovite, biotite, rock fragments, and very little matrix. The feldspars are sodic plagioclase, orthoclase, and microcline, and the rock fragments are mainly fine-grained basic to intermediate volcanics and phyllite and slate. The arenites also contain a little myrmekite, epidote, zircon, hematite, sphene, and opaque minerals. Burial metamorphism has resulted in some recrystallization of quartz, albitization of plagioclase, and the growth of sericite and possibly stilpnomelane?. Elsewhere the sandstones are generally similar, but tend to be quartzofeldspathic rather than arkosic, and contain higher proportions of matrix and rock fragments.

The lava flows on the north limb of the Kubor Anticline are probably altered andesite and dacite. The less altered rocks contain oligoclase-andesine, and possibly some potash feldspar. Augite is preserved in two specimens, but the ferromagnesian minerals are generally altered to epidote, chlorite, and calcite. In the more altered rocks the feldspars are commonly albitized or replaced by calcite which forms up to 70 percent of some of the rocks. Two are altered dacite or rhyolite. Some of the rocks contain amygdales filled with chlorite or calcite.

A fine-grained vitric tuff near an intermediate lava flow on the north limb of the Kubor Anticline, 11 km southwest of Kundiawa, consists of devitrified glass shards and some detrital quartz and feldspar. The shards have been altered to chlorite, albite, calcite, leucoxene, and opaque minerals. One of the specimens contains 40 percent calcite. Edwards & Glaessner (1953, p. 109) have described two radiolarian cherts from the upper third of the Maril Shale in the Wahgi gorge.

The Maril Shale is relatively unaffected by burial metamorphism. Laumontite and prehnite are abundant in the volcanolithic and tuffaceous sediments in the overlying Kondaku Tuff and Chim Formation (p. 00), but have not been recognized in the Maril Shale, probably because of the paucity of volcanic detritus and the high carbonate content which would inhibit the growth of lime zeolites or prehnite during burial metamorphism (Coombs et al., 1970).

Provenance and depositional environment

Most of the detritus in the Maril Shale was probably derived from granitic and metamorphic rocks, but some of it may have been derived from the Kana and Mongum Volcanics. The most likely source of the granitic detritus is the pre-Mesozoic basement in the highlands and western Papua. In contrast with the overlying Cretaceous sediments, contemporaneous volcanism played only a minor part.

The fine-grained calcareous sediments were laid down on a shallow marine shelf during a period of relative stability and reduced volcanic activity. The absence of coarse sediments, except for the basal breccia-conglomerate and lenses of arkose around the Kubor Anticline, suggests that most of the beds were deposited some distance from land or that the landmass had a subdued relief. The axis of the Kubor Anticline was probably partly emergent at times. The arkose member on the north limb probably originated from erosion of exposed islands of Kubor Granodiorite, as ripple marks, shallow-water cross-bedding, and plant fragments occur in the arkose.

Upper Jurassic sediments crop out over large areas of the western highlands and have been recorded in many petroleum exploration wells in western Papua (APC, 1961). In the western highlands, fine-grained marine sediments containing *Malayomaorica* have been reported from the Wok Feneng, a tributary of the Fly River (Kuabgen Group; Osborne, 1945) and from the Strickland gorge (D. Jenkins, BP Petroleum Development Pty Ltd (Australia), pers. comm.). The thick marine sediments in the Telefomin area contain Late Jurassic ammonites (APC, 1961) and *Malayomaorica* occurs in the Sitipa Shale in the April River area (Dow et al., 1973).

Kondaku Tuff
(Edwards & Glaessner, 1953)

Nomenclature

The name Kondaku Tuffs was used by Edwards & Glaessner (1953) for the basal sandy part of the Cretaceous section along the Wahgi and Chimbu gorges, which was measured by Noakes (1939). Rickwood (1955) used the name for 'about 6,000 feet of well-bedded volcanic breccia, tuff, conglomerate, greywacke siltstone and shale' in the Kubor Range/Wahgi valley area. The name has been amended to Kondaku Tuff to conform with the Australian Code of Stratigraphic Nomenclature, and refers to the Lower Cretaceous tuffaceous sandy part of the Wahgi Group.

Distribution and thickness

The Kondaku Tuff is exposed continuously around the periphery of the Kubor Anticline. It extends from the foothills, at an altitude of about 2200 m, outwards into the Wahgi, Nebilyer, and Kaugel valleys, and southwards into the Mount Suaru area and southeastwards to the Asaro River. The formation is also exposed on the Jimi-Wahgi divide to the northwest and northeast of Kerowagi, where small blocks, surrounded by older Triassic and Jurassic rocks, have been caught up in the Bismarck Fault Zone. It crops out in prominent ridges and dip-slopes formed by resistant beds of sandstone and tuff. The drainage has a well developed rectilinear pattern.

Noakes (1939) and Rickwood (1955) estimated the thickness of the Lower Cretaceous sequence in the Chimbu River section at 2000 m, but detailed mapping in 1968 has shown the thickness to be about 2450 m. The average thickness elsewhere is about 2000 m, but in many areas the sequence is partly repeated by faulting (Wahgi valley) or folding (south flank of the Kubor Range).

Lithology

The Kondaku Tuff consists of interbedded grey-green lithic and tuffaceous sandstones, dark grey and green-grey shale, siltstone, tuff, coarse sandstone, conglomerate, lava, and agglomerate. The shale and siltstone are generally interbedded on a small scale, while the sandstone forms separate, thicker beds. Sandstone is more abundant in the lower part of the formation than the upper, and is most abundant north of the Kubor Range, where it forms about 35 percent of the sequence.

Shale and siltstone are common throughout the formation, but predominate in the upper part of the sequence. Tuff, coarse sandstone, and conglomerate also occur throughout the formation, and some lavas and agglomerates occur in the middle part of the sequence in some areas.

The shale and siltstone, some of which is calcareous, are generally finely interbedded, and occur as thin partings in sandstone and in beds up to about 100 m thick with minor sandstone partings. There are some beds of massive, banded, or laminated shale which lack intercalated siltstone, and some beds of banded to finely laminated siltstone which lack shale. Soft-sediment slump deformation is common, and intensely disturbed sequences up to 30 m thick have been observed. Calcareous nodules up to 60 cm long are common, but less so than in the overlying Chim Formation. They are dark grey to black, and composed mainly of fine-grained clays and calcite. The nodules are ellipsoidal or lenticular, and many of them have surficial polygonal desiccation cracks and deep gashes filled with white coarsely crystalline calcite. The shale and siltstone in the upper part of the formation are characterized by vague dark streaks and traces of worm or bivalve burrows lined with dark organic (faecal?) material. Small lenses of diatomite and thin beds of impure limestone also occur in a few places in the upper part of the unit.

The sandstone in the Kondaku Tuff is green to grey-green and predominantly lithic or tuffaceous. It occurs in units up to 150 m thick, composed of laminae or beds up to 7 m thick. The presence of thinner beds of sandstone, rhythmically interbedded with shale and siltstone beds of similar thickness, is a characteristic feature of the Kondaku Tuff. The thicker sandstone beds commonly contain thin pebbly layers, scattered fragments of black shale (up to 10 cm), and, less commonly, small fragments of grey limestone. Lenses of diatomite, layers of lapilli and pumice fragments, and highly contorted sandstone clasts occur in a few places. Tuffaceous layers rich in charred plant remains (e.g. 21NG1074) or shelly fossils are common near the top of the formation.

Sedimentary features in the sandstones include small-scale cross-bedding in the laminated sandstone and graded bedding in the coarser banded sandstone. Many of the sandstone beds have irregular contacts with the underlying shale, and fragments of shale have been plucked out and incorporated in the basal part of the sandstone. Intraformational breccias are less common; they are composed of angular to subangular, generally blocky fragments of sandstone set in a matrix of sand with a slightly different colour and grainsize. In places, the sandstone clasts have been rotated, possibly as a result of solifluxion and the injection of unconsolidated sand into fractures in more compact beds. The highly disturbed laminated sandstone seen in some outcrops probably also resulted from solifluxion.

The tuff beds are concentrated in the lowermost and uppermost parts of the formation, and near the top they commonly contain abundant charred remains of leaves and twigs. The beds are thin, laminated to massive, and friable. Outcrops are commonly flaggy.

Outcrops of resistant coarse sandstone and conglomerate are common, although they only form a few percent of the sequence. They are composed of subangular to rounded clasts of greenish, grey, and reddish fine-grained volcanic rocks, slate, black chert, pale grey limestone, coarse-grained granodiorite or diorite, yellow-brown quartzite, and rare fragments of brachiopods and gastropods. Volcanic clasts are the most common, and some of the conglomerate beds are composed almost entirely of fragments of greenish grey fine-grained volcanic rocks. The beds of coarse-grained sediments are up to 10 m thick, and are generally hard and massive. Sorting is fair to good, with little matrix, and there is commonly a cement of zeolite or calcite, or both.

Lava flows occur in the middle part of the sequence, mainly north of the Kubor Range between Minj and Kundiawa. They range from unaltered augite rhyodacite (21NG1167) and slightly altered andesite (20NG2612A) to spilite (20NG2610B).

Stratigraphic relationships and age

The Kondaku Tuff rests on the Upper Jurassic Maril Shale, from which it is distinguished by the presence of green tuffaceous sandstone. In places there is clear evidence of angular unconformity, but elsewhere there is a paraconformable relationship. In the Wilde River area, on the southwest flank of the Kubor Range, the Kondaku Tuff directly overlies the Kubor Granodiorite and Omung Metamorphics. The sequence grades up into the Upper Cretaceous Chim Formation, and the contact is taken where the massive beds of lithic sandstone disappear.

The Kondaku Tuff is probably of early Aptian to Albian age. Edwards & Glaessner (1953) list the following Early Cretaceous fauna collected by G. A. V. Stanley near Kundiawa: *Deshayesites* sp. nov. (early Aptian), *Cymatoceras* sp., fragment of a large phragmacone of *'Belemnites' sellheimi* Tenison Woods, and *Pleuromya* sp. Stanley also collected the following Albian fossils 18 km southeast of Kundiawa: *Puzosia* sp., *Cymatoceras* sp., *Aucellina gryphaeoides hughendenensis* (Etheridge),and foraminifera including *Pleurostomella reussi* Berthelin.

Edwards & Glaessner (1953) found *Globigerina*, Radiolaria, and in the upper 460 m of the formation, *Ostrea* sp., *Pseudavicula* sp., and abundant plant remains. They maintain that the fauna and flora are similar to those in the Lower Cretaceous Purari Formation of northern Papua.

Rickwood (1955) also recorded the presence of *Glomospira* sp., *Ammodiscus* sp., *Dorothia* sp., *Cibicites* sp., and *Gyroidina* sp. in the red shale near the base of the Kondaku Tuff.

During the 1968 survey, abundant *Ostrea*, coiled gastropods, and charred plant remains were found in the friable tuffaceous sandstone at numerous localities in the upper part of the formation; 18 km west-northwest of Kerowagi on the Highlands Highway, gastropods, bivalves, and belemnites were found in tuffaceous sandstone (20NG2625 and 20NG2626).

Petrography

The petrography is summarized in Table 1.

The shale and siltstone generally consist of clay minerals, feldspar (mainly plagioclase), quartz, and fragments of volcanic rocks, including some altered glass. The calcareous rocks are composed predominantly of micritic calcite and clay, and commonly contain scattered foraminifera.

The sandstone is predominantly lithic labile or sublabile, and is composed of fragments of fine-grained basic volcanic rocks and subordinate fine-grained sedimentary rocks. About half the sandstone is tuffaceous and contains glass shards. Other clasts include plagioclase, quartz, augite, potash feldspar, and minor biotite, muscovite, hornblende (up to 1 cm), iron oxides, tourmaline, zircon, apatite, and sphene. Edwards & Glaessner (1953) also recorded topaz, ilmenite, and rare enstatite and sulphides. Occasional small pellets of bright green fine-grained glauconite or chlorite, or both, are also present. Plagioclase, much of which has been albitized, is ubiquitous, as is quartz, but augite and potash feldspar are absent in much of the sandstone. Secondary quartz, prehnite, and calcite are common, and much of the volcanic detritus, including glass shards, has been chloritized.

The tuff consists of glass, angular grains of quartz and albitized feldspar, opaque minerals, and generally some secondary chlorite; some of the glass is partly chloritized. Prehnite and calcite are commonly present, but zeolites (usually laumontite) are rare.

Provenance and depositional environment

The Kondaku Tuff consists mainly of volcanic detritus and volcanic rocks. The abundance of lava flows and agglomerates, and fragments of volcanic rock and glass, decreases rapidly to the south of the Wahgi valley. Edwards & Glaessner (1953) concluded that the source of the volcanic detritus was to the north of the Wahgi valley, probably around the Jimi-Wahgi divide. The granitic detritus in some of the quartzose sandstones includes a variety of heavy minerals that are not found in volcanic rocks, and was probably derived from the ancestral Kubor Range.

The lithology and sedimentary structures indicate deposition in a shallow subsiding trough (cf. Edwards & Glaessner, 1953) close to the volcanic source rocks. The presence of coarse conglomerate, pebble bands, lava flows and agglomerate, and small-scale cross-bedding all indicate deposition in shallow water. As the trough deepened the proportion of conglomerate and lava flows decreased, and the overlying Chim Formation was laid down in moderately deep water.

Burial metamorphism

Crook (1961) recognized the effects of burial metamorphism in the Kondaku Tuff. The specimens he examined were collected by Noakes (1939) and described by Edwards & Glaessner (1953). The plagioclase is albitized throughout the formation, and in the top 900 m some of it has been replaced by laumontite. In the bottom 900 m

TABLE 1. ESTIMATED MODES, KONDAKU TUFF‡

	Quartz (%)	Plagioclase (%)	Potash Feldspar (%)	Rock Fragments (%)	Augite (%)	Biotite (%)	Opaque Minerals (%)	Calcite (%)	Prehnite (%)	Height Above Base (m)	Other Minerals
1.	—	20(Ab)	tr.	5*	1	tr.	tr.	—	40	0	tr. muscovite & epidote. *5% chlorite after volcanic glass
2.	1	5	—	5+	1-2	—	3	—	10	0	2% glass
3.	tr.	—	tr.	60?	tr.	—	—	5	—	2500±	tr. chlorite
4.	2-3	15(Ab)	—	55*	5	—	tr.	tr.	10	1000	*5-10% chlorite after volcanic glass
5.	2-3	20	—	60*	—	—	tr.	2	—	?	5% leucoxene. *10% chlorite after volcanic glass
6.	7	20	5(S)	55	8-10	—	tr.	tr.	—	1400	—
7.	10	15	5	45-50*	—	—	8	2	—	top	5-10% leucoxene. *5% chlorite after volcanic glass
8.	15	25(Ab)	—	20	altered	—	tr.	—	20	0	5% tourmaline, 15% chlorine, tr. epidote
9.	15	5	—	60	—	—	1-2	15	—	0	tr. glauconite
10.	15	5-10	—	50	tr.	—	10-15	tr.	—	0	10-15% altered glass, tr. chlorite
11.	15	25	—	25*	20	—	tr.	—	10	0	2% zeolite, 5% matrix. *25% chlorite after volcanic glass
12.	15	5	—	35-40	—	—	2	35-40	—	?	3% glauconite
13.	20	10(Ab)	3	37	—	1	10	15	—	top	3% glauconite, 1% chlorite
14.	3	30(Ab-Ol)	—	40*	2	tr.	—	—	20	300	tr. hornblende *5% chlorite after volcanic glass
15.	5(sec.)	40(Ab)	8	10*	—	—	10	2	15	0	*10% chlorite after volcanic glass
16.	10(sec.)	60(Ol)	—	10	5	—	—	—	10	0	2% hornblende, tr. sphene, 5% chlorite
17.	40	10	—	40*	—	tr.	1-2	—	—	?	*5% chlorite after volcanic glass
18.	60	15(Ol-And)	2-3	15	—	—	1	1	—	900	2% glauconite
19.	40	10(Ol-And)	—	35	5	—	2	tr.	1	300	1% hornblende, 5% chlorite
20.	30	25	—	25*	—	—	tr.	5	—	1300	rare zircon. *10% chlorite after volcanic glass
21.	35	3(Ab)	10	tr.	—	tr.	10	35	—	300-600	tr. apatite, 5% glauconite
22.	50	—	—	30	—	tr.	—	10	—	200	tr. tourmaline & glauconite
23.	50	tr.(Ol)	—	15	—	tr.	—	30	—	900	tr. muscovite & glauconite
24.	50	tr.(Ab)	—	38(glass)	—	—	10	—	—	600	tr. muscovite, 2% glauconite
25.	25	5	10	60	—	—	—	—	—	2200	tr. hornblende, garnet, glauconite, matrix, & chlorite

TABLE 1—*continued*

	Quartz (%)	Plagioclase (%)	Potash Feldspar (%)	Rock Fragments (%)	Augite (%)	Biotite (%)	Opaque Minerals (%)	Calcite (%)	Prehnite (%)	Height Above Base (m)	Other Minerals
26.	tr.	abundant(Ab)	—	altered	abundant	—	—	—	—	near top	5% brookite, abundant zeolite
27.	25	5(Ab)	—	5(glass)	—	—	tr.	—	—	900	15% chlorite
28.	20	20(Ab)	—	60(glass)	—	—	—	—	10	600	tr. epidote
29.	5(sec.)	35	—	2-3(glass)	—	—	2	30	—	450	25% chlorite after volcanic glass
30.	tr.	5	5	5(glass)	tr.	—	—	—	60	0	10% chlorite after volcanic glass, 1% epidote
31.	15	15	tr.	60(glass)	—	tr.	2	3	—	0	5% chlorite
32.	—	80(And)	—	—	19	—	2	—	—	1200	tr. apatite, 5% chlorite, 2% leucoxene
33.	—	40(Ab?)	—	—	—	—	5-7	40	—	900	3% chlorite
34.	20	15	—	—	10	—	—	2	5	600-900	30% chlorite, 15% actinolite, 1% epidote
35.	5	20(Ab)	—	—	—	—	—	5	—	300	50% chlorite

‡Components which can be identified—the remainder consists of matrix. *Partly to completely chloritized—see Other Minerals.
Abbreviations: Ab—albite, And—andesine, Ol—oligoclase, S—sanidine, sec.—secondary.

Tuffaceous/volcanolithic sediments

1. Tuffaceous feldspatholithic arenite (21NG1035B)
2. Tuffaceous arenite/grit (20NG1254G)
3. Feldspatholithic greywacke (21NG0548A)
4. Tuffaceous feldspatholithic labile arenite (21NG1151)
5. Tuffaceous feldspatholithic arenite (20NG0599)
6. Feldspatholithic labile arenite (21NG2584A)
7. Tuffaceous quartz-feldspatholithic labile arenite (20NG1212A)
8. Feldspatholithic greywacke (21NG1035C)
9. Feldspatho-quartz lithic arenite (20NG1239)
10. Tuffaceous lithic labile siltstone (20NG1254A)
11. Tuffaceous lithic greywacke (21NG1050A)
12. Calcareous lithic arenite (20NG2626A)
13. Calcareous lithic arenite (21NG1087A)

Feldspathic sediments

14. Tuffaceous feldspatholithic labile arenite (20NG1295A)
15. Tuffaceous feldspatholithic greywacke (21NG1024A)
16. Lithofeldspathic sublabile greywacke (21NG1024D)

Quartzose arenites

17. Quartzose lithic labile arenite (20NG0597)
18. Feldspatholithic sublabile arenite (21NG2610A)
19. Quartzose lithic labile arenite (20NG1295B)
20. Quartzose feldspatholithic labile arenite (21NG0607A)
21. Calcareous feldspathic quartzose arenite (21NG1101)
22. Quartzose lithic labile arenite (21NG0544B)
23. Calcareous quartzose lithic labile arenite (21NG0555)
24. Tuffaceous quartzose lithic labile arenite (21NG1285)

Coarse-grained sediments

25. Lithic grit

Tuffs

26. Zeolitized tuff (21NG0548B)
27. Altered tuff (21NG1366)
28. Altered tuff (21NG1289)
29. Vitric-crystal tuff (21NG1109)
30. Altered tuff (21NG1304A)
31. Altered tuff (21NG0531)

Lavas

32. Augite andesite (20NG2612A)
33. Altered amygdaloidal lava (spilite) (20NG2610B)
34. Metamorphosed augite rhyodacite (20NG1169)

some of the plagioclase is replaced by prehnite, which also forms a cement in many of the rocks. He suggests that a temperature of 300°C and a pressure of at least 1450 bars are required for the formation of prehnite.

Crook estimated a depth of burial of 10 500 m; but more detailed mapping in 1968 indicates that the depth of burial of the base of the Kondaku Tuff was about 5500 m. This estimate is based on a thickness of 2500 m of Kondaku Tuff and 3000 m of Chim Formation. It is unlikely that the Eocene-Miocene sequence covered the Kondaku Tuff, as assumed by Crook, but if it did, and extended over the Kubor Range, the total depth of burial could have been no more than 6300 m.

Zeolitization was noted in only two specimens collected in 1968, but prehnite is abundant in the lowermost 100 m of the formation, which contains a high proportion of volcanic detritus, lava flows, and agglomerate. With a few exceptions, prehnite does not occur in association with calcite. Coombs et al. (1970) have pointed out that under conditions of high partial pressure of carbon dioxide in burial metamorphism, lime zeolites, prehnite, pumpellyite, and zoisite can all be suppressed in preference to calcite and chlorite. This explains the absence of prehnite in the calcareous rocks in the lower part of the Kondaku Tuff and most of the underlying Maril Shale.

The effects of burial metamorphism are manifest at a depth of only 4500 m in the Wahgi valley sequence in contrast to 7000 m in the Southland sequence in New Zealand and 4900 m in the Tamworth Trough (Crook, 1961). This is probably due to the nature of the rocks involved. A thick pile of basic volcanic detritus, basic lava flows, and agglomerate, and interbedded siltstone and shale would probably retain some magmatic heat, and would generate an appreciable amount of radiogenic heat. The volcanic and volcanolithic rocks would also be more susceptible to chemical changes relative to pelitic, quartzofeldspathic, or siliceous sediments that are more stable at the low temperature of burial metamorphism.

Structure

In the Wahgi valley area, the Kondaku Tuff dips regularly at 20° to 35° to the northeast, and is disturbed only by a small number of faults. Small faults (such as those shown in Fig. 21) have juxtaposed different beds within the formation, while

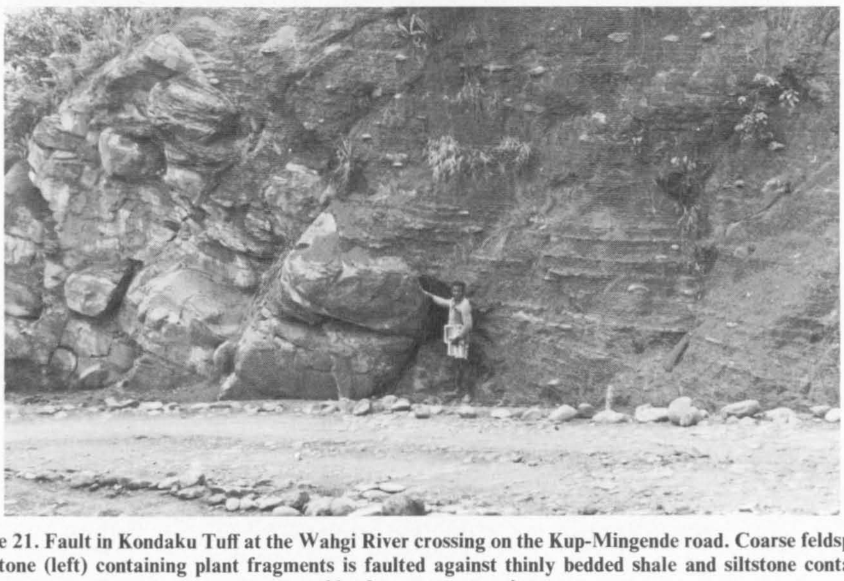


Figure 21. Fault in Kondaku Tuff at the Wahgi River crossing on the Kup-Mingende road. Coarse feldspathic sandstone (left) containing plant fragments is faulted against thinly bedded shale and siltstone containing ovoid calcareous concretions.

larger faults have either repeated parts of the sequence (near the Wahgi River), or have brought the Kondaku Tuff into contact with older formations (north side of the valley). Northwest and southeast of the Kubor Range, along the axis of the Kubor Anticline, small gentle folds (Fig. 22) and minor faults are present. South of the Kubor Range, stronger folding about closely spaced non-parallel axes has taken place, and dips are irregular. The massive sandy beds in the Kondaku Tuff have behaved as competent units, but there has been some soft-sediment slumping in the thicker shaly interbeds. The amplitude of most of the slump folds ranges from a few metres to a few tens of metres. The sandstone and tuff are divided into blocks by a system of rectilinear joints, from 10 cm to about 1 m apart, but some of the massive tuffaceous beds are poorly jointed.

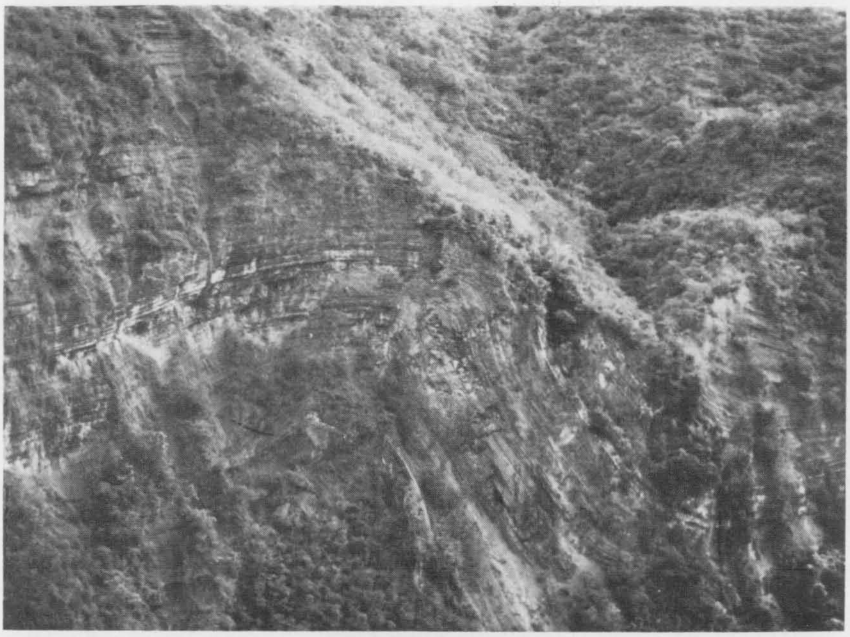


Figure 22. Monoclinal fold in Kondaku Tuff on southern side of the Wahgi River gorge, 20 km west of Lufa.

Chim Formation
(Rickwood, 1955)

Nomenclature

After examining specimens collected by Noakes (1939) in the Chim (now Chimbu) River, Edwards & Glaessner (1953) divided the Upper Cretaceous rocks into the Maram Shales and Chimbu Tuffs. Rickwood (1955) used the name Chim Group for the Upper Cretaceous sequence of 'shales with occasional cone-in-cone structure, greywackes and tuffaceous mudstones' in the Chimbu area. As no separate formations were recognized by us, the name has been amended to Chim Formation.

Distribution and thickness

The Chim Formation crops out around the outer flanks of the Kubor Anticline, from the Bismarck Fault Zone near Kerowagi southeastwards to Mount Michael, and westwards to Mount Ialibu and into the Nebilyer valley.

Relief is moderate to gentle, and the streams cutting the formation generally have broad V-shaped valleys, with very few gorges. Outcrops are mainly restricted to the streams.

Noakes (1939) estimated the thickness of the type section of the Upper Cretaceous sequence along the Chimbu River to be 3200 m, and we estimate a thickness of about 2400 m east of the Chimbu River, where the dip is consistently to the northeast at about 30°. The sequence is probably thickest to the south of the Kubor Range, but it is difficult to estimate the true thickness because of folding and faulting. The average thickness of the formation is probably about 3000 m.

Lithology

The Chim Formation consists predominantly of grey, dark grey, and almost black micaceous mudstone and siltstone which, in places, contain ovoid fine-grained calcareous nodules, and subordinate interbeds of sandstone, conglomerate, tuff, agglomerate, calcarenite, and limestone.

The mudstone and siltstone beds range from massive and uniform to thin and rhythmically interlaminated, and commonly contain vague dark streaks and worm burrows, as in the Kondaku Tuff. The calcareous nodules range from a few centimetres to over a metre long, and many contain microfossils, ammonites, bivalves, and belemnites.

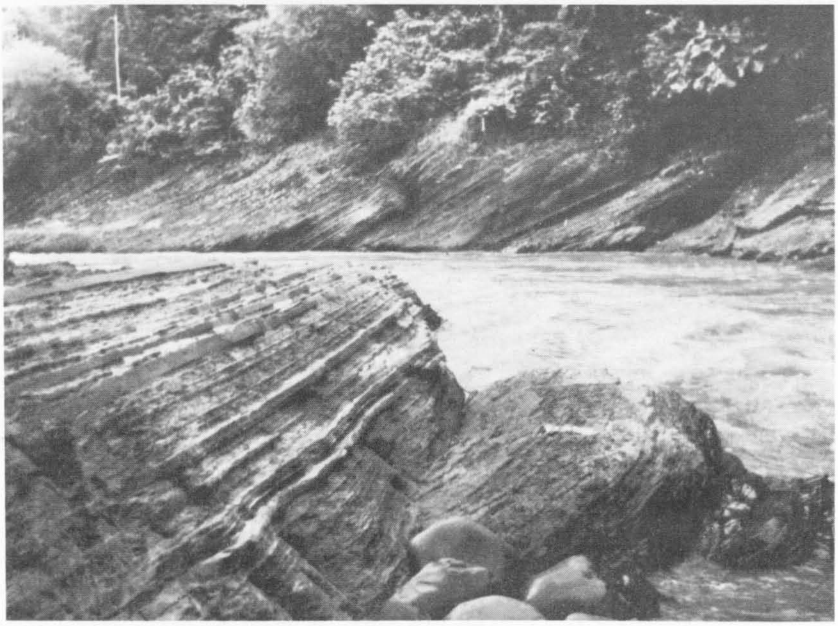


Figure 23. Interbedded sandstone, siltstone, and limestone of the Chim Formation in the Tua River, 30 km west-southwest of Lufa.

Thin (Figs. 23, 24) to thick (Fig. 25) very fine to medium-grained, pale to dark greenish grey sandstone interbeds are present throughout the mudstone and siltstone sequence. They are widely to closely spaced and some display small-scale cross-bedding and ripple marks.

The mudstone and siltstone are also commonly interbedded with thin beds (Fig. 23), lenses, and nodules, up to 10 cm long, of pale grey to medium grey fine-grained limestone. Cone-in-cone structure is common in the darker beds and lenses.

Figure 24. Thinly bedded siltstone and sandstone of the Chim Formation in the west bank of the Tua River about 1 km downstream of the confluence of the Wahgi and Asaro Rivers.

Figure 25. Massive bedded sandstone of the Chim Formation in the Tua River adjacent to and stratigraphically below the beds shown in Figure 24. The vine bridge is about 12 m above the river.

Chimbu River section

We have remeasured the upper part of the type section taking advantage of almost continuous outcrop along the newly made roadway parallel to the river on the west bank. The thicknesses given in the following description are only approximate.

Thickness (m)	*Top*
57	No outcrop.
12	*Shale*, grey brecciated.
1.2	*Sandstone*, coarse-grained, lithofeldspathic, grains angular, and some polymict pebble *conglomerate*.
23	*Conglomerate*, polymict, pebble to cobble, with clasts of fine-grained acid? volcanics, sandstone, shale, and limestone and matrix grading downwards from shale to tuffaceous siltstone and sandstone. Clasts, especially limestone, larger and more numerous towards base of unit; some shell casts.
21	*Conglomerate*, as above but even coarser in lower half, and two beds, each 3 m thick, of massive grey *shale* in upper part.
7	*Sandstone*, lithic, beds 2-30 cm thick, interlaminated with beds of *shale* 2-5 cm thick and rare beds of *calcarenite* 5-10 cm thick; downwards increase in percentage of shale, and strong penecontemporaneous deformation in lower 3 m.
16	*Siltstone-sandstone*, calcareous, laminated, rhythmically interbedded with laminated *shale* in beds 2-10 cm thick. Shale slightly subordinate at top but predominant at base.
4	*Calcarenite*, laminated, beds 10-20 cm thick, with interbeds of *shale* 2-5 cm thick; some intraformational faults with displacements up to 10 m and penecontemporaneous deformation.
21	*Shale*, thick beds, with minor interbeds of *sandstone* (15-30 cm at top, grading downwards to 2-5 cm at base) and massive beds and lenses of *calcarenite* 30 cm-2 m thick. Shale beds strongly deformed by penecontemporaneous slumping; late Cenomanian/early Turonian foraminifera (20NG0688).
2	*Conglomerate*, sheared.
12	*Shale* and *sandstone*, as above, with coarse-grained 2.5-m bed of *calcarenite* containing shale clasts.
21	*Shale*, beds 5-15 cm thick, with rare lenses of fine-grained *limestone* up to 2.5 cm thick interlaminated with beds of *siltstone* and *sandstone* 5-15 cm thick and minor *calcarenite* beds up to 40 cm thick. Possible ripple mark casts on base of sandy beds.
15	No outcrop.
15	*Calcarenite*, laminated, cross-bedded, coarse-grained, with large shale clasts and pebbly beds 1-2 m thick and thin interbeds of *shale* 5-8 cm thick.
7.5	*Shale* thinly and rhythmically interbedded with *sandstone*; penecontemporaneous deformation in upper 3 m.
13.5	No outcrop.
7.5	*Greywacke*, massive greenish grey, coarse-grained, calcareous, volcanolithic, with fragmental fossil shell material.
29	No outcrop.
18	*Shale*, massive, fissile, grey.
48	No outcrop.
31.5	*Shale*, massive, silty, with some fine sandy beds.
48	No outcrop.
109.5	*Shale* with interbeds of fine grey-green lithic *sandstone* and *calcarenite*, up to 40 cm thick and about 1-2 m apart, and some calcareous nodules (2 cm $\times$ 15 cm); numerous small faults.
24	No outcrop.
31.5	*Sandstone*, pale greyish green, cross-bedded, tuffaceous, thinly interbedded with coarse *siltstone* and thin laminae of dark grey *shale*.
42	No outcrop.
16.5	*Shale*, dark grey, dark greenish grey *siltstone*, and minor laminae of coarse lithic *sandstone* 1-5 cm thick in upper part; laminated *sandstone* and interbeds of *shale*, 15 cm thick, in sets ranging from 15 to 30 cm thick in lower part.
21	No outcrop.
12	*Shale* interlaminated with *sandstone*.
58	No outcrop.
1	*Agglomerate*, weathered.
51	No outcrop.
9	*Agglomerate*, dark green, faulted against laminated medium-grained lithic *sandstone* with interbeds of *shale* 1 cm thick.
12	*Sandstone*, tuffaceous, grey, pale weathering, beds 8-15 cm thick, with *shale* interbeds.
6	*Agglomerate* and *volcanic breccia*.
	Lower part of formation not measured but predominantly massive grey shale with calcareous nodules.

Stratigraphic relationships and age

The Chim Formation is of earliest Late Cretaceous age and conformably overlies the Lower Cretaceous Kondaku Tuff. Along the northeastern and eastern flanks of the Kubor Anticline it is overlain unconformably or at least paraconformably by the Eocene to Oligocene Chimbu Limestone. The precise nature of this relationship is not known as the upper contact is not exposed. If there is an angular discordance it may be due either to tilting and erosion, or partly or wholly to thrusting of the Chimbu Limestone to the south over the Chim Formation. South of the Kubor Anticline, the Miocene Darai Limestone generally rests on the Chim Formation with strong angular unconformity, but in places the contact is apparently conformable. Jenkins et al. (1969) believe that the Chim Formation was involved in the diapiric folding of the Darai Limestone into flat-bottomed steep-sided synclines. Sliding on a décollement at the base of the Darai Limestone may have truncated the steep-limbed diapiric anticlines in the Chim Formation and juxtaposed the flat-lying limestone and near-vertical mudstone.

Around Mount Michael the middle Miocene Movi Beds rest unconformably on the Chim Formation, and east of Mount Sauru the formation is unconformably overlain by the upper Palaeocene Pima Sandstone. In the Nebilyer valley, the Chim Formation is overlain by Palaeocene calcareous mudstone and the Eocene to Oligocene Nebilyer Limestone.

The following Cenomanian ammonites, collected at Mingende by Noakes (1939), were identified by Glaessner (1945): *Euomphaloceras hoeltkeri* (Erni), *Puzosia* sp., *Turrilites* cf. *scheuchzerianus* Bosc., *Inoceramus* sp., and a few foraminifera, including *Textularia* cf. *washitensis* Carsey.

The specimens collected by Noakes in the Chimbu River section include *Textularia* sp., and among the specimens from the Mingende area given to G. A. V. Stanley by the local people (Stanley, 1950) were *Mantelliceras* sp. and *Turrilites* cf. *acutus* Passy.

The specimens collected in 1968 from the Tua River, south of Mount Suaru, contain the following species: *Praeglobotruncana stephani* (including *turbinata*-forms) and *Hedbergella* spp. (21NG0648) and *Globotruncana* spp. (including the *G. lapparenti* group), *Praeglobotruncana* sp. cf. *P. stephani*, *?Hedbergella* sp., *Heterohelix* sp., *Anomalinoides* sp. cf. *A. undulatus* Belford, *Textularia* sp., and *Hyperammina* sp. (abundant) (21NG0651).

The fauna from specimen 21NG0648 is late Cenomanian to early Turonian (Binnekamp & Belford, 1970). Specimen 21NG0688, collected 160 m stratigraphically below the top of the type section in the Chimbu River gorge, contains a fauna of similar age (D. J. Belford, pers. comm.).

No fauna younger than Turonian has been found in the Chim Formation, and the age ranges from Cenomanian to early? Turonian, that is, early Late Cretaceous.

Petrography

The mudstone and siltstone consist of clay minerals, angular to subrounded fragments of volcanic rock, quartz (up to 30%), and plagioclase (generally oligoclase or andesine), and small amounts of muscovite, biotite, calcite, and heavy minerals. The siltstone is well sorted and contains only a small amount of clay matrix, but the mudstone consists predominantly of clay minerals, with small quantities of quartz, micas, and other fragments. The heavy minerals include magnetite, limenite, zircon, epidote, and rare tourmaline.

The sandstone is composed of quartz, fragments of volcanic rocks, plagioclase, muscovite, biotite, small rounded aggregates of glauconite, and traces of zircon and ilmenite. In places the sandstone contains a high proportion of calcite cement and grades into sandy limestone; in others, it consists almost entirely of quartz, rock fragments, and feldspar. Sorting is good to very good, and the grains are generally subangular to subrounded. The ilmenite is commonly altered to 'leucoxene' (anatase or brookite, or both); other secondary minerals recorded in places include hydrated iron oxides, calcite, and chlorite.

Structure

Northeast of the Kubor Anticline, the Chim Formation dips regularly to the northeast. There are numerous small folds to the east and southeast of the Kubor Range, and strong folding and faulting to the south. Faulting has caused some deformation northeast of Kerowagi, and vertical dips associated with shearing are common in the Tua River area, near Mounts Suaru and Karimui.

Superimposed on the large-scale folding and faulting are numerous folds and contortions produced by contemporaneous and intra-formational slumping, notably west of Kerowagi. Deformation ranges from gentle irregular intraformational folds to intensely and complexly contorted beds. The folds have an amplitude of up to several metres.

Provenance and depositional environment

Edwards & Glaessner (1953) noted the lack of granitic detritus in the Cretaceous sediments of the Wahgi valley, and the apparent subaerial origin of much of the tuffaceous detritus. They concluded that the beds were laid down in a shallow geosyncline and that the sediment was derived from an andesitic volcanic source to the north.

Small-scale cross-bedding, ripple marks, fine laminations, and well sorted sandy beds all point to shallow-water deposition. No detritus from the core of the Kubor Anticline has been positively identified in the Chim Formation. These observations support the conclusions of Edwards & Glaessner (1953) (see p. 00).

TERTIARY
(Fig. 26)

Ta STAGE (Upper Palaeocene/Eocene)

Pima Sandstone
(new name)

Definition

The Pima Sandstone is a sequence of fossiliferous sandstone and interbedded siltstone and mudstone, which crops out extensively to the east of Mount Suaru and extends across the Tua River to longitude 145°E. The name is derived from the Pima River (6°23′S, 145°49′E) where the formation is well exposed.

The thickness probably exceeds 2000 m in the type area in Oliabai Creek, and may be as much as 3000 m elsewhere. At the base of the sequence a massive bed of sandstone, at least 300 m thick, rests unconformably on mudstone and siltstone of the Chim Formation. The basal sandstone and other sandstone beds higher in the sequence thin to the west, and to the west of Mount Suaru the sequence consists almost entirely of mudstone. The western end of the Pima Sandstone is covered by the Pleistocene Suaru Volcanics.

EPOCHS	East Indian "letter" Stages		Planktonic Foraminiferal Zones	APC and BP informal Papuan Stages
late Miocene	Tg	?	N 15	
	Tf	upper (f 3)	N 14 N 13	Ivorian
middle Miocene	Tf	?	N 12 N 11 N 10	Taurian
		?	N 9	
early Miocene	Te	upper (e 5)	N 8 N 7 N 6 N 5 N 4	late Kereruan
late Oligocene	Te	lower (e 1 - 4)	N 3 (= P·22) N 2 (= P·21) N 1 (= P·20)	Kereruan
middle Oligocene	Td			
early Oligocene	Tc			
late Eocene	Tb			upper Eocene
middle Eocene	Ta 3			middle Eocene

B55/A/31

Figure 26. Tertiary nomenclature.

Topography

The formation crops out as prominent strike ridges, dip-slopes, and bluffs of massive sandstone, especially south of the Tua River. The basal sandstone forms an almost continuous scarp which can be traced on the aerial photographs around the Pima Syncline. The Pima River and other streams have cut deep gorges across the sandstone.

Lithology

The sandstones are fine to coarse-grained, pale grey, green-grey, or dark grey, and feldspatholithic. The beds are up to 3 m thick, with numerous lenticular fossiliferous beds up to 1 m. In Oliabai (or Olu) Creek, southeast of Mount Suaru, tuffaceous beds and rare conglomerate are present. Fine laminations, ripple marks, and small-scale cross-bedding are well developed in some of the sandy beds. The massive sandstone beds are intercalated with beds of dark grey to black mudstone and siltstone, which are laminated in part, and thin interbeds of fine sandstone. The sandstone beds are up to 200 m thick, and are rich in carbonaceous matter, rock fragments, and clay minerals. Ferruginous nodules and sandstone clasts are present in places.

Structure

The Pima Sandstone has been folded into a broad synclinorium with many smaller folds and a few small faults. The general trend is east-northeast, but swings to east-west near Mount Suaru. Except where the beds are disturbed by faulting, the dip is generally less than 50°, and becomes subhorizontal east of Mount Suaru.

Fossils and age

Skwarko (pers. comm.) has identified Ostraeidae, possibly related to *Ostrea* and *Exogya, Rotularia* sp. (closely resembling *R. spirulaea* (Lamarck) , and fragments of various Pectinidae and gastropods in the sandstone from Oliabai Creek. A similar fauna, including *Pecten*-like pelecypods, was noted in the Pima River and an unnamed tributary, 19 km east-southeast of Mount Suaru. The age of the fauna is considered by Skwarko to be Late Cretaceous to Eocene, probably Eocene.

The sheared mudstone (21NG0618) from a tributary of the Kaugel River, east of Mount Ialibu, was found to contain: *Subbotina triloculinoides* (Plummer), *Globorotalia pseudomenardi* Bolli, *G. chapmania* Darr, *G. aequa aequa* Cushman & Renz, and a group of *Globigerina mckannai* White. This fauna belongs to the late Palaeocene *Globorotalia pseudomenardii* Zone of Binnekamp & Belford (1970), and is therefore correlated with the Pima Sandstone. Similarly, the calcareous mudstones beneath the Nebilyer Limestone in the Nebilyer valley are correlated with the Pima Sandstone. Because of insufficient information, neither of the mudstones has been separated from the Chim Formation.

Provenance and environment of deposition

The presence of shelly beds and ripple marks indicates that the Pima Sandstone was laid down in shallow water. The most likely source of the detrital material is the older rocks to the north in the Kubor Range. The Pima Sandstone closely resembles the tuffaceous sandstone of the Kondaku Tuff, and probably contains at least some reworked material from it.

Ta_3-Tc STAGE (Eocene- Oligocene)

Chimbu Limestone
(Rickwood, 1955)

Nomenclature

Rickwood (1955) applied the name Chimbu Limestone to the prominent strike ridge of Eocene-Oligocene limestone (Fig. 27) that extends for 73 km to the southeast from near Kerowagi almost to the Asaro River north of Lufa. In the type section in the Chimbu River gorge he tentatively included 100 m of Miocene (upper Te) limestone. However, the Miocene limestone occurs only as lenses in the fine-grained Miocene clastics and only near Nambaiyufa does the upper Te limestone rest on Oligocene limestone. We propose to restrict the use of the name Chimbu Limestone to the Eocene-Oligocene limestone, and to include the lenses of upper Te limestone in the Movi Beds (see p. 00).

Distribution and thickness

The Chimbu Limestone at the base of the Tertiary sequence in the southwest limb of the Yaveufa Syncline has been strongly deformed by folding and faulting. Several fault wedges of the limestone occur in the Chimbu gorge. Apart from a few small outcrops in the Goroka valley, the limestone does not appear in the northeast limb of the Yaveufa Syncline. About 300 m of calcarenite and limestone have been measured in the Chimbu River gorge. This appears to be the average thickness, although in places it is much thinner and at Mount Elimbari (Fig. 28) it may exceed 1000 m.

Figure 27. Mount Elimbari, a prominent peak at the summit of the southeasterly trending cuesta of Chimbu Limestone, from a mountain pass on the track from Chauve to Kundiawa. The Chimbu Limestone is underlain by Cretaceous sediments (right) and overlain by lower to middle Miocene sediments (left). The peak in the background is Mount Michael.

Figure 28. Mount Elimbari from the northwest.

Lithology

The Chimbu Limestone consists entirely of massive limestone and calcarenite. The sequence in the type section is as follows:

Thickness (m)	*Top*
90	*Limestone*, pure white, composed almost entirely of *Nummulites*.
60-135	*Algal* and *Heterostegina limestone*, very fine-grained, grey and buff.
7.5	*Lacazinella limestone*, brown to buff.
75	*Calcarenite*, dark grey, coarse-grained, and finer-grained brownish grey to buff *limestone* containing numerous *Fasciolites*.

The limestone contains many large solution cavities, most of which are partly filled with recemented limestone rubble. The limestone is cut by large and small faults, especially in the Bismarck Fault Zone, and small slickensided faces are common. The buff-coloured Eocene limestone, notably near Chuave, commonly contains abundant well preserved open and closed-coil gastropods, belemnites, pelecypods, and echinoids, and there is an unsubstantiated report that a complete large fish was found at one of the quarries near Chuave.

The formation was laid down in shallow water which deepened as deposition progressed.

Stratigraphic relationships and age

From near Kerowagi to the Asaro River the Chimbu Limestone rests with paraconformity? on the Upper Cretaceous Chim Formation. In the Chimbu River gorge it is overthrust onto the Maril Shale. In the Goroka valley near Asaro village it rests non-conformably on Lower Jurassic granite (Page, 1971) and near Geppavi Hill, 15 km southeast of Goroka, it overlies the Goroka Formation metamorphics, which are possibly of Palaeozoic or Mesozoic age (McMillan & Malone, 1960). The limestone is overlain by the lower Miocene Movi Beds with slight disconformity; near Namaiyufa they overlap the Chimbu Limestone cuesta.

The formation contains abundant foraminifera of middle Eocene to early Oligocene (Ta_3-Tc) age (Bain & Binnekamp, 1973), and is therefore a correlative of the Eocene-Oligocene Nebilyer Limestone, the Eocene limestone in the Erun Anticline (Rickwood & Kent, 1956), and the Eocene-Oligocene Yala Limestone (Jenkins et al., 1969). The rich macrofauna has not yet been described, but Binnekamp (Bain & Binnekamp, 1973) has completed a study of the microfossils.

Nebilyer Limestone
(Rickwood, 1955)

Distribution and thickness

The Nebilyer Limestone forms a prominent scarp on the west side of the Nebilyer valley. Rickwood (1955) described it as 'hard, grey, frequently argillaceous limestone of Eocene to Oligocene age', with a maximum thickness of 300 m.

Photogeological interpretation shows that the limestone extends to the Kaugel River, 30 km south of the Mount Hagen volcano; the outcrop is nowhere more than a kilometre wide, and in the extreme north and south it is covered by Quaternary volcanics. Jenkins et al. (1969) have recently shown that the limestone west of Togoba is only 106 m thick. The formation thins appreciably in the south and appears to lens out completely near the Kaugel River.

Lithology

The Nebilyer Limestone consists almost entirely of limestone and calcarenite with a few argillaceous and silty interbeds. The section described by Jenkins et al. (1969) is as follows:

Thickness (m)	*Top*
40	*Calcarenite*, massive, medium-grained, grey and grey-brown.
45	*Micrite*, dark grey-brown, beds 2-5 cm thick. Lower part darker, finer-grained, and more argillaceous than upper part. Lowermost 10 m consists of beds from 15 to 45 cm thick containing calcite veins and a little pyrite.
21	*Calcarenite*, dark grey to grey-brown, with thin silty and argillaceous interbeds.

Age and stratigraphic relationships

The limestone contains rare *Globigerina, Truncorotaloides,* and keeled *Globorotalia* sp. of probable Eocene age (Schuyleman, *in* Jenkins et al., 1969). Small Rotaliids, agglutinating foraminifera, rare plankton, algae, and bioclastic debris are also present.

The limestone grades conformably down into calcareous siltstone of probably late Palaeocene age, and is conformably overlain by a 6-m bed of Miocene greywacke, followed by over 550 m of mudstone and greywacke.

LOWER Te/UPPER Tf STAGE (upper Oligocene/middle Miocene)

Darai Limestone
(Buchan & Robinson, 1969)

Nomenclature

The thick Te-Tf shelf limestones in the Mendi-Kagua area were called the Darai Limestone by Buchan & Robinson (1969) and Jenkins et al. (1969). The formation covers most of the southern fall of the central range of Papua New Guinea to the west of Mount Karimui and Mount Favenc. We have included the cliffed outliers of subhorizontal lower Te-Tf limestone south and southwest of Mount Suaru in the formation.

Topography

The Darai Limestone crops out in small subhorizontal areas with a mature karst topography, which are bounded by cliffs and sharp ridges (Fig. 41). More extensive strike ridges with a superimposed karst topography and pinnacles have been developed in the south and west. The joints in the massive limestone are widely spaced, and it weathers to large cubic blocks.

Thickness

The formation is only 100 m thick in the Kubor area, but thickens to about 1200 m to the south and west. Near the Purari River, 10 to 15 km farther south, it is 500 to 1000 m thick.

Lithology

The Darai Limestone consists of thick-bedded to massive light-coloured biosparite, and calcareous arenite, with minor biosparudite* and breccia.

* The terminology is that of Folk (1965).

In the map area the lower part of the formation consists of yellow, brown, and buff to pale grey calcareous arenite and sparites, both of which are partly bioclastic, interbedded with occasional beds of calcareous siltstone and sparudite. The upper part is composed mainly of micrite and sparite.

The cross-bedded coarse-grained calcareous arenite, forming low cliffs on the south side of the Tua River west of Karimui, consists of angular fragments of quartz and feldspar (up to 60%), fragmental bioclastic material, some intact foraminiferal tests, and an ironstained calcareous cement. The calcareous arenite grades laterally and vertically into biosparite containing up to 20 percent angular to rounded clasts of fine siltstone and about 5 percent cement.

The micrite is commonly bioclastic, and may be white, cream to pale brown, or pale grey. It is composed of up to 90 percent organic detritus, consisting mainly of benthonic and planktonic foraminifera and algae. The massive micrite commonly contains interbeds and small patches of biosparite, composed almost entirely of foraminiferal tests and comminuted shells.

The dark grey-brown intrasparite is commonly composed mainly of algal, foraminiferal, and pelletal micrite fragments set in a sparry cement. Limestone breccia, some of which is intraformational, and conglomerate containing predominantly limestone detritus were observed as boulders in the streams, but both appear to be relatively rare.

Stratigraphic relationships and age

The subhorizontal Darai Limestone rests on near-vertical upper Cenomanian/lower Turonian siltstone, and is overlain by Pleistocene volcanics from Mount Karimui and Mount Ialibu. It contains foraminifera of lower Te to lower Tf age (Binnekamp & Belford, 1970). West of the Kubor area, Jenkins et al. (1969) noted that the Darai Limestone 'overlies Upper Eocene to Oligocene limestone along the northeastern flank of the Wage Anticline, and oversteps onto progressively older units of the Upper Cretaceous to the southwest. It rests on Turonian siltstones in the Mubi Valley.' In the west the formation is of lower Te to upper Tf age, and is conformably overlain by the upper Miocene to Pliocene Orubadi Beds. Similar stratigraphic relationships obtain in the Pio-Purari area south of Mount Karimui (Rickwood & Kent, 1956).

Provenance and environment of deposition

The bulk of the formation is composed of bioclastic debris and chemically formed carbonate matrix or cement of local origin, but the lowermost beds and the outcrops near the Kubor Range contain clastic quartz, feldspar, and siltstone, which were probably derived from the south side of the Kubor Range.

The medium-scale cross-bedding in the arenites and the wide-spread distribution of the bioclastic carbonate deposits indicate that the formation was laid down on a shallow marine shelf. It is the shelf facies equivalent of the basinal Aure Beds.

Aure Beds

Nomenclature

The sequence of Miocene thinly bedded calcareous clastic sediments conformably overlying the Nebilyer Limestone in the Kaugel Syncline southwest of Mount Hagen town was originally called Gai Group (Rickwood, 1955, p. 77); It has since been mapped as Pundugum Formation (Dow et al., 1973) and Aure Group (A. L. Findlay, pers. comm.). Findlay's correlation with the extensive Aure Beds 140 km to the southeast is preferred and the name Aure Beds is used here. However, the Kaugel

Syncline sequence is not representative of the entire Aure Beds (in particular there are no transitional facies beds).

Lithology and structure

West of Mount Hagen town the sequence consists of thin-bedded to laminated dark greenish grey mudstone and siltstone, medium to coarse-grained green to almost black volcanolithic sandstone, interlaminated mudstone, siltstone, and sandstone, and minor grey algal or laminated limestone. The sandstone consists of fragments of fine-grained volcanic rocks most of which have been replaced by calcite, some detrital quartz and plagioclase, and rare grains of quartzite, muscovite, and zircon set in a matrix of very fine-grained calcite. The rock contains 65 percent calcite, 5 percent of which consists of fragments of coarse limestone. The grains are subrounded to rounded, well sorted, and range from 0.2 to 1.0 mm across. The beds are flat to gently dipping, but to the south the dip steepens around the northwesterly axis of the Kaugel Syncline. The axis of a monoclinal or asymmetrical anticlinal flexure trends north-northwest along the west side of the Gogimp valley.

The sequence in the Kaugel Syncline is exposed along the road from Mount Hagen to Tambul, beyond the western boundary of the Kubor area, where it crops out in an area of moderate to strong relief. Apart from road cuttings, outcrops are confined to stream channels and eroded tracks; most are deeply weathered and partly covered by Quaternary volcanic ash. (For a description of the Aure Beds south of the Kubor Anticline see Karimui Explanatory Notes.)

Age

No diagnostic foraminifera were found in the Kaugel Syncline sequence, but the beds are believed to be Miocene on the basis of correlation with fossiliferous Aure Beds to the west and southeast.

Provenance and environment of deposition

The Aure Group was laid down in moderately deep water flanking the Kubor Range. However, the provenance is predominantly volcanic, and possibly includes both older and contemporaneous volcanic rocks.

UPPER Te/LOWER Tf STAGE (lower to middle Miocene)

Movi Beds
(new name)

Nomenclature

The Movi Beds consist of 4000 m of upper Te to lower Tf calcareous volcanolithic siltstone, sandstone, conglomerate, and limestone which crops out in the Asaro River north of Lufa. The name is derived from Movi Mission 10 km north of the Asaro River section.

Distribution and thickness

The Movi Beds are restricted to the Yaveufa Syncline and the nose and northeast and southeast flanks of the Kubor Anticline. Beyond the Kubor area, the formation extends eastwards to Okapa and southwards into the Aure Trough.

The thickness ranges from about 4000 m in the Asaro River section to less than 500 m in the Chimbu River area, both of which lie within the Bismarck Fault Zone.

The estimated thickness in the Asaro River does not allow for possible minor repetition in the incompetent shales and siltstones. However, fossil and lithological evidence shows that there is no major repetition in the sequence. The estimated thickness in the Chimbu River area may be less accurate as part of the sequence has possibly been removed by erosion.

Stratigraphic relationships and age

In the Yaveufa Syncline the Movi Beds rest unconformably on the Chimbu Limestone and are conformably overlain by the Yaveufa Formation. West and south of Mount Michael, the beds rest unconformably on the Chim Formation and possibly on the Kondaku Tuff, and are overlain near Nomane Mission by two small outliers of Holocene? olivine basalt. The basal unconformity is not exposed and has been deduced from structural and palaeontological evidence, and by photogeological interpretation. Near Nambaiyufa Mission, 12 km northwest of Lufa, upper Te to Tf limestone of the Movi Beds paraconformably overlies the Tc Chimbu Limestone. About 3.5 km west of the confluence of the Wahgi and Asaro Rivers it overlies the Chim Formation with marked angular unconformity. The formation is intruded by numerous gabbroic dykes and sills (Kenangi Gabbro) in the vicinity of the Yaveufa Formation, and by a large upper Miocene hypabyssal diorite stock (Michael Diorite) to the south of the Yaveufa Syncline.

Within the Kubor area, the formation has been dated as upper Te to Tf Stage on the basis of an abundant fauna of large and small foraminifera (Binnekamp & Belford, 1970). The Asaro River section was sampled in detail in 1970, but the material has not yet been examined. The poorly preserved echinoids from the Asaro River have been submitted to Professor G. M. Phillip for identification; other macrofossils (e.g. gastropods and bivalves) have not yet been identified.

Lithology

The Movi Beds contain a wide variety of marine sedimentary rocks, and the lithology varies considerably from place to place. The sequence consists mainly of calcareous siltstone and conglomerate with some tuffaceous beds and limestone lenses, but to the southeast of the Kubor area the flysch sequence consists of a great thickness of volcanolithic turbidites (greywacke with interbedded shale, siltstone, and intraformational slump breccias). Only the occurrences within the Kubor area, and especially the Asaro River section, are described here.

The sedimentary rocks range from calcareous shale and siltstone to volcanolithic and tuffaceous sandstone and polymict pebble conglomerate. Limestone beds and lenses up to 100 m thick occur throughout the sequence, and hornblende mangerite or gabbro dykes and sills are common in the uppermost 500 m. The dykes and sills are probably the intrusive equivalents of the volcanic rocks of the Yaveufa Formation.

The formation is well bedded (Figs. 29, 30) and consists of cyclic units from 100 to 1000 m thick composed of beds ranging from microlaminated siltstone and shale, 1 to 2 mm thick, to beds of sandstone, limestone, and conglomerate, 3 to 4 m thick. The bedding in the incompetent shales has been contorted by penecontemporaneous slumping (Fig. 31) and post-Miocene faulting, but the competent sandstone, limestone, and conglomerate units are relatively undeformed (Figs. 29, 30).

The thin sequence in the Chimbu River valley consists of light grey calcareous siltstone with a few interbeds of greenish sandstone and conglomerate. Some of the siltstone beds are micaceous, others are marly. No section was measured because the sequence is complexly folded and faulted, and poorly exposed.

In the valley of the Mai River, the Movi Beds are well exposed in small stream beds and road cuttings. The thickness is probably 2000 to 3000 m, rather than 1500 m

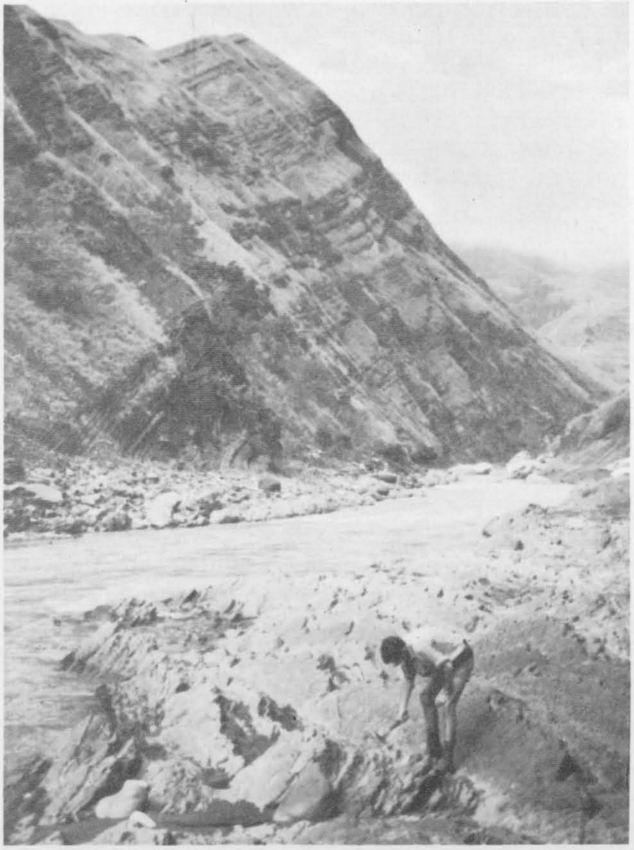


Figure 29. Interbedded sandstone and siltstone of the Movi Beds in the Asaro River, 6 km northwest of Lufa.

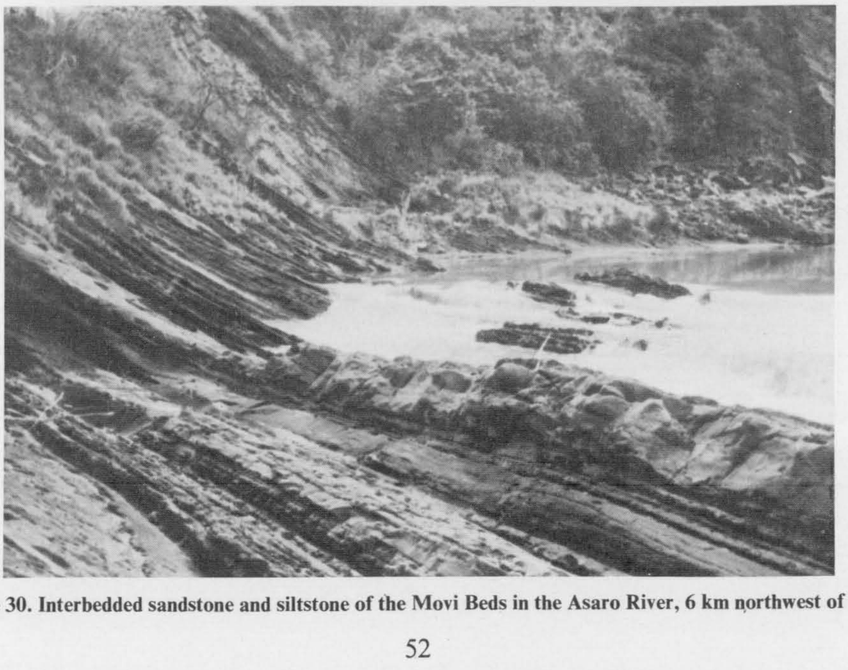


Figure 30. Interbedded sandstone and siltstone of the Movi Beds in the Asaro River, 6 km northwest of Lufa.

Figure 31. Slumped beds of shale and siltstone of the Movi Beds in the Asaro River, 6 km northwest of Lufa.

as estimated by McMillan & Malone (1955). The lowermost part of the sequence consists of interbedded tuff and limestone, with minor pebble beds. Slickensides are found on the upper and lower surfaces of the limestone beds. The tuff and limestone are overlain by interbedded dark green-grey shale and siltstone, sandstone, and dark green polymict pebble conglomerate. The conglomerate contains rounded pebbles of chert, limestone, sandstone, and various types of volcanic rocks. Some of the sandstone beds are highly feldspathic and appear to be tuffaceous. The upper part of the sequence between Chuave and Mount Kerigomna consists of massive light grey siltstone, containing sparse round pebbles of chert, limestone, and volcanics, small lenses of limestone, well indurated polymict conglomerate, and massive highly indurated fine-grained light grey sandstone. McMillan & Malone (p. 32) describe the uppermost 1500 m in the Watabung area as a sequence of grey shale and mudstone, which is calcareous in part and contains lenses of grey limestone up to 60 m thick, overlain by bedded greywacke containing abundant charred plant material. The topmost 90 m contains massive discontinuous beds of polymict pebble conglomerate up to 12 m thick.

The Te-Stage grey calcareous shale and mudstone, with thin beds and lenses of grey-green calcareous greywacke, conglomerate, and limestone, in the Asaro-Daulo area (McMillan & Malone, p. 29), are here included in the Movi Beds; the Te-Stage chert beds north of Daulo (p. 29) are also tentatively included.

A complete section of Movi Beds, 4100 m thick, is exposed in the banks of the Asaro River about 7 km north of Lufa. This is the greatest thickness recorded in the map area, and is the only complete measured section. The thicknesses given in the following description are only approximate.

Asaro River section

Thickness (m)	*Top*
0-125	*Shale*, dark grey, interlaminated with light grey calcareous *sandstone*.
125-225	*Mangerite* sill (Yaveufa Formation or Kenangi Gabbro).

Thickness (m)	*Top*
225-540	*Shale* and calcareous *siltstone*, both red and grey; minor pebble *conglomerate*; two porphyritic hornblende *mangerite* sills (1-2 m).
540-640	*Coral reef breccia*, buff.
640-800	*Siltstone* and *shale*.
800-925	*Shale* interlaminated with *siltstone* and *sandstone*; minor pebble beds.
925-1020	*Siltstone* and *shale*.
1020-1140	*Coralline limestone* (10 m), sheared, buff, grading down into greenish grey thick-bedded tuffaceous *sandstone* with calcite veins and calcareous beds (10 cm) and nodules (elongate); *conglomcrate* (5 m) containing much algal material; lithic, grey-green, massive coarse-grained, ironstained *tuff*, including 1-m beds with sandstone concretions 20-30 cm in diameter; some pebbly beds (1-2 m) and rare *sandy siltstone* beds (2-3 m) (pebbles are silicified and well indurated siltstone, sandstone, limestone, and volcanics).
1140-1240	*Siltstone*, greenish grey, coarse-grained, calcareous, friable, some laminated, some massive poorly bedded; minor thin (5-10 cm) light grey *calcareous mudstone* beds; *Operculina* sp., small gastropods and bivalves common.
1240-1285	*Sandstone*, greenish grey, thin-bedded, calcareous, with limestone clasts (2-3 cm) and nodules (20-30 cm), and angular shale fragments.
1285-1335	*Limestone*, buff, algal (20-25 m), grading upwards and downwards into grey-green calcareous *tuffaceous sandstone*; upper tuffaceous part contains coral.
1335-1520	*Sandstone*, greenish grey, tuffaceous, with abundant *Cycloclypeus* sp. (up to 60% of rock, numerous specimens up to 2 cm in diameter).
1520-1700	*Sandstone*, green, tuffaceous, beds 1-2 m thick, with beds and lenses of polymict pebble *conglomerate* from 5 cm-5 m thick. Rounded pebbles consist of green and red chert, volcanics, quartz, limestone, siltstone, sandstone, and gabbro.
1700-2100	*Sandstone*, coarse, green, calcareous, medium-bedded (10 cm-1 m) to massive (2-4 m) and *conglomerate* (1-2 m) interbedded with *shale* (10-20 m); shale contains thin (5-15 cm) beds of sandstone about 1 m apart.
2100-2200	*Shale*, light grey, massive, and minor thin calcareous beds.
2200-2210	*Limestone breccia*, cream, 1 m by 3 m lenses, contained in massive shale. Probably tidal scour channel filled with coral reef rubble and now seen in cross-section.
2210-2840	*Shale/siltstone*, light grey, massive, and minor thin calcareous beds.
2840-2890	*Siltstone* (50 m), containing *Globorotalia* sp. and *Orbulina* sp., interlaminated with *calcarenite* or *calcareous sandstone* (1-3 cm) containing abundant *Lepidocyclina*, *Miogypsina*, and rare *Spiroclypeus*.
2890-3040	*Sandstone* beds (2-60 cm), medium to coarse-grained, green, tuffaceous, with interbeds of *calcarenite* (1-3 cm); coarse sandstone beds contain lighter-coloured concretions (toroids?).
3040-3080	*Calcarenite/coral breccia* (2-5 m); grey-green *siltstone/shale* and thin interbeds of laminated *tuffaceous sandstone*; massive polymict *conglomerate*; lenses of *sandstone* and *coralline limestone breccia*.
3080-3110	*Sandstone* and *siltstone*, regularly thin-bedded (2-4 cm), greenish.
3110-3210	*Sandstone* and *siltstone*, medium-bedded (15-20 cm), tuffaceous; *limestone* (20-30 cm).
3210-3360	*Siltstone*, thinly bedded, blue-green.
3360-3860	*Siltstone/shale*, massive, laminated, grey to grey-brown, with numerous thin contorted and slickensided calcite veins.
3860-4110	*Sandstone* beds (2-10 cm), tuffaceous, green, with abundant ripple marks and carbonized wood, interbedded with grey poorly bedded *siltstone*; laminations (1-10 mm) present in both rocks; irregularly shaped beds (10 cm-4 m) of *intraformational shale* and *sandstone breccia*, especially in upper part of interval.

Unconformity

The section lies within the Bismarck Fault Zone and is strongly faulted. Disturbed bedding, small displacement faults, irregular slickensided thin calcite veins, and sheared limestone-shale interfaces are common; large parts of the thick shale/siltstone units are sheared and contorted. Small local unconformities, concretions (Fig. 32), plant material, large and small foraminifera, macrofossils, cross-bedding (Fig. 33), ripple marks, scour channels, and reef corals are common throughout the sequence.

About 20 km south-southeast of the Asaro River section, the Movi Beds contain calcareous beds up to 300 m thick which form prominent cliffs on the southern slopes of Mount Michael. The calcareous sequence consists of buff and pale grey clastic and reef limestone, calcarenite, lithic limestone breccia, and grit overlain by beds of mudstone and shale. It is strongly folded and faulted, possibly partly as a result of forceful intrusion of the adjacent Michael Diorite.

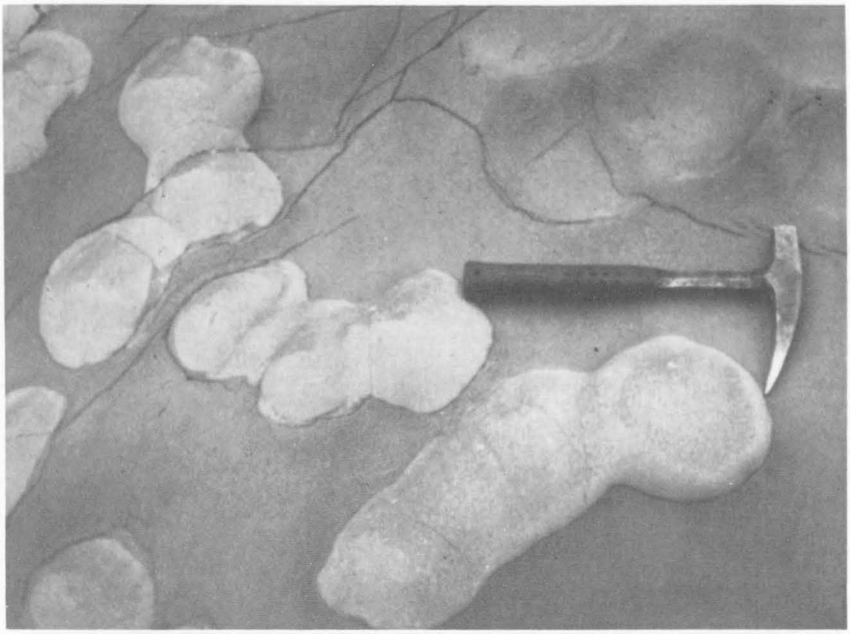


Figure 32. Toroids? on a bedding plane in tuffaceous sandstone of the Movi Beds in the Asaro River, about 6 km northwest of Lufa.

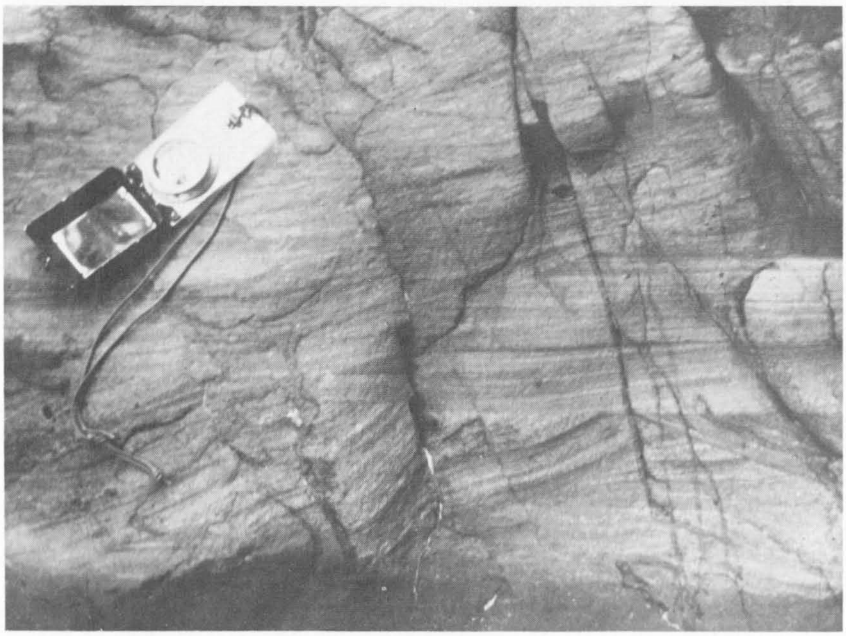


Figure 33. Cross-bedded tuffaceous sandstone of the Movi Beds, 15 km east of Mount Michael. The compass is 18 cm long.

Provenance

The siltstone, sandstone, and conglomerate were derived predominantly from andesitic rocks, although grains and small pebbles of chert, limestone, plutonic rocks, and metamorphic rocks are commonly present. The fragments of chloritized lavas and pyroclastic rocks, grains of partly sericitized and abraded feldspar, and ironstained altered ferromagnesian minerals were probably derived from late Mesozoic formations on the Miocene Kubor landmass. Reworked Chimbu Limestone is the probable source of most of the calcareous detritus. Much of the fresh clastic plagioclase and ferromagnesian crystals and fragments of fresh to partly altered volcanic rock were derived from lavas similar to those in the overlying Yaveufa Formation.

The abundance of fresh crystalline volcanic material associated with the detritus from the Kubor-Bismarck landmass (Fig. 34) suggests contemporaneous volcanism, and the freshness of the volcanic detritus indicates rapid erosion. The abundance of wood fragments and the presence of coral reefs suggest a tropical climate with a high rainfall. A similar provenance is described by Edwards (1950, p. 141) for the sediment in the southern part of the Aure Trough.

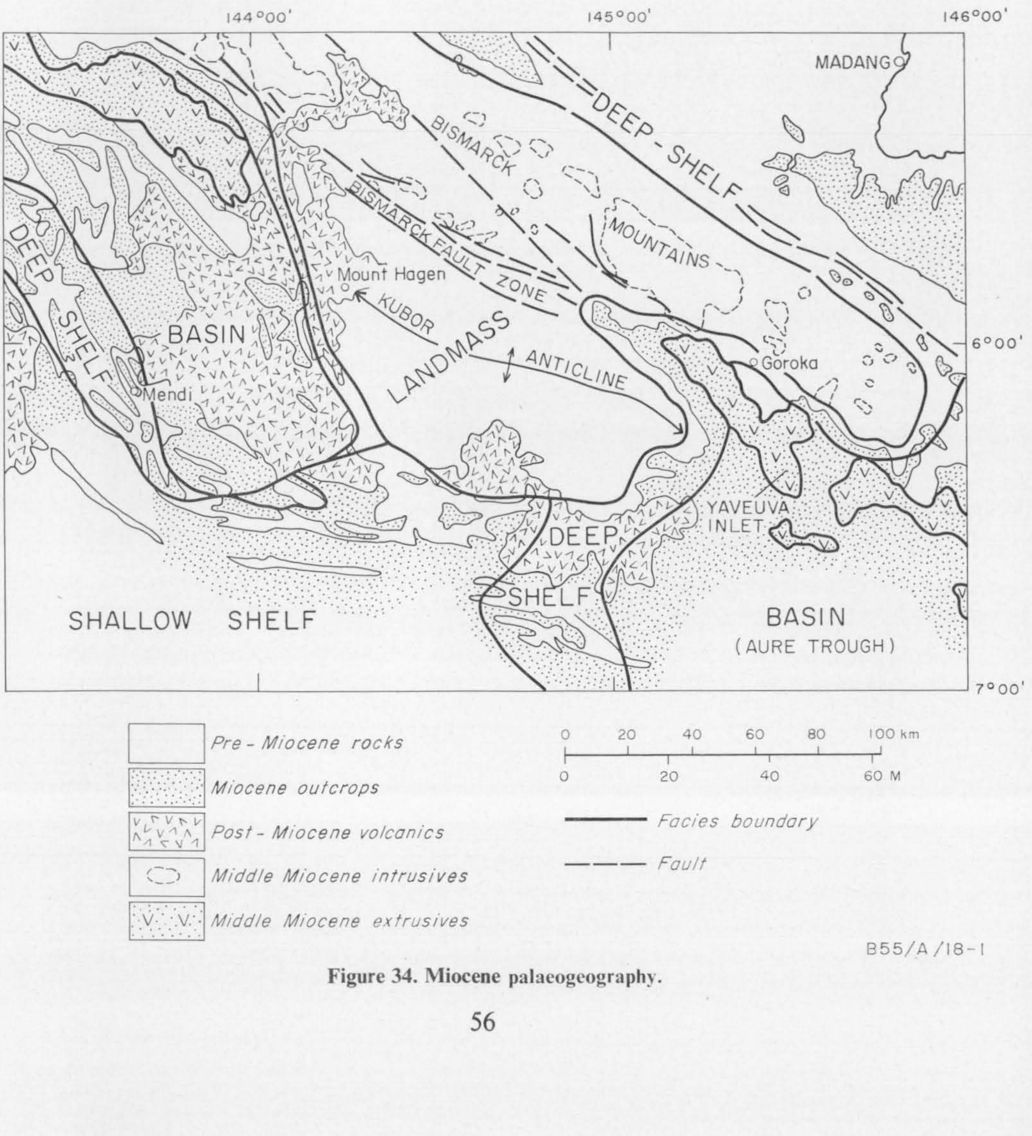


Figure 34. Miocene palaeogeography.

The scarcity of granitic detritus close to the Bismarck Intrusive Complex indicates that it was not exposed during the deposition of the Movi Beds. Very little of the sediment was derived from the pre-Tertiary Kubor Granodiorite, Mount Victor Granodiorite, and several small unnamed intrusives in the Goroka and Bena Bena Formations, probably because they were so far away and small in area.

Depositional environment

The thickness of the sequence (4000 m), the abundance of wood fragments, and the presence of coral reefs and shallow water sedimentary structures indicate deposition in a shallow subsiding basin. The basin or embayment was located at the northwest end of the Aure Trough. The thinning of the sequence from 4000 m in the Asaro River section to less than 500 m in the Chimbu valley indicates that the basin shallowed rapidly to the northwest. Furthermore, in the Chimbu valley, there is a greater proportion of limestone, and the siltstone is more calcareous than in the Asaro River section. Lateral thinning and facies changes indicate that the basin was only slightly more extensive than the present-day outcrop area. The sequence in the Yaveufa Syncline was deposited in a narrow marine inlet (Yaveufa Inlet), some 25 km wide and 50 km long, surrounded by deeply dissected mountains, but open to the sea in the southeast. The sediments in the southeastern part of the Kubor area (Aure Trough) are less calcareous than those in the Yaveufa Syncline and have deep-water turbidite characteristics.

Figure 34 is a simple reconstruction of the Miocene palaeogeography, based on the work of Jenkins et al. (1970), including their data on the Mendi area (Fig. 11). The facies boundaries correspond approximately with the boundaries of the various Miocene formations. For example, the shallow shelf area contains only the Darai Limestone; the deep shelf areas contain the Movi Beds and the transitional facies of the Aure Beds (Nembi Group in the Mendi area, Jenkins et al., 1969, and the Puri Limestone south of Mount Karimui, Rickwood & Kent, 1955). The basin areas contain rocks of the Aure and Movi Beds and the Yaveufa Formation. The landmass consisted of Palaeozoic and Mesozoic formations and Miocene intrusives which had not yet been exposed by erosion.

The basin west of Mount Hagen and the Aure Trough were connected only by very shallow seas south of the Kubor Anticline, which remained as a land area during the Miocene.

LOWER Tf STAGE (middle Miocene)

Yaveufa Formation
(new name)

Nomenclature

The lower Tf Asaro Conglomerate (volcanolithic conglomerate and greywacke) of McMillan & Malone (1960, p. 34) interfingers with and grades into contemporaneous basic volcanics which they called the Daulo Volcanics. As it is not possible to map these units separately, the volcanolithic sediments and volcanics are renamed the Yaveufa Formation. The Lamari Conglomerate mapped near Okapa and Kainantu by Dow & Plane (1965) is included in the Yaveufa Formation. The formation is named after the Yaveufa Syncline. The type area is west of Kami (6°13′S; 145°25′E), where the Asaro River has exposed a complete section composed mainly of volcanolithic sediments. The volcanics are best developed in the Daulo Pass area.

Distribution and thickness

The Yaveufa Formations crops out in a belt 10 to 15 km wide along the west side of the Goroka valley from Mount Kerigomna to the Okapa and Kainantu area 100 km to the southeast. Within the Kubor area, the formation is confined to the Yaveufa Syncline. About 8 km north of the Asaro River gorge the maximum thickness, including the well developed volcanic component, has been estimated from the aerial photographs as 4800 m. However, the formation thins appreciably to the northwest and southeast, and appears to thicken in the trough of the syncline. The Yaveufa Syncline probably represents the original lower Tf-Stage depositional basin, which has been only moderately deformed and eroded. From about 13 km north of Lufa to the vicinity of Mount Kerigomna, volcanics predominate almost to the exclusion of the volcanolithic sediments. Elsewhere, the volcanics are only poorly developed. For example, the formation immediately east of Mount Michael and southwards as far as the Okapa area consists almost entirely of volcanolithic sandstone and conglomerate.

Topography

High to moderate relief, steep slopes, and fine dendritic drainage pattern, partly controlled by bedding (Fig. 35), characterize the formation, especially in the grassy areas along the east limb of the Yaveufa Syncline.

Figure 35. Yaveufa Formation (hills in middle distance with fine dendritic drainage pattern) overlying Movi Beds (foreground), 10 km north-northeast of Lufa.

Lithology

The Yaveufa Formation consists of interfingering and interbedded volcanolithic sediments and volcanics. The volcanolithic sediments consist of waterlaid tuff, polymict pebble, cobble, and boulder volcanolithic conglomerate, greywacke, and calcarenite which commonly contains volcanic detritus. The volcanics consist predominantly of coarse red, purple, or multicoloured agglomerate interbedded with subordinate reddish or dark grey to black porphyritic basic lavas, volcanolithic rudite, and welded ash-flow tuff. Zeolites are common, particularly in the agglomerate, both as infillings in vesicles and other cavities, and as veins. The agglomerate consists of angular to subrounded fragments of porphyritic amygdaloidal basic lavas set in a zeolite-bearing matrix of coarse crystal-lithic tuff.

In the Yaveufa Syncline, about 13 km north of the Asaro River gorge (also Stanley, 1950), the sequence consists of about 1000 m of massive chocolate and red tuffs and porphyritic basic lavas overlain by a lenticular coralline limestone, about 80 m thick, which contains *Miogypsina* sp. This in turn is overlain by about 1000 m of conglomerate, tuff, and fine agglomerate which contain a few thin beds of siltstone and pink and chocolate gritty limestone containing *Miogypsina* sp. The remainder of the sequence consists of about 2000 m of agglomerate, tuff, and lava flows.

The volcanolithic conglomerate contains fragments of limestone as well as pebbles, cobbles, and boulders of a variety of porphyritic volcanic rocks. The clasts are commonly rounded to well rounded and are set in a matrix of coarse tuffaceous sandstone or crystal-lithic tuff.

In the Kainantu-Okapa area the formation has been described by Dow & Plane (1965): 'The larger fragments are rounded to subangular pebbles and cobbles of basalt, gabbro, andesite, and silicified siltstone. The matrix is an unsorted crystal and lithic tuff made up of the following angular fragments in order of decreasing abundance: basalt and andesite, siltstone, plagioclase, augite, and quartz. The matrix is generally considerably altered to chlorite, epidote, and kaolinite; and the sedimentary rock fragments are commonly epidotized near their margins.'

The predominance of conglomerate and the presence of lenses of reef limestone indicate that beds were laid down in shallow water.

Petrography

Sedimentary rocks. Specimens were collected from two outcrops of volcanolithic conglomerate, one 7.5 km north of Movi Mission and the other about 12 km east-southeast of the mission. The first outcrop consists of angular to subrounded cobbles and boulders of augite andesite (see p. 00) set in a matrix of ferruginized augite latite tuff containing 5 percent sanidine. The second is a coarse polymict conglomerate with a varied assemblage of rounded boulders and cobbles set in a matrix of pebbly sandstone composed of fragments of fine-grained volcanic rock and crystals of augite and plagioclase. The clasts include olivine-augite andesite, altered andesitic welded ash-flow tuff, hornblende-augite andesite, biotite-augite andesite/latite, altered olivine-augite andesite, olivine-augite-albite analcitite (metamorphosed?), and fine-grained white limestone.

The volcanic rudites (Table 2, Nos. 23-31) consist of subrounded fragments of andesite, basalt, shoshonite, analcitite, and rare limestone, from 3 to 10 cm across, set in a sandy crystal-lithic matrix.

Volcanic rocks. The volcanics in the Yaveufa Formation are characterized by the rarity of quartz and the presence of analcite and potash-rich phases such as sanidine and biotite. Preliminary analytical data show a range from highly undersaturated basaltic rocks rich in potash to absarokite and shoshonite, and to oversaturated andesite and dacite that are rich or poor in potash. The lavas containing appreciable amounts of analcite are unusually rich in potash, and contain normative nepheline. Much of the analcite, which appears to be primary, has a striking morphological similarity to leucite and may represent pseudomorphs after leucite. The high potash content of the analcite-bearing lavas may be attributed to the high potash content of the analcite, and to the presence of appreciable amounts of interstitial sanidine. These rocks may have been similar to the Ugandan leucitites and leucite basanites (Holmes & Harwood, 1937) when erupted.

TABLE 2. ESTIMATED MODES, YAVEUFA FORMATION

	Total Plagioclase (%)	*Plagioclase Phenocrysts*	*Alkali Feldspar* (%)	*Augite* (%)	*Olivine* (%)	*Magnetite &/or Ilmenite* (%)	*Zeolites & Analcite* (%)	*Other Minerals* (primary; secondary)
1.	80	small	1-2	2	—	3-4	—	3% basaltic hornblende, 1% quartz; 5% chlorite, tr. prehnite
2.	50-60	abundant	2-3	5-10(g.o.)	—	4	—	7% basaltic hornblende, 1-2% quartz, 2-3% calcite, 1% prehnite; 20% green secondary minerals (including chlorite)
3.	70	altered	5	10	—	3-4	1-2 laumontite	1-2% quartz, tr. apatite; 1% calcite
4.	57	—	—	35	—	2	wairakite?	tr. sphene; 3% chlorite, 2% epidote
5.	60-75	—	5 (S phenocrysts)	10	—	5(mt)	5-10 laumontite	5% basaltic hornblende, 2-3% quartz, tr. apatite, tr. chlorite
6.	50	altered	—	25	—	10(mt)	—	5% green biotite; iddingsite, bowlingite
7.	80−	altered	tr.	10	—	5-7(mt)	—	3-5% basaltic hornblende, 1% analcite, 3% nepheline?
8.	10	extensively altered	—	15	2-3	—	60 natrolite	15% ferruginized groundmass
9.	55	30%(An_{70})	—	20	altered	10+(mt)	—	10% green biotite & 5% bowlingite after olivine
10.	35+	micro-phenocrysts	—	40−	5(altered)	5(mt?)	—	15% devitrified glass; biotite, bowlingite, iddingsite after olivine
11.	70(An_{50})	—	1	10	2-15	2(mt)	tr. heulandite?	1% basaltic hornblende (replaced by magnetite); iddingsite in olivine
12.	40	—	5(?)	30	5(g.o.)	7-8(ilm)	—	10% biotite in groundmass
13.	70	An_{65}	2-3	15	5	5(mt)	—	2% talc & serpentine after olivine
14.	—	—	—	25	7	2(mt-ilm)	25 primary analcite	tr. apatite; 40% chloritized interstitial glass containing opaques, minerals & micas
15.	—	—	2-3(Or)	30	5(altered)	5-7(mt)	25-30 analcite, 2 natrolite?	tr. apatite
16.	65	rare(And)	1-2	20	5-7	1-2	5 primary analcite	1% biotite, tr. apatite
17.	40% plagioclase & sanidine			25	5(bowl-ingitized)	3(mt)	15 primary analcite, tr. zeolite	tr. muscovite, apatite, & biotite; 1% calcite
18.	40-45	micro-phenocrysts	15-20(S)	10	5(altered)	7(mt)	15 altered primary analcite	3% hydrated iron oxides, 5% alteration products of olivine

19.	54	present	20(?)	10	—	8(mt)	1 primary analcite, 1 secondary analcite	1% apatite; 5% chlorite
20.	60	altered	5-10(S?)	20	—	1-2(mt)	—	1-2% calcite, 2-3% chlorite, 3-5% epidote
21.	—	—	60+(S)	15	5(largely altered)	2-3(mt)	10 primary analcite	1-2% chlorite, tr. biotite after olivine
22.	5-10	—	25-30(S)	35	3-4 (altered)	5(mt)	15 primary analcite	tr. apatite; chlorite, muscovite, & opaque minerals after olivine
23.	80	present	—	10-12	—	5(mt)	—	5% biotite
24.	75	An_{50}	tr.	20	2(altered)	3(mt)	—	tr. apatite; 2% iddingsite after olivine
25.	75	—	tr.	10	8(g.o.)	7(mt)	—	tr. apatite
26.	0.15-0.20 mm calcite crystals with rare grains of quartz, plagioclase, & fragments of fine-grained volcanic rock							
27.	15	—	—	—	—	2	—	73% glassy matrix, 5% volcanic rock fragments, 5% basaltic hornblende
28.	70	present	—	15	—	10(mt)	—	1-2% basaltic hornblende; 2-3% red-brown iron oxides
29.	65	present	—	20	5(altered)	5-7(mt & ilm)	2-4 wairakite	tr. apatite; tr. calcite, iron oxides, hornblende, & biotite after olivine
30.	30(Ab)	—	—	15	2	5-7(mt)	15 analcite	1% apatite
31.	85	present	—	5	—	5+(mt)	tr.(fibrous)	1% basaltic hornblende; 2% chlorite
32.	75	An_{47}	—	10	—	5-7(mt?)	—	5% rock fragments, 50% matrix

Abbreviations: Ab—albite, And—andesine, g.o.—groundmass only, ilm—ilmenite, mt—magnetite, Or—orthoclase, S—sanidine

1. Hornblende-augite andesite (21NG1075A)
2. Altered hornblende-augite andesite (21NG1075G)
3. Hornblende-augite andesite (21NG1077)
4. Incipiently metamorphosed augite andesite (21NG2031)
5. Hornblende-augite andesite (21NG2500A)
6. Biotite-augite andesite (21NG2508A)
7. Hornblende-augite andesite (21NG2531)
8. Altered zeolitized olivine basalt (21NG2508B)
9. Olivine basalt (21NG2509)
10. Olivine basalt (21NG2524)
11. (Hornblende)-olivine basalt (21NG2524A)
12. Absarokite (21NG1075B)
13. Shoshonite (21NG0630)
14. Augite-olivine analcitite (21NG2037)
15. Olivine-augite analcitite (21NG2505)
16. (Biotite)-analcite basanite (21NG2034)
17. Analcite basanite (21NG2041)
18. (Olivine)-analcite mugearite or latite (21NG2053)
19. Augite-analcite latite (21NG2044)
20. Basic augite latite (21NG2502A)
21. Augite-olivine analcite trachyte (21NG2035)
22. (Olivine)-augite-analcite trachyte or latite (21NG2036)
23. Biotite-augite andesite (21NG2533D)
24. (Olivine)-augite andesite (21NG2533E)
25. Shoshonite (21NG2533G)
26. Limestone (21NG2533H)
27. Altered andesitic welded ash-flow tuff (21NG2533I)
28. Hornblende-augite andesite (21NG2533J)
29. Altered olivine basalt (21NG2533L)
30. (Olivine)-augite-albite analcitite (metamorphosed) (21NG2533M)
31. (Hornblende)-augite andesite (21NG2533N)
32. Andesitic crystal tuff (21NG2529)

Note: Nos. 23-31 are clasts in volcanolithic rudites.

The petrography of the volcanic rocks is summarized in Table 2. The lavas are all porphyritic and include the following rock types: hornblende-augite andesite, hornblende andesite, olivine-augite andesite, hornblende-augite-olivine andesite, augite andesite, olivine basalt or shoshonite, (hornblende)-olivine basalt, absarokite, shoshonite, augite-olivine analcitite, (biotite)-analcite basanite, analcite basanite, (olivine)-analcite mugearite or latite, augite-analcite latite, and augite-olivine-analcite trachyte.

The andesites contain phenocrysts of andesine, pale green or green-brown augite, yellow-brown hornblende with rims of fine-grained magnetite and pyroxene, and colourless magnesium-rich olivine, which is commonly partly to completely altered, in the combinations set out above. The fine-grained groundmass consists of plagioclase, augite, and iron oxides, generally magnetite, and contains up to 5 percent sanidine (Table 2, No. 3), which is interstitial or forms rims on plagioclase. These rocks grade with the incoming of olivine into shoshonite. Hypersthene-bearing andesites are also present, mainly in the south, near the Asaro River.

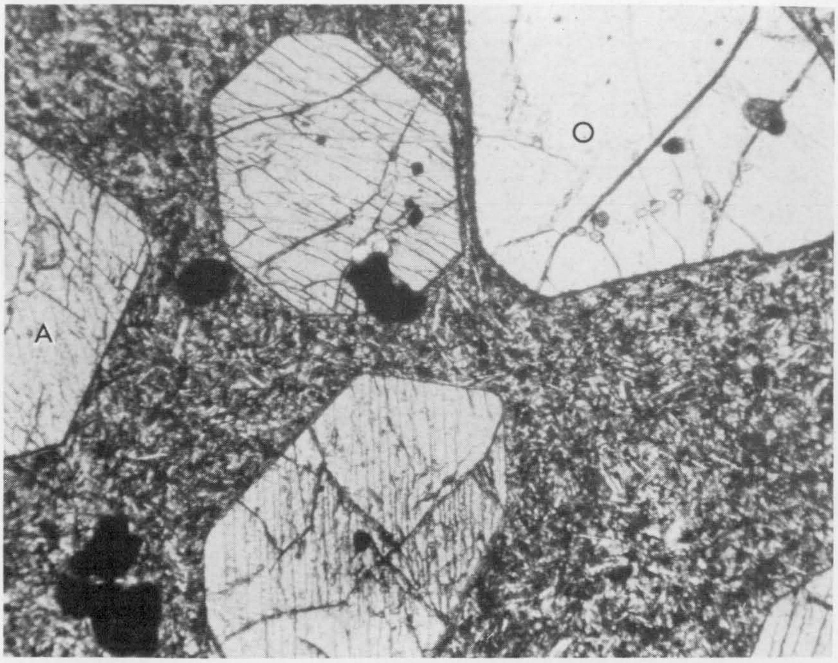


Figure 36. Absarokite (21NG1075B) of the Yaveufa Formation. The rock consists of euhedral phenocrysts of augite (A) and olivine (O), and microphenocrysts of titaniferous magnetite and ilmenite, set in a groundmass of labradorite, augite, biotite, sanidine, ilmenite, and apatite. x 45, plane polarized light.

The basalts consist of phenocrysts of labradorite, pale green augite, partly to completely altered olivine, and, rarely, hornblende replaced by magnetite (Table 2, No. 11), set in a groundmass of labradorite, augite, magnetite (up to 10%) and, in one specimen, secondary green biotite. One of the rocks (Table 2, No. 12; Fig. 36) can be classified as an absarokite (Joplin, 1968). It consists of large augite and olivine phenocrysts set in a groundmass of plagioclase, biotite, augite, ilmenite, and interstitial potash feldspar. The shoshonite is similar, but contains plagioclase phenocrysts, less potash feldspar, and little or no biotite.

Augite-olivine analcitite (e.g. Table 2, Nos. 14-15; Figs. 37, 38) was recorded from two widely separated localities. It contains euhedral phenocrysts and smaller crystals of analcite or possibly leucite, very pale brown augite, and partly to completely altered olivine. One specimen (Table 2, No. 15) contains sanidine, and the turbid analcite shows ghost cross-hatched multiple twinning (Fig. 37) like that commonly exhibited by leucite. The analcitite also contains a little magnetite, ilmenite, and apatite. The biotite-analcite basanite and analcite basanite (Table 2, Nos. 16-17) are similar to the analcitite, but contain less analcite, up to 65 percent andesine, and up to 20 percent sanidine, with augite, olivine, magnetite, and in one specimen minor biotite phenocrysts.

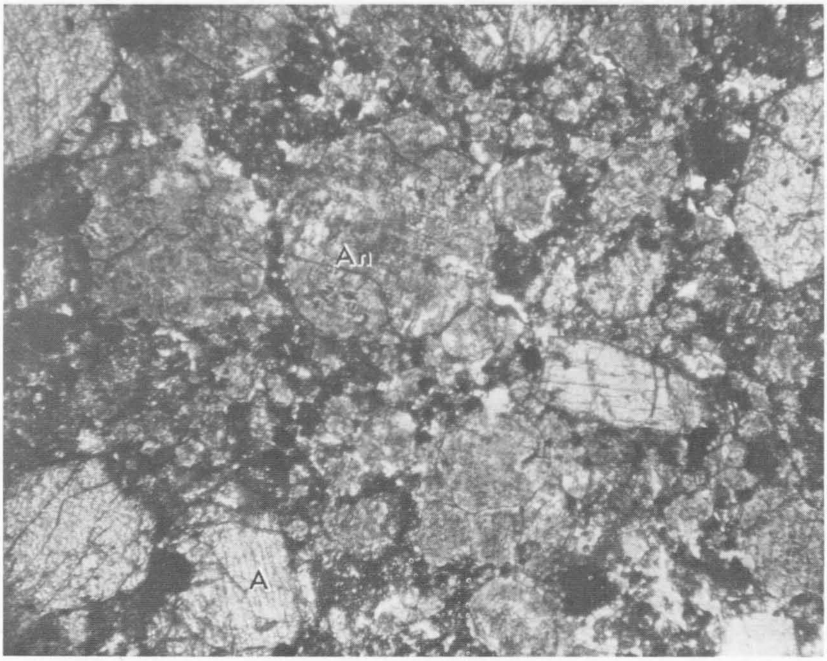
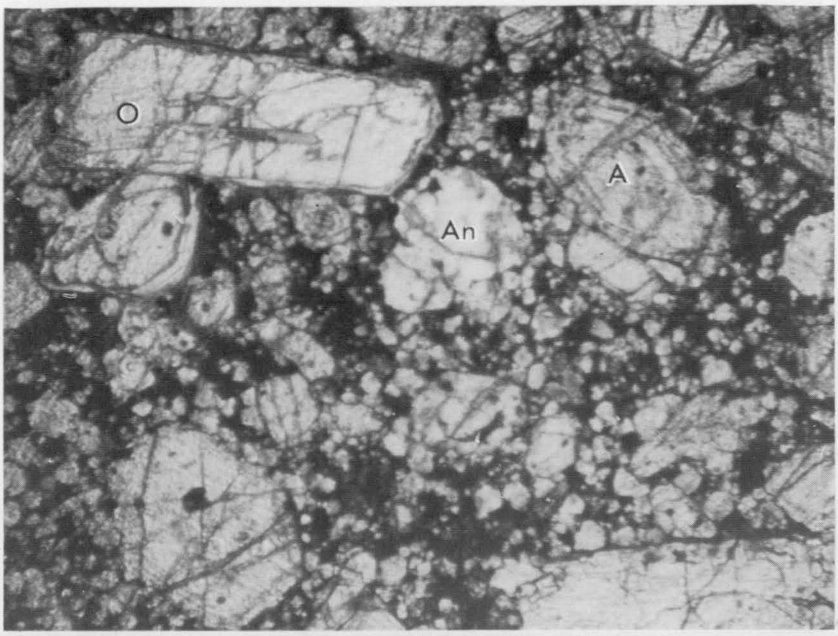


Figure 37. Augite-olivine analcitite (21NG2505) of the Yaveufa Formation showing phenocrysts of augite (A) and analcite (An) with cross-hatched lamellar twinning set in a groundmass of augite, analcite, magnetite, sanidine, and olivine. x 45, plane polarized light.

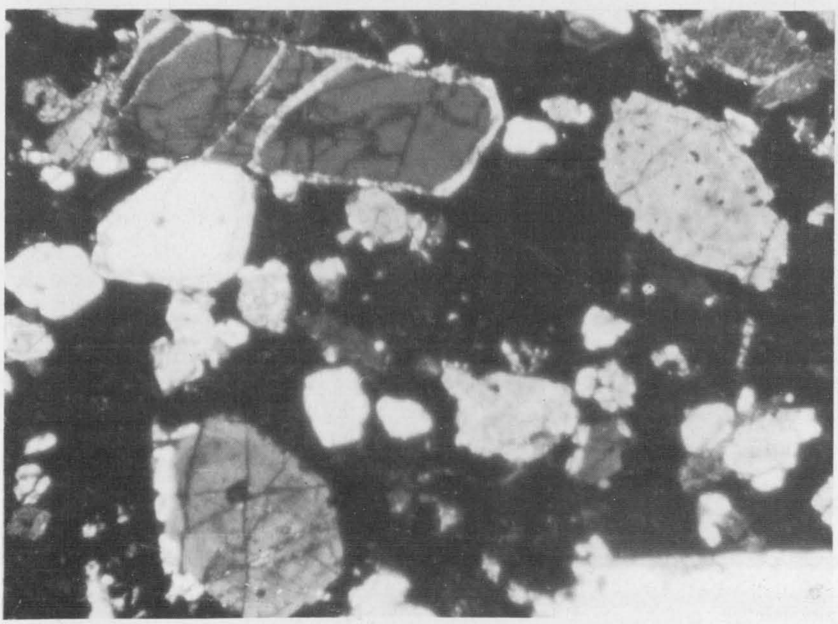
The (olivine)-analcite mugearite or latite (Table 2, No. 18) consists of phenocrysts of augite, altered primary analcite and olivine, and microphenocrysts of plagioclase and magnetite, set in a groundmass of sanidine (15-20%), plagioclase, analcite, augite, and magnetite. The augite-analcite latite (Table 2, No. 19) is similar, but lacks olivine, and contains about 20 percent sanidine. The augite-olivine-analcite trachyte (Table 2, Nos. 21-22) consists of phenocrysts of augite, olivine, and analcite in a groundmass of sanidine (up to 60%) analcite, magnetite, and secondary minerals. Specimen 21NG2036 (Table 2, No. 22) contains 5 to 10 percent groundmass plagioclase.

The typical agglomerate or volcanic breccia consists almost entirely of porphyritic augite-analcite basanite containing phenocysts of plagioclase, augite, and rounded analcite crystals with altered cores, set in a fine-grained groundmass of analcite, microlites of plagioclase, minute granules of augite, and magnetite.

The welded ash-flow tuff in the Yaveufa Formation consists of small fragments of altered glassy volcanic rock and broken crystals of plagioclase and augite in a matrix of deformed glass shards, altered glassy ash, and lithophysae. The glass shards are bent around the crystal and rock fragments.



a



b

Figure 38. Olivine-augite analcitite (21NG2037) of the Yaveufa Formation. Figure 38a shows phenocrysts of zoned augite (A), partly altered to olivine (O), and analcite (An) set in a groundmass of analcite, augite, magnetite/ilmenite, apatite, and altered glass. Figure 38b (crossed polarized light) shows the large proportion of isotropic analcite present. x 45.

The andesine-rich crystal tuff (Table 2, No. 32) also contains augite, fragments of fine-grained volcanic rock, and a large clast of hornblende microdiorite set in a very fine-grained matrix containing abundant opaque material.

Origin

The Yaveufa Formation formed from a small zone of volcanic activity offshore from the rising Kubor Anticline. A large proportion of the volcanic pile appears to have been extruded or deposited in a marine environment, though some of the tuffs, lavas, and volcanolithic conglomerates are subaerial. Subaerial exposure and erosion of the volcanic rocks resulted in the formation of interfingering sedimentary deposits which constitute the remainder of the formation.

The Miocene succession is underlain by a thick sequence of Mesozoic sediments resting on older rocks which probably include Palaeozoic metamorphics and late Palaeozoic to early Mesozoic intrusive rocks. Joplin (1968) has pointed out that rocks with alkaline and shoshonitic affinities are generally developed in relatively stable continental areas in association with upwarping and block-faulting (alkaline magmas) or recent stabilization (shoshonites). Calcalkaline lavas are usually generated in active island arc environments, such as Japan and the Kurile arc. The Yaveufa Formation volcanics were extruded in an environment which has some of the characteristics of both island arc and continental tectonics, and this may be the reason for the indistinct and mixed affinities of the volcanic rocks.

Age and stratigraphic relationships

North of Lufa the Yaveufa Formation conformably overlies the Movi Beds, which are exposed to the north and southwest, but are absent or concealed in the Goroka valley. Where volcanic rocks are present, the base of the formation is taken at the first thick lava flow or agglomerate bed. Where volcanics are absent, the boundary is gradational over several hundred metres, and is placed arbitrarily at the first major volcanolithic conglomerate. In the Okapa area, the Yaveufa Formation unconformably overlies the Omaura Greywacke (Dow & Plane, 1965); it overlaps progressively older beds near Asempa and Sonofi villages, and 7.5 km south of Bontaa village it fills a small valley eroded in the Omaura Greywacke (Dow & Plane, 1965).

The conglomerate encloses numerous lenses of light-coloured fine-grained limestone containing lower Tf-Stage foraminifera (Stanley et al., 1950; McMillan & Malone, 1960; Binnekamp & Belford, 1970). Recent isotopic K-Ar age determinations (Page & McDougall, 1970a) confirm the lower Tf age of the Yaveufa Formation. Only Quaternary alluvial deposits overlie these beds.

The Yaveufa Formation is thus a correlative of the Burgers Formation, Karawari Conglomerate, and Wogamush Beds to the northwest (Dow et al., 1973) and the Langimar Beds (Dow et al., in press) and other lower Tf volcanics (Macnab, 1970) to the southeast. All these formations formed part of a narrow Miocene volcanic arc extending from the Vogelkop in West Irian to within a few tens of kilometres of Port Moresby (Dow & Bain, 1970).

QUATERNARY

The Highlands Volcanoes
(Fig. 39)

Mounts Hagen, Giluwe, Ialibu, Suaru (Fig. 40), and Karimui (Figs. 41, 42), and Crater Mountain are large Quaternary stratovolcanoes on the outer western, south-

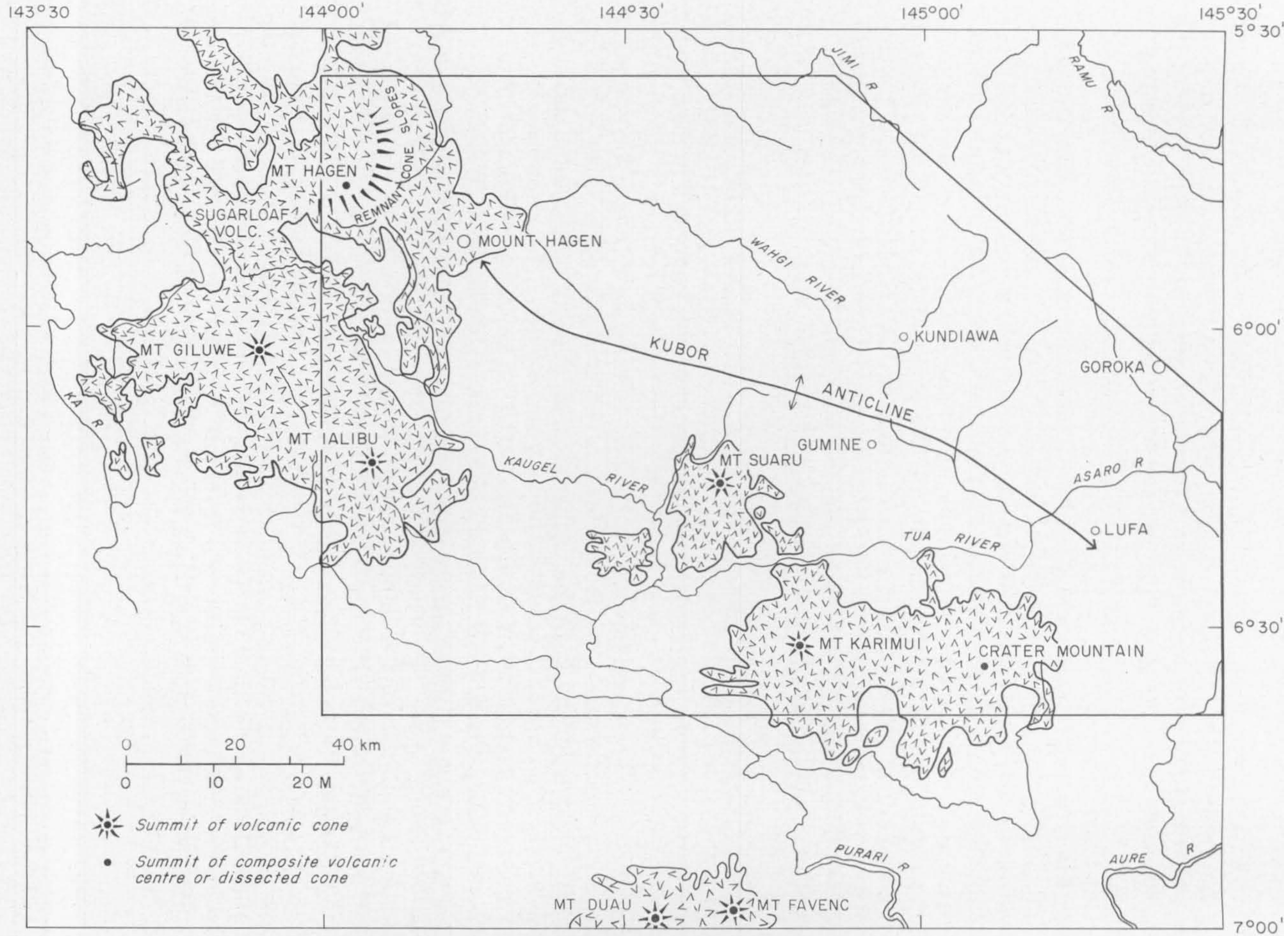


Figure 39. Distribution of Pleistocene volcanic rocks.

Figure 40. Mount Suaru from Karimui airstrip. Note the V-shaped gorge bisecting the cone.

western, and southern flanks of the Kubor Anticline. The volcanoes are believed to be of Pleistocene age, and some have been affected by late Pleistocene glaciation (Perry, 1965; Blake & Löffler, 1971). The dimensions of the volcanic cones are summarized below:

Name	*Height Above Sea Level* (m)	*Diameter of Cone* (km)
Mount Hagen	3762	25+
Mount Giluwe	4160	20
Mount Ialibu	3465	16
Mount Suaru	2665	12
Mount Karimui	2570	14
Crater Mountain	3200	No single major cone

Each cone is surrounded by a broad apron of lava and volcanic debris.

The relatively deep dissection of Mount Hagen suggests that it is probably the oldest of the volcanoes.* Its northern and western slopes have been deeply eroded, but the elliptical outline of the volcano is still apparent in the less deeply eroded southern and eastern slopes. The remnants of cirques and moraines on the jagged rocky crest are the result of late Pleistocene glaciation (Perry, 1965; Blake & Löffler, 1971). There is a satellite cone, 200 m high, and a smaller lava dome on the southeast flank, a small cinder cone on the northeast flank, and several small scattered cones on the apron to the east. Mount Hagen is surrounded by an extensive apron which extends for 40 km south to the Kaugel River, 25 km east into the Wahgi valley, 50 km west to

* Recent dating of two specimens from Mount Hagen indicates an age of 210 000 years (Page & Johnson, 1974).

Wabag, and for 130 km along the Yuat River. The apron consists of layered tuff, beds of rubble, lava flows, conglomerate, lahars, and nuée ardente deposits. The deposits are commonly extremely poorly sorted, with blocks up to a metre or more across set in a sandy or silty matrix. Vesicular lava was found south of Kuta, 30 km southeast of the summit of Mount Hagen. Small-scale unconformities are present in the stratified tuff and ash exposed in cuttings along the Mount Hagen/Wabag road.

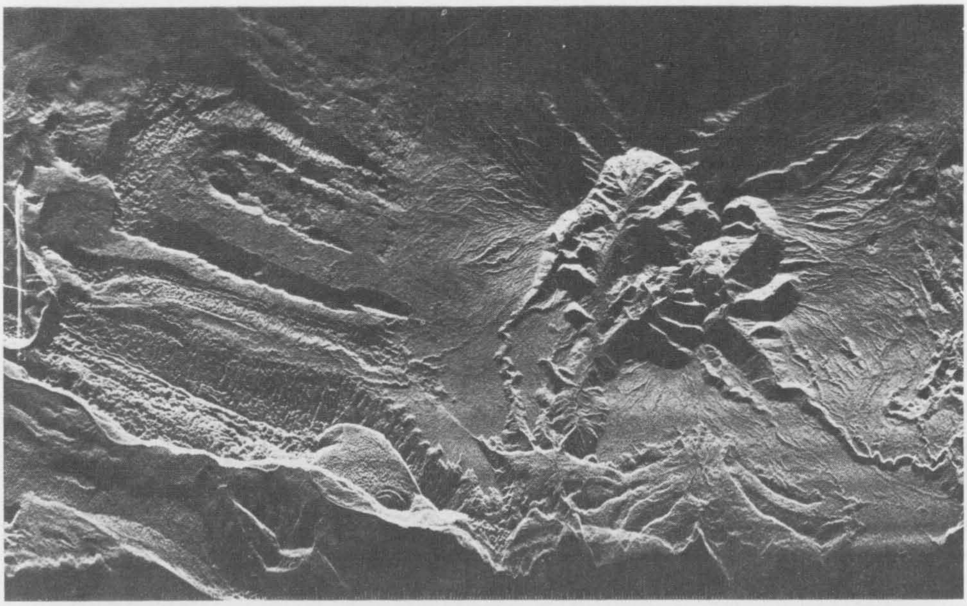


Figure 41. Mount Karimui, a deeply dissected Quaternary volcano overlying folded Darai Limestone and Chim Formation. Side-looking radar imagery (looking south). By courtesy of the Department of the Army.

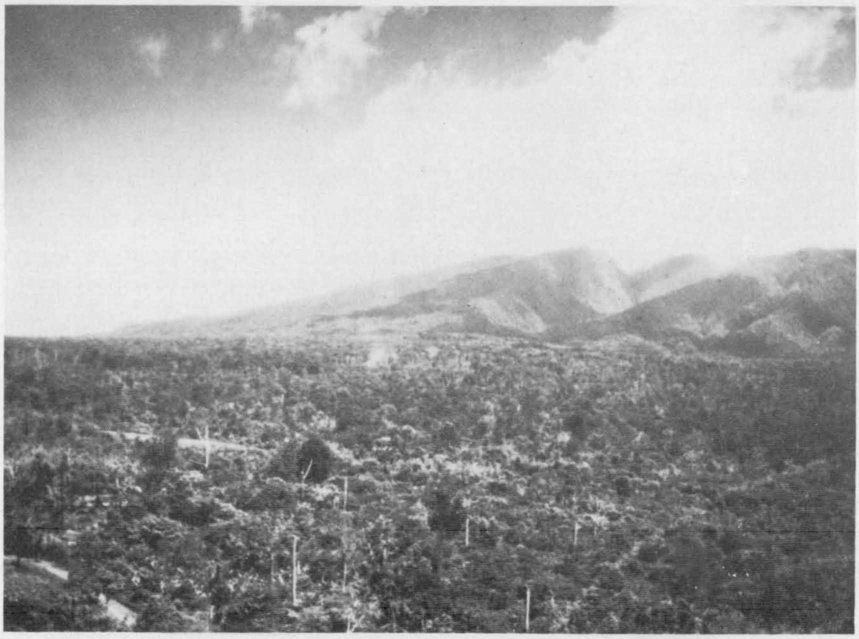


Figure 42. Deeply dissected northeast slopes of Mount Karimui.

Mount Giluwe is the best preserved and probably the youngest of the six volcanoes. The Kara Plug, southwest of Mount Ialibu, has been dated at 1.11 ± 0.4 m.y. (late Pleistocene), and is believed to be related to the Giluwe Volcanics (Buchan & Robinson, 1969). The cone is well preserved (Blake & Löffler, 1971), but some of the streams on its upper slopes are deeply incised. Moraines, cirques, tarns, polished pavements, and rugged pinnacles in the summit area are evidence of past glaciation. Blake & Loffler have recorded the presence of intraglacial lava estimated to be about 25 000 years old. Mount Giluwe has numerous small satellite vents and domes some of which are shown on the map. On the flanks of the volcano, about 16 km southeast of the summit, there are six small craters on and near an easterly trending en echelon normal fault system. D. H. Blake (pers. comm.) believes that these craters may be as young as 1000 years. From a small prominent cone, 22 km south-southwest of Mount Hagen township (Fig. 43), lava flows extend 3 km to the east. This cone may be related to Mount Giluwe. Thin lava flows, lava domes, plugs, and dykes were seen on the summit area of Mount Giluwe and the volcano is surrounded by an apron of vesicular lava and volcanic rubble mantled by ash.

Figure 43. Small volcanic cone in the Nebilyer valley, 22 km south-southwest of Mount Hagen township. The basalts from this cone are interbedded with lavas and agglomerates from the Mount Hagen volcano.

The summit and north flank of Mount Ialibu are highly dissected, but the other slopes are well preserved. Perry (1965) considers Mount Ialibu to be Pleistocene; it is probably older than Mount Giluwe, but younger than Mount Hagen.

Mount Suaru and Mount Karimui (Figs. 40-42) are similar in size and state of preservation, and both are probably younger than Mount Ialibu. The cone of Mount Suaru is almost cut in two by large gorges, and Mount Karimui is eroded almost to base level on its southern side. Mount Suaru has two small satellite cones, one of which contains a crater lake; the small cone of hornblende andesite 6 km east of the Pima River may also be related to Mount Suaru. Both Mount Suaru and Mount Karimui consist mainly of massive and vesicular lava, subordinate agglomerate and rubble, and some ash, tuff, and lahars.

Crater Mountain consists of an extensive volcanic complex overlain by about 12 small younger cones, water-filled craters, and associated lava flows. The basal volcanic complex, which may date back to the Pliocene, comprises thick piles of lava from at least three deeply eroded eruptive centres, and covers an area of 700 to 800 km^2. Remnants of massive lava flows extend as cappings on the ridges towards the Tua River to the north, and also to the south almost to the Pio River (Fig. 39). The group of small eroded centres at the west end of the complex has been partly buried by lava from Mount Karimui. The well preserved younger centres and lava flows cover a large area of the older volcanics. The flows, which extend down several stream valleys, one as far as the Tua River and another to near Agotu Mission, have diverted a number of streams. The younger flows are covered by only small trees and are probably Holocene.

Petrography

The petrography is summarized in Table 3.

TABLE 3. ESTIMATED MODES, THE HIGHLANDS VOLCANOES

	Plagioclase† (%; comp.)	*Augite*† (%)	*Olivine*‡ (%)	*Magnetite* (%)	*Alkali Feldspar* (%)	*Other Minerals* (primary; secondary)
1.	40-45(An$_{70}$) (g.o.)	20	10	2-3	tr.	25-30% altered glass
2.	70(An$_{50-55}$) (g.o.)	15	5-7(g)	5	2.3	1% apatite, 1-2% altered glass
3.	55-60(An$_{65}$) (g.o.)	15-20	2-3	10	—	10% hypersthene (g.o.), 1-2% hornblende
4.	40(An$_{55}$) (g.o.)	15	—	5	tr.	15% hypersthene, 5% hornblende, tr. apatite, 1-2% analcite; 1% siltstone, 2% quartz inclusions
5.	60-65(An$_{65}$)	15-20	5(g)	3-5	—	10 hypersthene
6.	40(An$_{70}$)	30	5	5+	tr.	1-2% apatite
7.	60(An$_{70}$)	15-20	5	5	tr.	tr. apatite
8.	70(An$_{60}$)	15-20	5	2-3	tr.	1-2% hornblende, tr. apatite & glass
9.	73(An$_{40-65}$)	15	5	1-2	—	tr. apatite
10.	75(An$_{35-85}$)	15	5	1-2	tr.	1% apatite
11.	75(An$_{50}$)	5(g.o.)	—	8	—	10% hypersthene, 5% hornblende replaced by magnetite
12.	50(An$_{45}$)	20	5-7	5	—	tr. apatite
13.	60+	25	5	5+	?	5% devitrified glass
14.	60-65(An$_{50}$)	20	5	3-4	5	5% hypersthene (p.o.), 1% nepheline, tr. apatite; 2% chlorite
15.	60-65(An$_{65}$)	20	5	7	—	tr. apatite
16.	70(An$_{65}$)	15	5-8	5	—	tr. hornblende & apatite
17.	65(An$_{70}$)	25	1-2	5	tr.	tr. apatite; 2-3% calcite
18.	60(An$_{45-65}$)	20	5	7	—	1-2% hypersthene, 5% hornblende
19.	50(An$_{65}$)	20	5	5	up to 5	15% glass
20.	60-65 (An$_{30-55}$)	25-30	—	2-3	tr.	7% hornblende, 2-3% quartz
21.	75(An$_{40}$)	15	1-2	5	tr.	1% hornblende, tr. apatite; tr. chlorite
22.	70-75(An$_{40}$)	15	—	3-5	—	5% hypersthene, rare apatite
23.	70-75(An$_{55}$)	10	—	5	?	1-2% hypersthene (p.o.), 1% relict hornblende, 1% apatite
24.	70(An$_{40}$)	—	—	1-2	10	15% hornblende, tr. apatite
25.	20(An$_{65}$) (p.o.)	10(p.o.)	2-3	—	?	60-70% altered groundmass; tr. calcite
26.	25(An$_{60-65}$)	19	—	—	—	50% ferruginized glass; 5% zeolite, tr. chlorite & calcite

TABLE 3.—*continued*

	*Plagioclase** (%; comp.)	*Augite*† (%)	*Olivine*‡ (%)	*Magnetite* (%)	*Alkali Feldspar* (%)	*Other Minerals* (primary; secondary)
27.	60(An_{60-65})	25	7	5-7	1	2% apatite
28.	65(An_{45})	20	5	5	tr.	5% glass
29.	70-75 (An_{40-60})	15	5(g)	2-3	1	1-2% apatite
30.	70(An_{40})	15	5+	5-7	?	2-3% biotite, tr. apatite
31.	70-75(An_{45})	10-12	7-8	4-5	1-2	tr. apatite
32.	70− (An_{40-45})	15-20	5(g)	2+	2-3	1-2% apatite
33.	40(?) (rare phenocrysts)	30	25−(g)	5+	tr.	—
34.	50-55(An_{65})	35-40	1(g)	5	2-3	1% hornblende, tr. apatite, rare biotite
35.	55+ (An_{40-50}) g.o.	25	3-4	7-8	?	1% quartz, tr. apatite hornblende replaced by magnetite
36.	60(An_{55})	20+	10	5	tr.	tr. apatite
37.	65(An_{55-65})	20	—	2	—	5% hornblende, 5% hypersthene (p.o.), 1% apatite, tr. enstatite?
38.	70(An_{35})	—	—	2-3	10+	7% hornblende, 5% quartz, tr. apatite
39.	70(An_{30})	10	—	1	tr.	10% hornblende, 5% altered glass, 1% quartz, tr. apatite

†Occurs as phenocrysts and in groundmass unless otherwise indicated: g.o.—groundmass only; p.o.—phenocrysts only.
‡Occurs as phenocrysts only unless otherwise indicated: g—also in groundmass.

Mount Hagen

1.* Shoshonite (20NG0600)
2. Shoshonite (11NG1113)
3. (Hornblende)-two-pyroxene shoshonite (20NG1319)
4.* Hornblende-two-pyroxene high-alumina basalt (20NG1199)
5.* Olivine-bearing high-potash/low-silica andesite (20NG1320)

Mount Giluwe

6. Shoshonite (20NG0603B)
7.* Shoshonite (20NG0601)
8.* Hornblende-bearing shoshonite (20NG0603A)
9.* Shoshonite (13NG6007)
10.* Shoshonite (13NG0503 & 0504)
11. High-potash andesite (13NG0501)

Mount Ialibu

12. Shoshonite (21NG0613)

Mount Suaru

13.* Absarokite (21NG1370)
14.* Absarokite (21NG4045B)
15. Shoshonite (21NG1383B)
16. Shoshonite (21NG1369E)
17.* High-potash/high-alumina olivine basalt (21NG3039)
18.* High-potash/high-alumina (olivine) basalt (21NG1369H)
19.* High-potash/low-silica andesite (21NG1383C)
20. Hornblende andesite (21NG3040A)
21.* Olivine-bearing high-potash/low-silica andesite (21NG4040C)
22.* High-potash/low-silica andesite (21NG1369G)
23. High-potash/low-silica andesite (21NG1383A)
24. Hornblende high-potash andesite or latite (21NG1435)

Mount Karimui

25. Ferruginized olivine basalt (21NG0594A)
26.* Ferruginized shoshonite (21NG0594B)
27.* Shoshonite (21NG2859A)
28. Shoshonite (21NG2859C)
29. Shoshonite (21NG2860A)
30.* Biotite-bearing shoshonite (21NG2860B)
31. Shoshonite (21NG2862A)
32. Shoshonite (21NG2864)

Crater Mountain

33.* Absarokite (21NG4033D)
34. Shoshonite (21NG2855)
35.* High-potash/high-alumina basalt (21NG2858)
36.* High-potash/high-alumina basalt (21NG4033E)
37. High-potash/low-silica hornblende-two-pyroxene andesite (21NG4033C)
38. High-potash hornblende andesite (21NG0592C)
39. High-potash hornblende-augite dacite (21NG4033F)

*Analysed specimens.

The rocks are generally light grey to black, according to the grainsize and magnetite content and, to a lesser degree, to the ferromagnesian content. They contain phenocrysts, from less than 1 mm to nearly 1 cm across, of white plagioclase, dark green to black pyroxene or hornblende, or both, and green olivine. Few of the rocks are vesicular, and flow-alignment of microlites is rarely displayed. Partly assimilated inclusions of phyllite, amphibolite, diorite, quartzite, and quartz are present in many of the rocks, mainly in the hornblende-bearing types.

The rocks contain the following assemblages of phenocrysts set in a fine-grained feldspathic groundmass: plagioclase, augite, and olivine (39 specimens), plagioclase, augite, olivine, hornblende, and hypersthene (3), augite and olivine (2), plagioclase, augite, and hypersthene (2), plagioclase and hornblende (2), plagioclase, augite, hornblende, and hypersthene (5), plagioclase, augite, olivine, and hornblende (4), plagioclase, augite, and hornblende (7), and plagioclase, augite, olivine, and hypersthene (1).

The labradorite or andesine usually displays strong oscillatory zoning and complex albite-Carlsbad twinning; alteration to muscovite and epidote is common, particularly in the cores. The idiomorphic augite is very pale green-brown and has a slight dispersion and a 2V of about 60°; the elongated euhedral prisms of hypersthene (Fig. 44) are pleochroic from faint green to pale pink. The euhedral prisms of basaltic hornblende (or lamprobolite) are strongly pleochroic from pale yellow or yellow-brown to deep yellow-brown and dark to very dark brown, red-brown, or blood-red. The crystals are partly or completely replaced by fine-grained magnetite or augite, or both (Figs. 44, 45). Some of the idiomorphic to subidiomorphic crystals of olivine (Fig. 46) are altered or partly altered to iddingsite or bowlingite. When hypersthene is present the olivine grains have a narrow rim of fine-grained orthopyroxene.

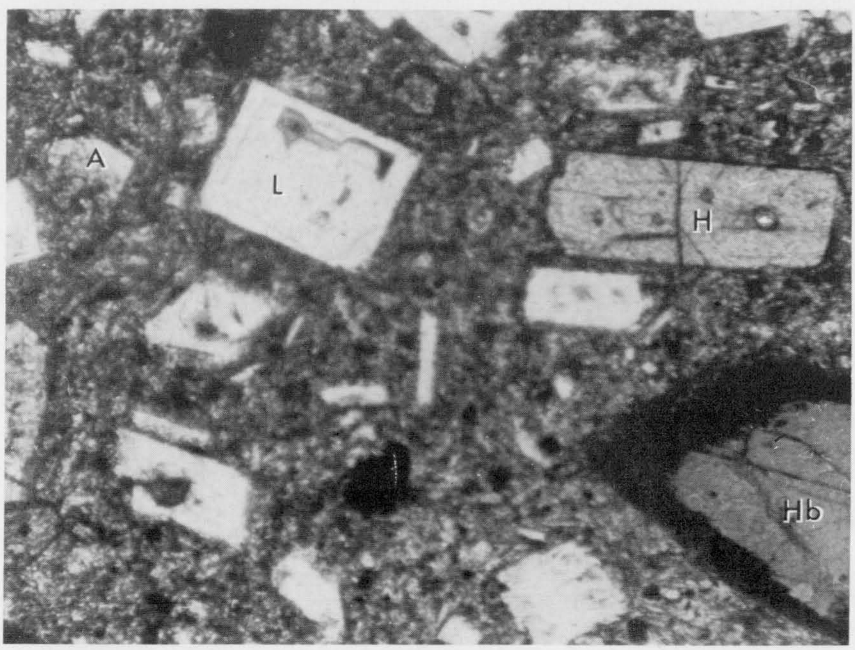


Figure 44. Hornblende-2-pyroxene basalt (21NG4033C) from Crater Mountain. The rock consists of phenocrysts of labradorite (L), augite (A), hornblende (Hb) with reaction rim of magnetite, and hypersthene (H), set in a groundmass of labradorite, augite, and magnetite. x 83, plane polarized light.

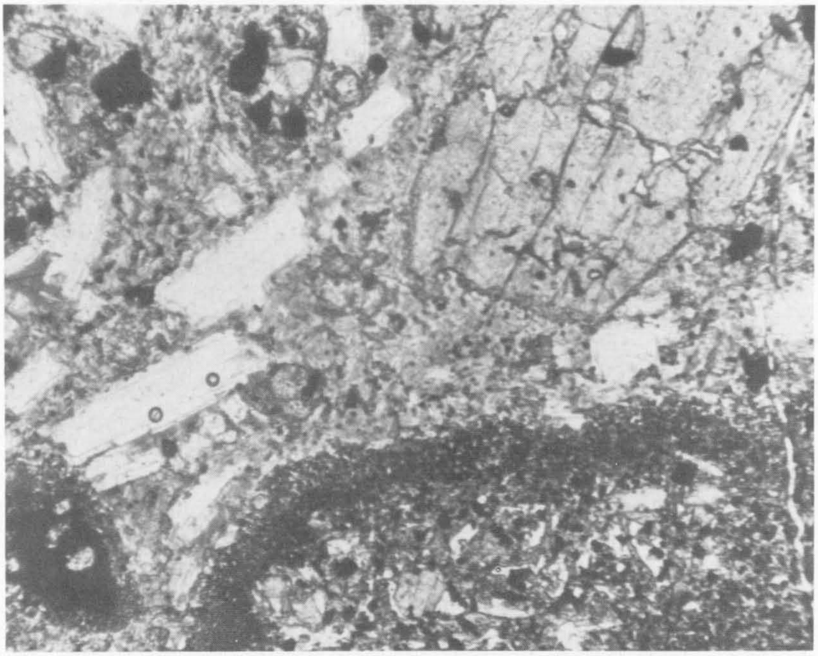


Figure 45. Shoshonite (21NG1383C) from Mount Suaru. Phenocrysts of augite, labradorite, olivine, and hornblende pseudomorphed by pyroxene and magnetite are set in a groundmass of labradorite, augite, magnetite, and glass. The plagioclase is mantled by clear rims of alkali feldspar. x 83, plane polarized light.

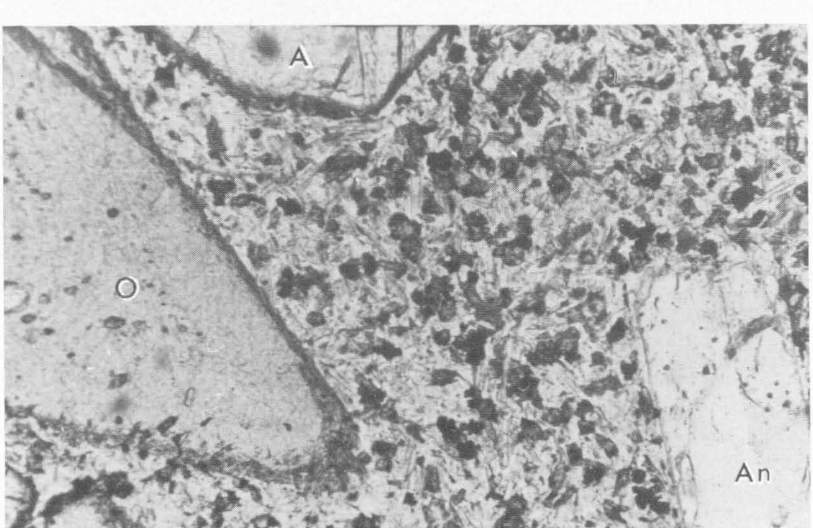


Figure 46. Potash-rich olivine andesite, or shoshonite (21NG2862A), from Mount Karimui. The phenocrysts of augite (A), olivine (O), and andesine (An) mantled by alkali feldspar are set in a groundmass of andesine, augite, magnetite, and interstitial sanidine. x 83, plane polarized light.

The plagioclase phenocrysts commonly form aggregates, and when both augite and olivine are present, they are commonly found as composite phenocrysts, usually with pyroxene enveloping olivine. In a few of the rocks the hypersthene crystals have irregular corroded cores of augite, or a ragged augite grain is surrounded by hypersthene crystals. Augite crystals with cores of hypersthene were seen in two specimens.

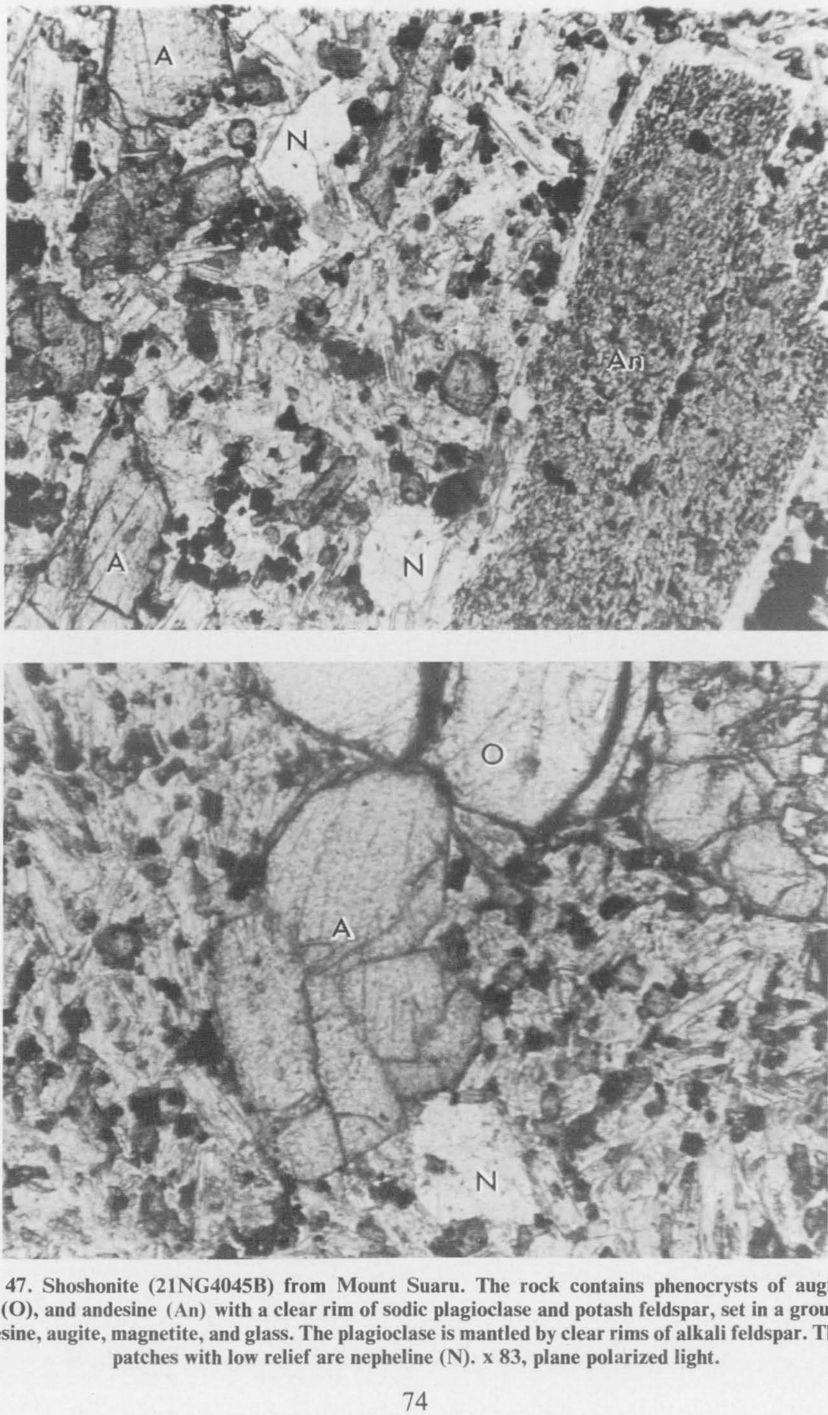


Figure 47. Shoshonite (21NG4045B) from Mount Suaru. The rock contains phenocrysts of augite (A), olivine (O), and andesine (An) with a clear rim of sodic plagioclase and potash feldspar, set in a groundmass of andesine, augite, magnetite, and glass. The plagioclase is mantled by clear rims of alkali feldspar. The clear patches with low relief are nepheline (N). x 83, plane polarized light.

In almost all the rocks the groundmass consists of small plagioclase laths, augite (except in Nos. 24 & 38, Table 3), magnetite, and apatite, with or without olivine, hypersthene, potash feldspar, or olivine and potash feldspar. Nepheline was identified in only one rock (Table 3, No. 14; Fig. 47), as was analcite (Table 3, No. 4). The plagioclase is andesine or sodic labradorite; the equant grains of augite are pale green to colourless and the olivine is generally completely iddingisitized. The small prisms of hypersthene are commonly stained yellow-brown by oxidation. Potash feldspar occurs as mantles on the plagioclase phenocrysts and microlites, and as interstitial patches in the groundmass of most of the rocks rich in olivine and poor in hypersthene (Figs. 45-48). The very low relief and birefringence and the small negative 2V indicate that it is probably sanidine. Glass is present in the tops of many of the lava flows (7 specimens in Table 3), and forms 60 to 70 percent of one rock from Mount Karimui (Table 3, No. 25).

The rocks which contain olivine and augite, and lack hornblende or hypersthene, or both, commonly contain a little alkali feldspar; those with hypersthene usually also contain hornblende, and the majority (7 out of 11) lack olivine.

Most of the rocks have been classified in two groups (Table 3): those that do and those that do not contain hypersthene. A few of the rocks have undersaturated alkaline features (e.g. No. 14, Table 3, from Mount Suaru), and some are similar to the calcalkaline basalts and andesites (e.g. No. 4 & 20, Table 3). All these types occur at Mount Suaru, and all except the undersaturated alkaline type at Mounts Hagen and Giluwe and Crater Mountain. Of the 19 specimens from Mount Karimui, however, none contain hypersthene or hornblende, and most contain a little alkali feldspar mantling the plagioclase; one contains biotite.

Joplin (1964, 1965, 1968) has described lavas with phenocrysts of labradorite, augite, and olivine, with or without hypersthene, in a groundmass of plagioclase and

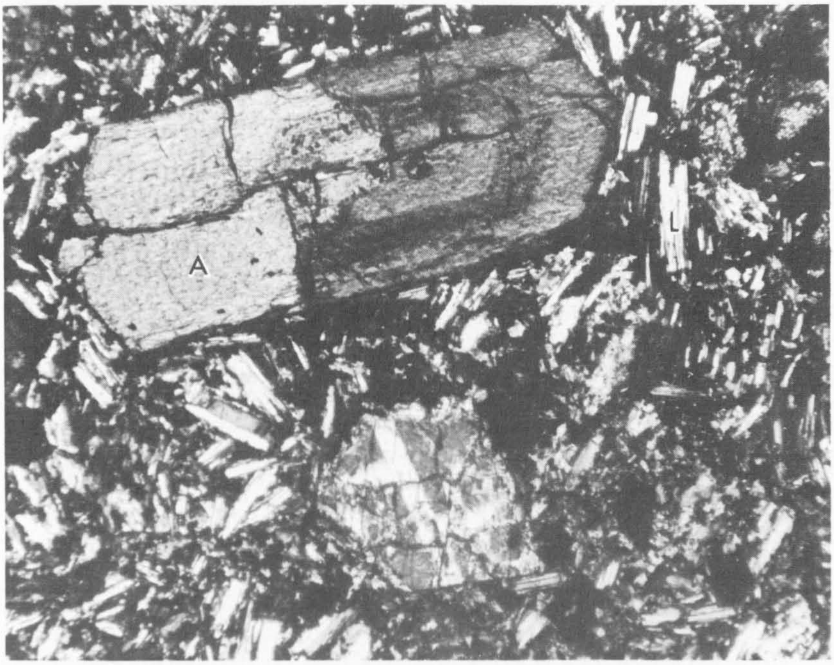


Figure 48. Potash-rich olivine basalt (11NG0059) from Mount Hagen showing euhedral phenocrysts of zoned augite (A) set in a groundmass of labradorite (L), augite, interstitial alkali feldspar, magnetite, and olivine. x 83, crossed polarized light.

augite and various combinations of potash feldspar, biotite, olivine, and hypersthene. Alkali feldspar commonly mantles the plagioclase phenocrysts. These rocks she classifies as shoshonites, and the otherwise similar rocks without plagioclase phenocrysts she classifies as absarokites. Both belong to the shoshonite association, which is characterized by a high potash/soda ratio relative to the alkaline series. Many of the lavas of the highlands volcanoes satisfy the criteria of Joplin's shoshonite or absarokite. Others are intermediate between shoshonite and calcalkaline basalt or andesite, or are calcalkaline in character.

The analcite-bearing lavas and absarokites from the Miocene Yaveufa Formation are also rich in potash, but they are more undersaturated than those of the highlands volcanoes. The Yaveufa Formation, however, does contain hypersthene-bearing lavaš, which are common in the highlands volcanoes.

Jakeš & White (1969) have analysed five rocks from Mount Hagen, two from Mount Giluwe, and one from Mount Ialibu. All except the calcalkaline andesite from Mount Ialibu they place in Joplin's shoshonitic series (four shoshonites, an absarokite, and a latite). They liken the shoshonitic lavas to shoshonites in Fiji and the Lesser Sunda Islands.

The chemical analyses and CIPW norms of 34 specimens from the highlands volcanoes support the conclusions drawn from the petrographic data (Mackenzie & Chappell, 1972). Corresponding with the change from olivine-rich basaltic rocks to hornblende and hypersthene-bearing andesitic rocks, there is a change from shoshonite and absarokite to high-potash/high-alumina basalt, high-potash/low-silica andesite, high-potash andesite, and high-potash dacite. The shoshonites and absarokites are saturated; the andesites are generally oversaturated. The trace element values show enrichment in strontium, rubidium, barium, and zirconium relative to andesite.

Joplin (1968) has documented examples of the shoshonite association in Montana, western Italy, Indonesia (Celebes, Java, Lesser Sunda Islands), the Bufumbira area in Uganda, the Rhine rift, the Sierra Nevadas, the south coast of New South Wales, Armenia, and Patagonia. She suggests that the shoshonitic association is characteristic of newly stabilized or stabilizing orogenic regions.

The area discussed in this Bulletin was affected by Late Tertiary orogeny and early Pleistocene uplift accompanied or followed, or both, by volcanism (Perry, 1965). It is now a relatively stable region.

Dickinson & Hatherton (1967) have related the composition of magma erupted at the surface to the depth of the Benioff Zone in island arc areas, and Jakeš & White (1969) have related the change from a tholeiitic magma type in the northern New Guinea arc to a shoshonitic magma type in the central highlands to a Benioff Zone which meets the surface in the Bismarck Sea and dips below northern Papua New Guinea. The best available seismic data (Johnson, 1970; and plots made by D. E. Mackenzie) show that at present there is no indication of a Benioff Zone beneath the highlands volcanoes; only a small number of shallow focus earthquakes, spatially unrelated to any volcanic centres, have been recorded.

It is concluded that the lavas of the highlands volcanoes originated in the mantle, possibly in sinking blocks of eclogite which separated from the base of the downwarped crust during the Late Tertiary orogeny. The lavas may have been enriched in potassium, strontium, rubidium by zone refining in a mantle layer containing interstitial partial melt (Mackenzie & Chappell, 1972).

Alluvial Fans

The alluvial fans in the Wahgi valley (Figs. 7, 49) are 10 to 100 m thick and slope at 1° to 30°. They commonly coalesce, and cover most of the floor of the Wahgi valley from Kerowagi to west of Banz, over an area of 40 km by 12 km (see maps). There is a small residual deposit at Kundiawa, near the confluence of the Chimbu and Wahgi Rivers, and smaller deposits interfinger with and overlie extensive lake sediments in the Baiyer River and Goroka valleys beyond the Kubor area.

Figure 49. Wahgi valley north of Minj, from the northwest, showing alluvial fans (foreground) and Cretaceous beds (dip-slopes on right skyline).

The fans consists of unconsolidated Pleistocene fluvial clay, silt, sand, pebble, cobble, and boulder gravel derived mainly from plutonic bodies to the north and south. There are minor tuff beds up to 2 m thick. The deposits are well bedded, though individual beds are unsorted. Cross-bedding is common and there are many small unconformities. The deposits vary greatly in structure and composition, the main variable being source materials and grainsize. This variation is reflected in the topographic expression of the individual deposits (cf. Haantjens, 1970).

The conglomerates were derived from both sides of the Wahgi valley. The Kubor Range contributed mostly plutonic and metamorphic detritus whereas the Jimi-Wahgi divide shed mostly volcanic, sedimentary, and minor plutonic rock material into the rapidly formed fans. Detritus entered the valley from at least six points on the north side and four on the south. The interfingering lacustrine deposits in the west indicate that the fans formed while the Wahgi valley was a lake (Pleistocene to Holocene). The clays in some of the deposits are finely laminated and have the appearance of varved clay formed by fluvioglacial processes. Some of the detritus is probably of fluvioglacial origin as parts of the source areas are known to have been glaciated during the late Pleistocene (Reiner, 1960; Löffler, 1970), but most of the sediment was probably formed during a period of greatly accelerated erosion due to recent uplift or during a period of intense earthquake activity (cf. Torricelli Mountains, Simonett, 1967). The interbedded tuffs were probably derived from Mount Hagen or one of the other highlands volcanoes, or possibly from volcanic centres in the Bismarck Sea.

Lacustrine Deposits

Extensive horizontal lacustrine sands, silts, gravels, peats, and muds cover the west end of the valley floor between Mount Hagen airport and Banz (Fig. 7). The beds were probably laid down in a lake formed when the ancestral Wahgi River, which flowed north into the Yuat River, was dammed by Mount Hagen Volcanics (Haantjens, 1970). When the lake was filled with sediment it overflowed to the east, where the new Wahgi River was captured by the Chimbu River. These deductions are supported by the flat mature form of the upper Wahgi valley (Fig. 7), the increase in the depth of incision of the valley to the east (Fig. 8), the youthful gorge upstream from the Wahgi-Chimbu confluence, and the rejuvenated gorge downstream (Figs. 9, 10; Frontispiece).

Scree

Extensive deposits of angular rock fragments, mixed with soil, occur below the scarps of the Chimbu and Nebilyer Limestones. The deposits, particularly west and northwest of Mount Elimbari, have moved a considerable distance down the slopes and can be traced on the aerial photographs as lobate mud flows on the Cretaceous strata.

The northern slopes of Mount Michael are mantled by boulders, sand, silt, mud, and soil derived from the Michael Diorite. The boulders are generally weathered and partly rounded, despite their close proximity to the diorite. The summit of Mount Michael has been glaciated, and it is possible that the deposits are partly reworked glacial sediments, or the product of more recent erosion of the nearby diorite bluffs and prominent sugarloaf hills.

Small deposits of scree and juvenile alluvial fans have been formed beneath the steeper slopes and bluffs bordering the alluvium along the Wahgi and Nebilyer valleys.

HOLOCENE

Alluvium

Clay, sand, silt, gravel, and minor peat and alluvial soils form river terraces, flood plains, and valley fill. Only the most extensive deposits have been mapped. Residual soils blanket most of the Kubor area.

INTRUSIVE ROCKS

Kubor Granodiorite
(Rickwood, 1955)

The Kubor Granodiorite (Rickwood, 1955) comprises several plutonic intrusions in the core of the Kubor Anticline. The main intrusion at the western end of the anticline is a composite body 39 km long and 27 km wide; it includes some roof pendants of Omung Metamorphics. Smaller stocks crop out in the Maril-Wahgi River area north of Gumine, in the Wahgi River 16 km west of Kundiawa, and in the Omung River and Numans Creek farther west. The granodiorite is also exposed as inliers in the Maril Shale 15 to 20 km west of Gumine, and in Ambaga Creek, 10 km west of Minj. The large plutons consist mainly of coarse-grained granodiorite and tonalite, which are generally weathered or altered to some extent; the small stocks and dykes consist of gabbro, diorite, and adamellite. The gabbros generally occur on the margins of the granodiorite and tonalite plutons.

The Kubor Granodiorite has intruded low-grade metamorphosed sediments and volcanics of the Omung Metamorphics, and is overlain non-conformably by the Kuta and Kana Formations and, in places, by the Maril Shale or Kondaku Tuff. In the Kuta area, at the west end of the Kubor Anticline, on Mount Oga, and near Gurumugl, beds of arkose occur between the limestone of the Kuta Formation and the Kubor Granodiorite.

The granodiorite and tonalite plutons are surrounded by zones of hornfels, except where the contacts are faulted and sheared. The hornfels zones are generally only a few tens of metres wide, but in the Omung and Minj Rivers, and in the valley south of Kudjip, they are several hundred metres wide; the presence of numerous small stocks and dykes in these wider zones suggests that they are underlain by larger plutons. The hornfelses have been described on page 00.

The Kubor Granodiorite is generally unaltered, but in places it is strongly metamorphosed and has a gneissic structure. The boulders in the streams and the outcrops seldom contain xenoliths of country rock or other inclusions, except near intrusive contacts or where the contacts have been disturbed by faulting, as for example west of Mount Kubor. The granitic intrusives are cut by numerous dykes of aplite and, in the Maril River area, by pegmatite dykes; the aplite dykes are associated with potash metasomatism in the surrounding granodiorite. The concentric folding of the aplites and pegmatites in the Maril River indicates deformation at high temperature.

Age

The Rb-Sr age of the Kubor Granodiorite, including the associated pegmatites and aplites, is about 244 m.y. (Page, 1971). This is in accordance with the tentative Permian-Triassic age of the overlying Kuta Formation and allows at least several million years for the unroofing and deep erosion of the granodiorite. On the other hand the K-Ar age (about 215-220 m.y.) appears to be too young to be regarded as a minimum age of emplacement.

Petrography

The Kubor Granodiorite is composed predominantly of unmetamorphosed granodiorite, tonalite, gabbro, and diorite, with minor adamellite and aplite (Table 4), but in places the rocks have been metamorphosed. In some of the gabbros and diorites hornblende has been replaced by actinolite, chlorite, and epidote, but others have been recrystallized to amphibolite with a relict igneous texture.

The granodiorite (Table 4, Nos. 1-8) consists of oligoclase-andesine (45-75%), quartz (10-40%), orthoclase microperthite (5-20%), and up to 15 percent biotite or hornblende, or both. The ferromagnesian minerals are commonly partly to completely altered to chlorite, epidote, sphene, and opaque grains. The irregular poikilitic crystals of orthoclase are up to 1 cm across, and commonly show patchy inversion to microcline.

The more basic tonalite (Table 5, Nos. 9-17) consists of zoned oligoclase-andesine (50-70%), quartz (10-40%), hornblende (1-20%), and biotite (1-8%), with little or no potash feldspar. In places, the biotite is partly chloritized (Table 4, Nos. 9-10, 15-16).

The gabbros are generally partly altered or slightly metamorphosed (Table 4, Nos. 18-23). They consist of zoned calcic plagioclase (An_{50}-An_{77}) and green hornblende or clinopyroxene, or both, or hornblende and biotite. The hornblende is overgrown and partly replaced by actinolite or partly altered to chlorite and opaque minerals. In places, the gabbro contains about 5 percent potash feldspar and 1 to 5 percent quartz (Table 4, Nos. 18-19), or quartz alone (Table 4, No. 22).

TABLE 4. ESTIMATED MODES, KUBOR GRANODIORITE

	Plagioclase (%; comp.)	*Potash Feldspar** (%)	*Quartz* (%)	*Hornblende* (%)	*Biotite* (%)	*Other Minerals* (primary; secondary)
1.	45	10-15	20	5	—	tr. magnetite (altered to hematite); 7% chlorite, 5% epidote
2.	50−(An_{20})	5	40+	—	3-4	tr. muscovite, sphene, magnetite, apatite, & garnet; tr. epidote & chlorite
3.	40(An_{35})	20(M,P)	35	—	chloritized	2% sphene, 0.5-1% ilmenite; 7-8% chlorite, 1% epidote
4.	55+	10-15	18	2	8-10	tr. ilmenite/magnetite & apatite; tr. chlorite & clay mineral
5.	55+(An_{30})	20(P))	15	—	3-5	tr. apatite, zircon, & ilmenite/magnetite; tr. clay mineral
6.	70-75	5-8	10-12	—	—	1% ilmenite/magnetite; 5% chlorite, 2-3% epidote
7.	60	5	25	—	—	5% chlorite, 1% calcite, 3% sphene
8.	45-50	10(P)	20	10	5	tr. ilmenite/magnetite & apatite; 4-5% chlorite, tr. epidote & clay
9.	60-65 ($An_{25\text{-}45}$)	2-3	15	2-3	4-5	2% muscovite, tr. magnetite, apatite, sphene, & zircon; 2-3% chlorite, tr. epidote
10.	60-65 ($An_{20\text{-}35}$)	5	25	3-4	2-3	tr. muscovite, 1-2% magnetite, 1% apatite, tr. sphene; 2-3% chlorite, 1% epidote
11.	70($An_{20\text{-}45}$)	5	3-5	15	—	1% muscovite
12.	50(An_{30})	2-3	40	1-2	1	tr. sphene; tr. epidote & chlorite
13.	60(An_{40})	1	10	5	7	tr. pyrite, sphene, & apatite; tr. chlorite & epidote
14.	30	—	—	60	5	tr. magnetite?; tr. chlorite & epidote
15.	60(An_{40})	—	10	20	1	1% sphene, tr. apatite & magnetite/ilmenite; 2% chlorite, 2% epidote, 2% sericite
16.	45($An_{30\text{-}35}$)	—	40	—	1	tr. sphene & ilmenite/magnetite; 7-8% chlorite, 2% sericite, 1% epidote
17.	70(An_{40})	—	10	10	5-8	tr. ilmenite/magnetite, apatite, & zircon; 1-2% chlorite
18.	60-65 ($An_{55\text{-}70}$)	5-10	2-5	5	—	15% clinopyroxene, tr. magnetite, apatite, & sphene; 1% chlorite & prehnite
19.	65($An_{35\text{-}60}$)	5	1	30	—	tr. magnetite, apatite, & sphene; 7-10% actinolite, 1% chlorite
20.	50+(An_{65})	—	—	—	—	30% clinopyroxene, 1% muscovite, 1-2% magnetite, 1% apatite & sphene; 5-10% epidote, tr. chlorite
21.	55(An_{75})	—	—	30	4-5	2-3% muscovite, tr. magnetite/hematite; tr. epidote
22.	75($An_{60\text{-}75}$)	—	2	15	1	1% clinopyroxene, 1% sphene & ilmenite/magnetite, tr. apatite; 1% chlorite, muscovite, & epidote
23.	60($An_{65\text{-}70}$)	—	—	5	—	10% clinopyroxene, 1-2% sphene, tr. ilmenite/magnetite; 15% actinolite, 5% epidote & chlorite

TABLE 4.—*continued*

	Plagioclase (%; comp.)	Potash Feldspar* (%)	Quartz (%)	Hornblende (%)	Biotite (%)	Other Minerals (primary; secondary)
24.	70(An_{40})	—	—	25	1-2	tr. magnetite, apatite, & sphene; 1% epidote & chlorite
25.	70+ (An_{20-40})	5-10(P)	5	7	1	tr. magnetite, sphene, & apatite; tr. chlorite & epidote
26.	60(An_{35-50})	—	1-2	30	—	1-2% muscovite, 3% magnetite/ilmenite, tr. apatite; 2-3% epidote
27.	80+(An_{35})	—	5-8	5-8	2-3	1% clinopyroxene, tr. magnetite/ilmenite; 2% actinolite, tr. sericite & epidote
28.	30(An_{30})	20+(M)	40	—	1	1% muscovite, 1-2% garnet, tr. sphene; tr. chlorite & epidote
29.	40(?)	20(M,P)	30	—	3-4	1% muscovite, tr. magnetite & sphene; 1-2% chlorite, 1% sericite
30.	15-20	25-30	50	—	1	1% garnet, 0.5% muscovite

Abbreviations: M—microcline, P—microperthite.

1. Altered granodiorite porphyry (20NG1197)
2. Quartz-rich biotite granodiorite (20NG1198B)
3. Altered biotite granodiorite (21NG0514)
4. Hornblende-biotite granodiorite (21NG2542)
5. Biotite granodiorite (21NG2544A)
6. Altered biotite granodiorite (21NG2736)
7. Altered biotite granodiorite (21NG2739)
8. Biotite-hornblende granodiorite (21NG2791)

9. Hornblende-biotite tonalite (20NG0580D)
10. Biotite-hornblende tonalite (20NG0580E)
11. Hornblende quartz diorite (inclusion in 20NG0580E)
12. Altered leucocratic biotite-hornblende tonalite (20NG1194)
13. Hornblende-biotite tonalite (20NG1198S)
14. Mafic xenolith in tonalite (20NG1198S)
15. Biotite-hornblende tonalite (21NG0517)
16. Altered biotite tonalite (21NG1032)
17. Biotite-hornblende tonalite (21NG2547)
18. Mixed hornblende-augite gabbro altering to quartz diorite (20NG0580B)
19. Altered hornblende gabbro (20NG0580C)
20. Altered pyroxene gabbro (20NG1148J)
21. Metamorphosed biotite-hornblende gabbro (20NG1198D)
22. Quartz-hornblende gabbro (21NG0521)
23. Hornblende-augite gabbro (21NG1028)
24. Altered hornblende diorite (20NG0580A)
25. Hornblende quartz diorite (20NG0592)
26. Partly recrystallized (quartz)-hornblende gabbro (20NG1198D)
27. Augite-biotite-hornblende quartz diorite (21NG1048)

28. Aplitic muscovite-biotite adamellite (20NG1194)
29. Biotite adamellite (20NG1198K)

30. Muscovite-garnet-biotite aplite (21NG2544B)

The diorite (Table 4, Nos. 24-27) generally contains quartz and grades into tonalite. It is composed of zoned plagioclase (An_{18}-An_{50}, 60-80%), biotite or hornblende, or both (35%), and up to 5 percent or more potash feldspar.

The leucocratic adamellite (Table 4, Nos. 28-29) is rich in quartz and contains about 20 percent large poikilitic crystals of microcline, a little muscovite and biotite, and calcic plagioclase. Garnet is present in one rock (Table 4, No. 29).

All the rocks contain accessory magnetite or ilmenite, apatite, and generally a little sphene; garnet and zircon are rare. Secondary epidote and chlorite are common, and calcite partly replaces plagioclase and hornblende in a few of the rocks.

Aplite dykes (e.g. No. 30, Table 4) are common. They consist of quartz (50%), microcline (25-35%), oligoclase (10-20%), and a little biotite, and also contain a variety of accessory minerals such as sphene, monazite, pink garnet, and muscovite.

Kimil Diorite
(new name)

The Kimil Diorite comprises several intrusions and numerous dykes and sills of diorite, tonalite, granodiorite, and basalt which intrude the Kana Formation, Balimbu Greywacke, and Mongum Volcanics in the Jimi-Wahgi divide and Jimi valley to the north of the Kubor area. The name is derived from the Kimil River, a tributary of the Wahgi River.

The contact between the Kimil Diorite and Balimbu Greywacke is generally faulted, but the Balimbu Greywacke is cut by dykes of Kimil Diorite. The Kana Volcanics have been hornfelsed by the Kimil Diorite, and are cut by numerous dykes, sills, and apophyses. In the Jimi valley the Kimil Diorite intrudes the Upper Jurassic Maril Shale and is cut by basaltic and andesitic dykes.

Petrography

The Kimil Diorite ranges from fine-grained dark green-grey diorite to coarse-grained leucocratic hornblende-biotite tonalite and granodiorite, with subordinate microdiorite, microgranodiorite, and basalt. The rocks are commonly hydrothermally altered and slightly metamorphosed, and in places they are strongly foliated.

All the rocks contain altered andesine, hornblende partly altered to fibrous actinolite, quartz (2-35%), and a little chlorite. Much of the potash feldspar in the granodiorite and in some of the diorite and tonalite is considerably altered. The tonalite contains rare biotite, which is largely altered to chlorite, epidote, and sphene (20NG1223B); augite occurs sporadically as relict cores in hornblende in the diorite (20NG0614). The accessories include magnetite or titanomagnetite, apatite, and sphene; pyrite is locally abundant. Partial recrystallization or replacement of hornblende by actinolite is common. Veinlets of potash feldspar cut the rocks in a few places, and prehnite partly replaces feldspar at one locality (20NG0613A).

The three specimens collected from the northern margin of the intrusion in the Jimi valley consist of quartz-plagioclase-muscovite gneiss (20NG2532) formed by the alteration of granodiorite or adamellite, weathered hornblende-biotite tonalite (20NG2535), and partly chloritized augite basalt intruding granodiorite (20NG2536).

Intrusive relationships and age

The Kimil Diorite forms a discontinuous chain of small plutons between the middle Miocene Maramuni Diorite and Bismarck Intrusive Complex, which are part of a belt of middle Miocene intrusives extending from Wau to the West Irian border. Furthermore, the type and degree of alteration of the Kimil Diorite, and the size of the intrusions, are similar to the type of alteration and size of the nearby middle Miocene Oipo Intrusives (Dow & Dekker, 1964). The preliminary results of the isotopic dating of the Kimil Diorite also indicate a middle Miocene age (R. W. Page, pers. comm.). The extensive alteration and metamorphism of the Kimil Diorite and Oipo Intrusives may have been caused by post-Miocene faulting which splayed around the Maramuni and Bismarck batholiths.

Bismarck Intrusive Complex
(Rickwood, 1955; amended)

Previous work

Stanley (1922) reported boulders of granitic rocks in the rivers flowing down the mountains southwest of the Ramu River, and Noakes (1939) described plutonic rocks ranging from diorite to granite which he termed collectively the Wilhelm granite. The name Bismarck Granodiorite was first used by Rickwood (1955), who likened the intrusives of the Bismarck Mountains to the Kubor Granodiorite. More recently, McMillan & Malone (1960) and Dow & Dekker (1964) have studied various parts of the Bismarck Granodiorite in more detail. The name has been amended to Bismarck Intrusive Complex because of the varied lithology.

Lithology

The southern and southwestern parts of the complex consist predominantly of coarse gabbro and diorite. According to McMillan & Malone (1960) the northeast and southeast parts consist of tonalite and granodiorite, with associated granite and aplite in the northeast (Yandera-Bononi area), and diorite and amphibolite in the southeast (Asaro valley). They reported tonalite with dykes of quartz diorite, basalt, and quartz-hornblende andesite from the Kerigomna plateau area (about 20 km north of Chuave), and gabbro, hornblende, and layered dunite-peridotite-anorthosite in the Mount Wilhelm area. Microtonalite, micromangerite, microgranite, and diorite porphyry occur to the northwest of Mount Kworu, near the northern boundary of the Kubor area (Dow & Dekker, 1964; Joyce, 1965). Dow & Dekker also mapped gabbro at the northern end of the batholith, some of which is foliated, especially along the northeast contact. Flow-alignment of crystals, foliation, and compositional banding are common on the west side of the batholith.

Distribution and topography

The main mass of the Bismarck Intrusive Complex is 51 km long and 19 km wide, and extends slightly east and well north of the Kubor area. Several small satellite intrusions crop out in the Goroka Formation to the east of the Kubor area.

The complex forms part of a rugged range culminating in Mount Wilhelm (4509 m; Fig. 4), with numerous other peaks over 3000 m. The deeply incised drainage is mainly controlled by joints and faults. Three main sets of lineaments, trending 300°, 360° to 030°, and 160° to 170°, can be distinguished on the aerial photographs. The main west-northwesterly set is parallel to the long axis of the batholith and the regional tectonic grain, and to the Bismarck and Bundi Fault Zones of Dow & Dekker (1964).

Intrusive relationships and age

The smoothly curved intrusive contacts of the batholith are surrounded by a narrow contact aureole. Small embayments are present in places (e.g. near Kworu). North of the Daulo Pass, the batholith is bounded by faults.

The complex is of middle Miocene age. Page (1971) has shown that the bulk of the complex is about 12.5 m.y. old, but in the Goroka, Mount Otto, and Yandera areas the isotopic ages range from 7 to 10 m.y. Some of the small intrusive bodies mapped by McMillan & Malone (1960) to the southeast are early Jurassic (180-190 m.y.). The gabbros at the northwestern end of the complex intrude the Upper Cretaceous to upper Te Asai Shale, but elsewhere the complex intrudes rocks no younger than Late Triassic (Kana Volcanics). Dow & Dekker (1964) state that the gabbros at the northwest end of the batholith are similar in composition to the gabbros on the summit ridge of Mount Wilhelm, but correlated them with the Tertiary Oipo Intrusives in the Jimi valley. They consider the remainder of the batholith to be Lower? Jurassic because it intrudes only the Upper Triassic Kana Volcanics and Palaeozoic? Goroka Formation, and because in one area the Kana Volcanics, but not the nearby Maril Shale, are mineralized. However, the absence of sulphide mineralization in the Maril Shale is probably due to the marked compositional and lithological differences between the shale and the volcanics. Recent petrographic studies and isotopic age determinations indicate that the gabbros in the northwest are of the same age as the remainder of the batholith.

Petrography

Specimens were collected from five main areas in the southern part of the complex during the 1968 survey. Porphyritic pyroxene microdiorite and hornblende-augite

TABLE 5. ESTIMATED MODES, BISMARCK INTRUSIVE COMPLEX

	Plagioclase (%; comp.)	*Quartz* (%)	*Hornblende* (%)	*Augite* (%)	*Other Minerals* (primary; secondary)
1.	60(An$_{81-87}$)	—	7-8	20-25*	4-5% magnetite
2.	70+(An$_{83}$)	—	7	10*	5% olivine, 5% magnetite; tr. chlorite
3.	60-65(An$_{88}$)	—	15	15*	5% magnetite
4.	85(An$_{76}$)	—	5-7	5*	1-2% magnetite, tr. apatite
5.	60(An$_{84}$)	—	25	10*	2% magnetite, tr. apatite
6.	65(An$_{90}$)	—	30	1-2*	2-3% magnetite?
7.	60(An$_{60}$)	—	30	5-6	2% magnetite, 1% apatite, tr. sphene; 1% chlorite, tr. epidote
8.	65(An$_{40-60}$)	1-2	25	5*	5-7% biotite, 1% apatite, tr. sphene; 1% chlorite, tr. epidote
9.	65(An$_{75}$)	—	30	—	3-4% magnetite, 1% sphene; 1% chlorite, tr. epidote
10.	60(An$_{60}$)	—	30-35	—	2-3% magnetite, 1-2% apatite, 1-2% biotite; tr. chlorite
11.	20(An$_{40}$)	1-2	70	10*	1-2% olivine, 3% opaque minerals including sulphides, tr. apatite & zircon; 1-2% calcite, tr. muscovite
12.	70(An$_{50}$)	1	20	2-3*	2-3% chalcopyrite, 2% apatite, 1% sphene, tr. biotite; 1% chlorite, tr. muscovite
13.	60(An$_{50}$)	—	30-35	2-3	2% chalcopyrite, 1% ilmenite, tr. apatite & sphene
14.	60(An$_{40-55}$)	5	25-30	—	1-2% biotite, 1-2% sulphide, tr. apatite & sphene; 2-3% chlorite, tr. epidote
15.	70(An$_{30-70}$)	15	10	—	1-2% biotite, 1-2% opaque minerals, tr. apatite & sphene; tr. chlorite
16.	60+ (An$_{3}$[illegible]$_{-35}$)	7-10	7-8	1-2	5-7% potash feldspar, 5-7% biotite, 1-2% opaque minerals, tr. apatite; 1-2% chlorite, tr. epidote

*Partly replaced by hornblende.

1. Hornblende-augite gabbro (20NG1270M)
2. Olivine-hornblende-augite gabbro (20NG1270J)
3. Hornblende-augite gabbro (10NG1270P)
4. Augite-hornblende gabbro (20NG0621)
5. Augite-hornblende gabbro (20NG1270T)
6. (Augite)-hornblende gabbro (20NG1270U)

7. Augite-hornblende gabbro (20NG1270N)
8. Quartz-augite-biotite-hornblende gabbro (20NG1270Q)
9. Pegmatitic hornblende gabbro (20NG1270G)
10. (Biotite)-hornblende gabbro (20NG1270L)

11. (Olivine)-augite-hornblende diorite porphyry (20NG1270F)
12. Augite-hornblende quartz diorite (20NG1270C)
13. Augite-hornblende diorite (20NG1270D)
14. (Biotite)-hornblende quartz diorite (20NG1270H)

15. Biotite-hornblende tonalite (20NG1270B)

16. Augite-biotite-hornblende mangerite (20NG1270A)

Note: Nos. 1-6 are bytownite gabbros with augite mantled by hornblende.

gabbro occur in the southeast part of the Kerigomna plateau. The gabbro (Table 5, Nos. 1-6) consists of rounded prisms of bytownite (85%) and irregular masses of pale green hornblende, which wholly or partly enclose plagioclase grains and partly replace ragged pale brown augite grains (Fig. 50).

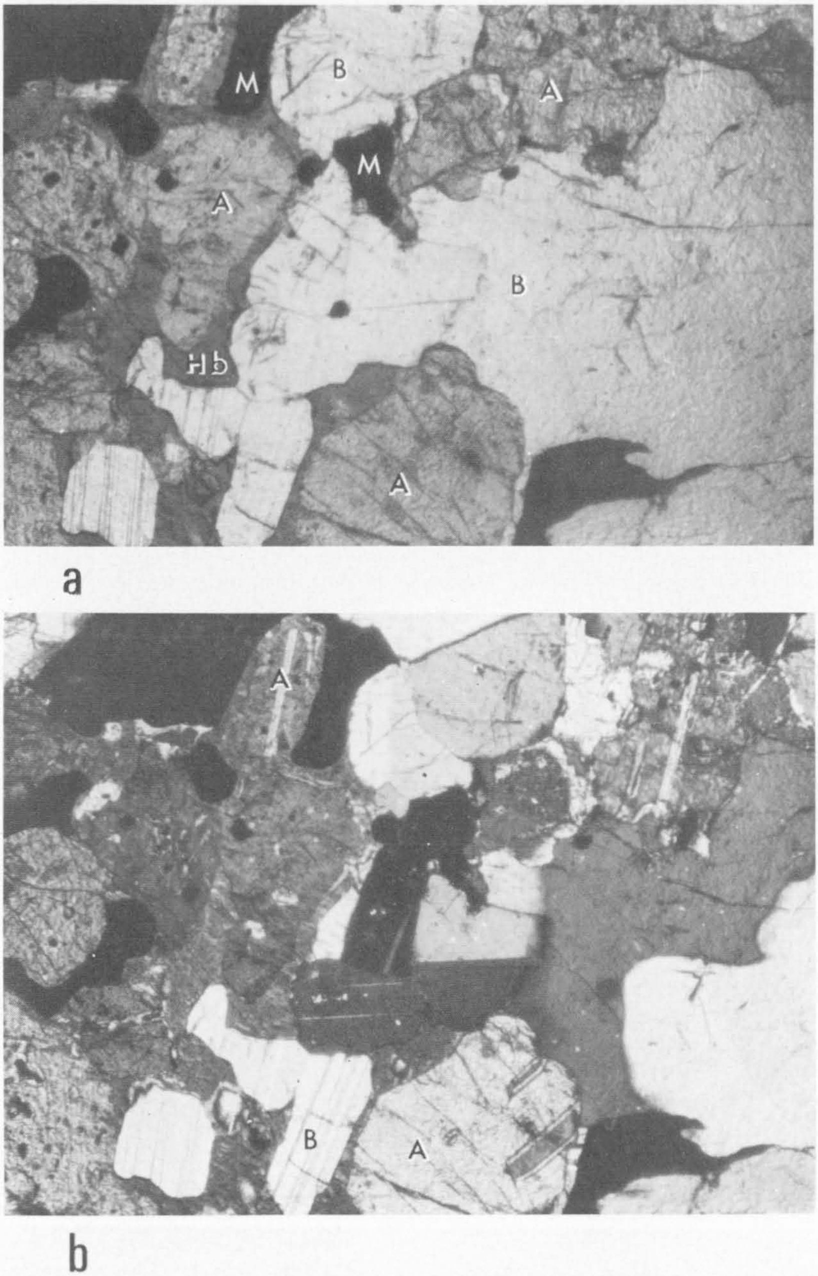


Figure 50. Hornblende-augite gabbro (20NG1270M) from the Bismarck Intrusive Complex in the Mount Wilhelm/Mount Kworu area. The rock is composed of bytownite (B), augite (A), and hornblende (Hb) which occurs in and around pyroxene, and magnetite (M). Figure 50b (crossed polarized light) shows the twinning in the plagioclase and pyroxene. x 45.

Gabbro (Table 5, Nos. 1-10) is predominant in the Kworu River area, and is associated with microdiorite, tonalite, and mangerite (Table 5, Nos. 15 & 16). The gabbro ranges from basic hornblende-augite gabbro as described above to varieties containing hornblende alone, hornblende, biotite, pyroxene, and quartz, hornblende and biotite, or hornblende, augite, and olivine (Table 5, Nos. 9, 8, 10, & 2). It contains very calcic plagioclase, and there are reaction relationships between augite and hornblende, and between olivine and hornblende. The diorite (Table 5, Nos. 11-13) consists of strongly zoned andesine-labradorite and hornblende (either alone or with augite), quartz and biotite (Table 5, No. 12), augite, olivine, and quartz (Table 5, No. 11), or biotite and quartz (Table 5, No. 14). The augite forms irregular relict cores in hornblende crystals.

In the very basic bytownite gabbros, the pyroxene, which is euhedral or in an early stage of reaction to hornblende, the opaque mineral (probably magnetite), and in one case olivine also, are mantled by yellow-brown hornblende. The texture resembles cumulus or eutectic texture: the grain boundaries tend to be curvilinear and plagioclase has convex boundaries against hornblende. The less basic rock contains less pyroxene (indicating a more advanced stage of reaction), and greener hornblende. Potash feldspar is absent in all but one of the specimens.

The dominant rock type in the southern part of the batholith is gabbro (Table 5, No. 4). Only in the northeast and southeast is granodiorite predominant. In other areas, tonalite, diorite, and mangerite are important. Systematic sampling of the complex would probably show that the main rock types are gabbro, tonalite, and diorite.

The complex is generally poorer in potash feldspar and quartz and richer in pyroxene and calcic plagioclase than the Kubor Granodiorite. As the Bismarck Intrusive Complex was emplaced farther away from the edge of the Australian continental block, the lower potash content is consistent with the hypothesis of Moore (1959), who correlates the increase in potash in Tertiary intrusives with increasing distance from the west coast of North America.

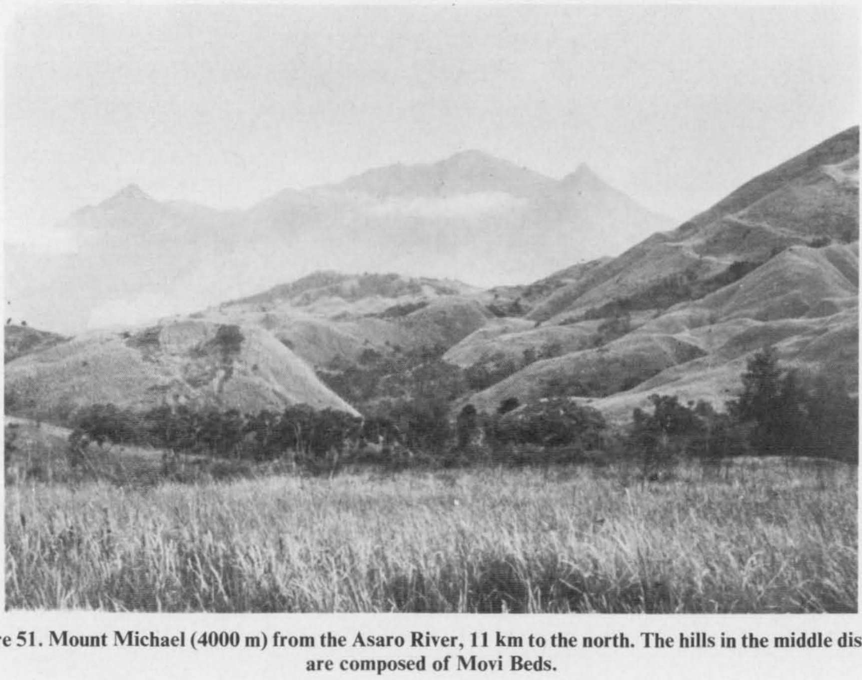


Figure 51. Mount Michael (4000 m) from the Asaro River, 11 km to the north. The hills in the middle distance are composed of Movi Beds.

Michael Diorite
(new name)

The Michael Diorite is a hypabyssal body, 10 km long and 6 km wide, forming Mount Michael (4000 m), 15 km east of the Wahgi-Asaro River junction (Figs. 51, 54). It consists of light to dark grey microporphyritic hornblende diorite with small phenocrysts of hornblende and square crystals of cloudy white plagioclase. The rock commonly contains finely crystalline mafic inclusions and occasional fragments of volcanic rock composed of feldspar clasts set in a yellowish glassy groundmass.

Petrography

The microporphyritic hornblende diorite (Table 6) consists of small phenocrysts of hornblende (10-20%) and andesine (35-40%) set in a finely crystalline quartzofeldspathic groundmass (about 40%). The diorite is intensely altered in places.

TABLE 6. ESTIMATED MODES, MICHAEL DIORITE

	Plagioclase (%)	*Potash Feldspar* (%)	*Quartz* (%)	*Hornblende* (%)	*Groundmass* (%)	*Other Minerals* (primary; secondary)
1.	40	5	—	20	40	tr. opaque minerals; tr. prehnite, calcite, chlorite, & epidote
2.	40	2-5	2-5	7-10	40	2% opaque minerals, tr. sphene; 2% epidote, actinolite, & chlorite
3.	35-40	5	5-10	10-20	40	2-5% opaque minerals, tr. sphene
4.	30-40	—	—	10-20	40-50	1-2% opaque minerals, tr. sphene

1. Microporphyritic hornblende diorite (21NG2645)
2. Microporphyritic hornblende diorite (21NG2636B)
3. Altered microporphyritic hornblende-quartz diorite (21NG1386)
4. Microporphyritic hornblende diorite (21NG2638)

In the unaltered rock, the squat prismatic plagioclase phenocrysts have sharp rounded outlines. Many of the crystals are complexly twinned and show strong normal and oscillatory zoning. Some crystals enclose small rounded grains of plagioclase, and the rims of many crystals are sieved with small inclusions. The plegioclase is also commonly fractured and veined, and partly replaced by potash feldspar. The euhedral hornblende prisms average about 0.5 mm long, with some up to 2 mm, and are zoned and twinned. Most of the crystals are pleochroic from pale yellowish green to deep green and greenish brown. In places the hornblende has been replaced by patches of calcite, actinolite, chlorite, prehnite, and opaque minerals, and by chlorite and sericite pseudomorphs. The altered rocks contain up to 5 percent sanidine and 2 percent pyrite. The sanidine occurs as veins in plagioclase, interstitial patches up to 1 mm across, generally moulded around the ends of plagioclase phenocrysts, and smaller interstitial patches between quartz and plagioclase granules in the groundmass. One specimen contains a few phenocrysts of quartz. The small rounded grains of pyrite contain many inclusions; most of the grains are moulded on plagioclase or replace plagioclase and hornblende. Some of the rocks contain aggregates of small granules of pyrite, which are commonly surrounded by sericite and epidote. The groundmass consists of a fine mosaic of quartz, plagioclase, and hornblende with interstitial potash feldspar and rare sphene. In the altered rocks the groundmass contains cloudy feldspar, epidote (or allanite?), chlorite, prehnite, sericite, and opaque minerals. One specimen has a sericitized and finely recrystallized glassy quartzofeldspathic groundmass.

The potash feldspar, and probably the pyrite, were introduced during late-stage high-temperature potash metasomatism. The subsequent alteration of the plagioclase and potash feldspar to calcite, chlorite, and prehnite, and the chloritization of hornblende, are due to lower-temperature hydrothermal activity.

Intrusive relationships and age

The texture and mineral composition indicate that the pluton is a high-level intrusion. The intrusive relationships and the doming of the surrounding sedimentary rocks provides corroborative evidence. The pluton rose to within 1500 m of the surface and possibly much closer. The numerous small patches of conglomerate and siltstone of the Movi Beds capping the summit area probably represent part of the roof cover. The streams on the mountain are deeply incised and the exposed margins of the diorite are some 2000 m below the summit of the intrusion. The diorite was emplaced largely by doming of the country rock, and although stoping has truncated some of the beds there is no major peripheral faulting or deflection of strata.

The only rocks intruded by the diorite are lower Tf shale, sandstone, and conglomerate of the Movi Beds. The preliminary results of isotopic age determinations indicate an age of 7.3 $\pm$ 0.2 m.y. (Page, 1971).

Mineralization

Elsewhere in eastern New Guinea (e.g. Frieda River, Dow et al., 1973) similar suites of hypabyssal and subvolcanic porphyries contain considerable amounts of disseminated copper or gold. Although the Michael Diorite contains an average of 1 to 2 percent pyrite, only rare grains of chalcopyrite were seen. However, detailed examination may reveal the presence of more copper sulphides. The subvolcanic Frieda Porphyry intrudes andesitic and basaltic lavas and volcanolithic sediments, whereas the Michael Diorite intrudes only shale, siltstone, sandstone, conglomerate, and limestone. No significant copper mineralization is likely to be present as no massive sulphides were seen in the streams draining the mountain nor do stream sediment samples contain anomalous copper values.

Kera Sill

Rickwood (1955) recorded a diorite sill in the Maril Shale in the Kera Creek area, south-southeast of Kundiawa. The sill was remapped in 1968 and found to extend at least 8 km west of the Wahgi River. It crops out on the Kundiawa-Gumine road, where it is about 15 m thick, and also intersects the Gumine-Neragaima road in two places. The presence of diorite boulders in a few of the streams farther west indicates that similar intrusives may be also present there.

The Kera Sill consists of medium to coarse-grained black and white diorite which grades into a fine-grained grey-green variety at the margins of the intrusion. The diorite consists of partly altered plagioclase, colourless corroded augite mantled by brown hornblende, and accessory apatite and ilmenite. At the east end of the sill the diorite (21NG1141) is very coarse-grained and has an ophitic texture. It also contains pale green chlorite after biotite, and accessory sphene. Farther west, the diorite is finer-grained and more altered, and contains a trace of alkali feldspar (21NG1143). At the west end, it is medium-grained and has an ophitic to subophitic texture, and is still more extensively altered. The hornblende is partly or completely pseudomorphed by chlorite, the plagioclase is partly altered, and the ilmenite is partly altered to leucoxene. Biotite occurs in places (e.g. 21NG2580A), and in others (21NG2580B) ilmenite forms elongated skeletal crystals up to 8 mm long.

Other Minor Intrusives in the Maril Shale

A small dyke of altered andesite (21NG1154), about 60 cm across, intrudes the Maril Shale 18.5 km west of Kundiawa. It is a fine-grained grey-green rock composed of relict phenocrysts of plagioclase, up to 3 mm long, pale green chlorite pseudomorphing ferromagnesian minerals, leucoxene after ilmenite, a little biotite, secondary muscovite, and 60 percent calcite which has replaced feldspar and other minerals.

A small intrusion of pale grey rhyodacite or rhyolite porphyry (21NG2554), in Maril Shale 5 km west of Gurumugl, consists of euhedral phenocrysts of quartz, about 2 mm long, and prisms of sanidine and oligoclase set in a fine-grained mosaic of feldspar and quartz, with a little green biotite, chlorite, and muscovite.

Dykes and sills of microdiorite are common in the Maril Shale west of Gumine. Some of the intrusions contain large masses of coarsely crystalline white to pink calcite. The altered rocks have been used as paving stones on the road west from Dirima.

Kenangi Gabbro
(new name)

The sills, dykes, and stocks of gabbro, mangerite, diorite, and granodiorite in the Kenangi-Watabung area are here named the Kenangi Gabbro. Similar dykes, sills, and small stocks occur in the Movi Beds and Yaveufa Formation to the south and southeast. Some of the intrusions were mapped by McMillan & Malone (1960).

Northeast of Chuave, there are numerous dykes and stocks of gabbro, mangerite, and granodiorite (21NG1075C,E,F, 21NG1706A,B). The dykes range from 1 to 10 m across, and the stocks are up to 2 km in diameter. Sills of hornblende mangerite porphyry from 1 to 100 m thick crop out in the Asaro River north of Lufa. The sills have irregular contacts and contact aureoles up to 12 m wide.

The gabbro, mangerite, diorite, and granodiorite (Table 7, Nos. 1-3, 4-5, 6, & 7) are commonly porphyritic and altered to various degrees. Pyroxene, olivine, and potash feldspar are common, but hornblende is less common than in the Bismarck Intrusive Complex. The presence of biotite in the groundmass of the olivine-bearing gabbro (Table 7, Nos. 1-2) and the mangerite porphyry (Table 7, No. 5) indicates shoshonitic affinities. The Kenangi Gabbro is probably genetically unrelated to the Bismarck Intrusive Complex, but has strong petrographic affinities with the lavas of the Yaveufa Formation which they intrude.

Benembi Diorite
(new name)

The Benembi Diorite is a small plug of hornblende-quartz diorite porphyry, 6 km southwest of Mount Hagen. It has intruded volcanolithic and tuffaceous sandstones of the Kondaku Tuff and has produced some hornfels. The porphyry contains white to yellowish plagioclase phenocrysts up to 4 mm long and small black prisms of hornblende set in a fine-grained yellowish grey groundmass of subhedral prisms, averaging 1 mm long, of altered zoned plagioclase (An_{39}-An_{18}, 70%), interstitial grains and irregular inclusions (in plagioclase) of potash feldspar (5-10%), interstitial quartz (5%), and partly chloritized euhedral prisms of hornblende, pleochroic as

TABLE 7. ESTIMATED MODES, KENANGI GABBRO

	Plagioclase (%; comp.)	*Potash Feldspar* (%)	*Quartz* (%)	*Hornblende* (%)	*Augite* (%)	*Olivine* (%)	*Biotite* (%)	*Other Minerals* primary; secondary)
1.	50	—	—	—	35	5	3-4	2-3% opaque minerals, tr. apatite
2.	70-75(An_{55-70})	—	—	5	10	2	3	tr. opaque minerals & apatite; 5-7% green alteration products of olivine, including green mica
3.	60	—	1-2	—	20	—	—	1-2% magnetite?; 2-3% calcite, 10-15% chlorite, tr. epidote
4.	55		5	—	30	—	—	2-3% magnetite; 5% chlorite; 2-3% green biotite/phlogopite
5.	45	10	—	tr.	25	10	5	1% apatite
6.	ca 40	?	1-2	15	—	—	—	40% actinolite, 10% epidote
7.	60+	10-15	15	1-2	—	—	—	1-2% opaque minerals; 5% chlorite, 1-2% calcite, 1% epidote

1. Altered biotite-olivine-augite gabbro porphyry (21NG1075F)
2. Altered olivine-biotite-hornblende-augite gabbro (21NG1076A)
3. Altered augite gabbro porphyry (21NG2681)
4. Altered augite micromangerite porphyry (21NG1075C)
5. Biotite-olivine-augite micromangerite porphyry (21NG1076B)
6. Metamorphosed hornblende diorite (21NG2503F)
7. Altered granodiorite porphyry (21NG1075E)

follows: α—very pale brown or pinkish brown (nearly colourless), β—brown-green to greenish brown, γ—pinkish brown with a green tinge. Other minerals are green biotite (extensively chloritized), magnetite, apatite, and secondary epidote-clinozoisite and sphene which partly replace plagioclase and hornblende.

Intrusive rocks in the Kondaku Tuff, which are probably equivalent to the Benembi Diorite, are considered to be responsible for the gold mineralization at Kuta (Ward, 1949; Rickwood, 1955), and gold mineralization could therefore be found around the Benembi Diorite.

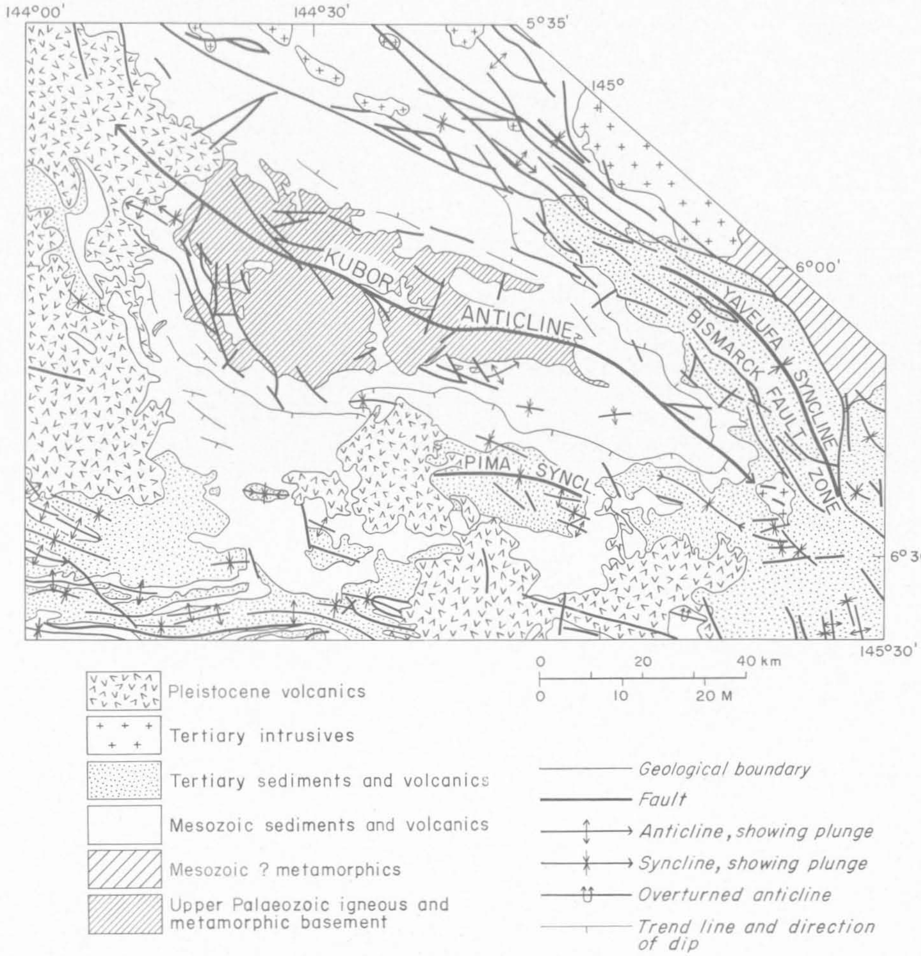


Figure 52. Structure. B55/A/7-1

STRUCTURE
(Fig. 52)

The Central Cordillera (or Central Highlands Orogenic Belt of Thompson & Fisher, 1965) is composed of two fundamental structural units: the New Guinea Mobile Belt and the stable crust block (Fig. 53), which have been briefly described by Dow et al. (1973).

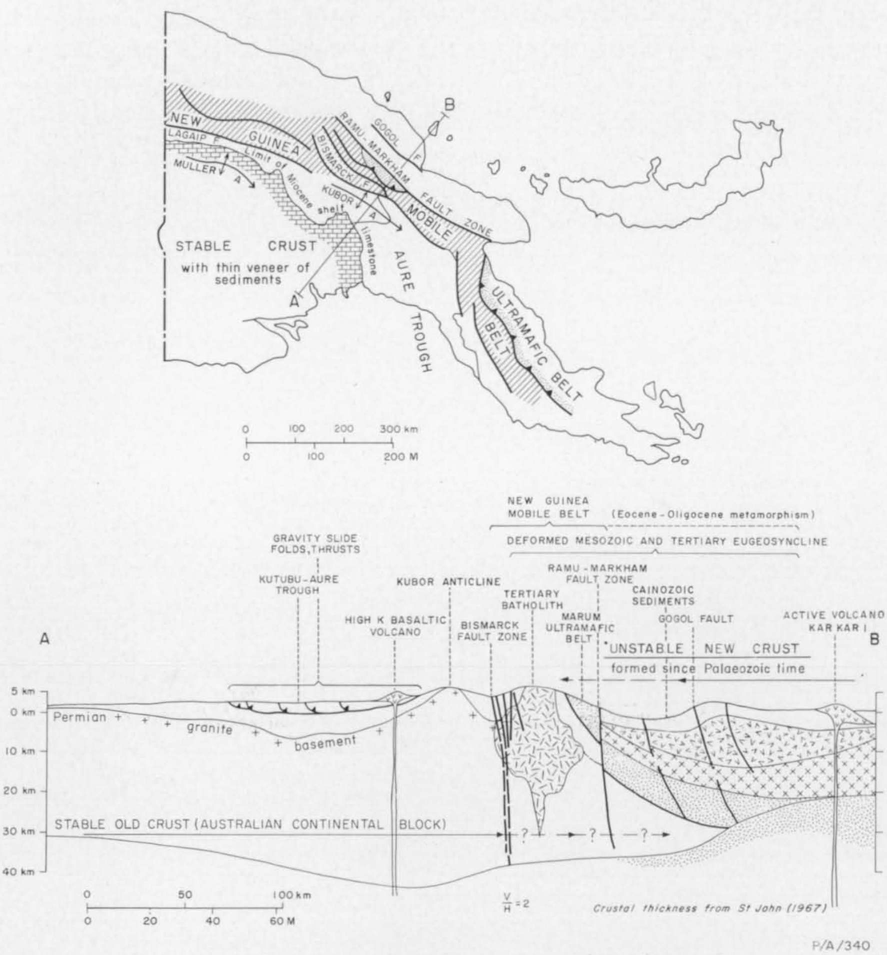


Figure 53. Main structural features of Papua New Guinea.

The stable crust block (Palaeozoic Australian continental block) consists of Palaeozoic metamorphic and igneous rocks overlain by several thousand metres of Mesozoic and Tertiary sediments (APC, 1961, p. 110). The metamorphic and igneous basement is a competent block, and apart from some strong deformation at the margin, the overlying sediments are only gently folded. Evidence of folding and uplift along the margin of the block is seen in the large low-amplitude folds in the Kubor Anticline and Muller Range (Muller Anticline) (Fig. 53). The sedimentary rocks on the southern flanks of the anticlines have been affected by gravity sliding and diapirism (Jenkins & Martin, 1969). The northern limbs are truncated by the faults of the Mobile Belt (a tectonically active zone that wraps around the northern edge of the stable crust block). The Bismarck and Lagaip Fault Zones (Dow et al., 1973) define the southern edge of the Mobile Belt; its northern limit is less precisely marked but probably corresponds to the Ramu-Markham and Sepik Faults (Dow & Dekker, 1964; Dow et al., 1973).

Kubor Anticline

The Kubor Anticline was named by Noakes (1939); the name was formalized by Rickwood (1955), who mapped the northern and eastern limits of the Palaeozoic core and the sediments on the northern limb. Igneous and low-grade metamorphic rocks form the triangular-shaped core, which crops out at altitudes up to 3960 m. The anticline is a broad gentle arch, up to 60 km wide (Frontispiece, Fig. 54) and 125 km long. The axis has a sinuous east-southeasterly trend, and can be traced from Mount Hagen town to Mount Michael, where it plunges below the Tertiary cover rocks. The axis plunges gently to the east and more steeply to the west, where it is covered by Pleistocene volcanics. The northern and southern limbs midway along the fold generally dip at 10° to 40°, with local steepening to 70° caused by minor folds and faults.

The maximum width of the basement exposed is 35 km, about 20 km from the west end of the anticline—the area of maximum doming and also of exposure of the bulk of the granitic rock. The arched basement is overlain by Mesozoic sediments that thicken considerably away from the axis.

A number of small faults occur within the basement and the surrounding sediments. They are short and straight, and generally radial to the margin of the crystalline core. South of Mount Digini they have small vertical displacements. Most of the faults are interpreted as tensional fractures resulting from doming of the basement.

Numerous small subsidiary folds have been formed in the Mesozoic sediments around the nose of the Kubor Anticline between the Wahgi River gorge and Mount Michael, and on its southern flank from the Nebilyer River to Agotu Mission. Those near the axis of the main anticline are commonly small, monoclinal, and faulted, and are difficult to recognize on the aerial photographs; they are not shown on the accompanying maps.

The several small east-west folds and faults on the southern slopes of Mount Michael are probably not related to the Kubor Anticline, but are thought to have been formed in response to the emplacement of the Michael Diorite.

East of Mount Suaru, on the south flank of the anticline, numerous small folds with easterly to southeasterly trending axes from 2 to 4 km apart are shown on the maps. Some have been photo-interpreted, and others were detected by ground traverses. Many are part of the easterly trending synclinorium known as the Pima Syncline.

Farther southwest on the southern flank of the Kubor Anticline, the Miocene Darai Limestone has been folded into a number of broad steep-sided flat-troughed synclines separated by long narrow strips of strongly deformed sediments of the Chim Formation. Anticlines are not preserved in the Darai Limestone. Many of the synclines are box-like and have squared-off ends (Fig. 41); others have tapered ends. These box folds have slightly offset axes parallel to the Kubor Anticline. In many places the synclinal limestone plates rest unconformably on near-vertical sediments of the Chim Formation. By analogy with similar structures farther west near Kagua and Pangia (Jenkins & Martin, 1969; Smith, 1965) they are thought to be detached diapiric folds above a décollement at the base of the limestone. The décollement developed as a result of uplift of the Kubor Range, and the gravity sliding initiated the diapiric structures. The soft sediments of the Chim Formation were injected into the cores of the tight parallel anticlines formed in the early stages of sliding. Continued sliding and diapirism in the late Miocene and Pliocene resulted in the synclinal limestone plates overriding some areas of highly disturbed Chim Formation.

Yaveufa Syncline

The Yaveufa Syncline is a Tertiary structure with a sinuous arcuate trend subparallel to the east end of the Kubor Anticline. From about 15 km west of the Chimbu River valley the axis trends southeast for about 45 km to the Mai River, thence south-southeast to a point about 12 km east of Lufa. There it is intruded by the Michael

Figure 54. Southeastern nose of the Kubor Anticline from the west. Oblique aerial photograph.

Diorite and disrupted and offset by the Kami and other faults immediately east of the Kubor area. Within the Kubor area, the outer limbs of the syncline are composed of cliffs of steeply dipping Chimbu Limestone. At the west end, the limestone is overlain by a small thickness of Te and Tf siltstone, and to the southeast by a much thicker sequence of coarse volcanolithic sediments and lavas. West of the Mai River, the Tertiary sequence thins considerably and the syncline narrows from about 25 km to about 10 km in the Bismarck Fault Zone, where the syncline has been so intensely deformed that the original synclinal form has been almost completely obliterated. Down plunge to the southeast, the considerable thickness (up to 4000 m) of volcanics in the sequence and the greater distance from the centre of the Wilhelm uplift have resulted in the formation and preservation of a simple southerly plunging synclinal form. In the vicinity of the westerly flowing Asaro River (6 km north of Lufa), the syncline is probably at least 25 km wide, although the Chimbu Limestone and overlying Te and Tf tuffs are not exposed in the east limb. The syncline was probably a sinking basin of deposition during most of the Tertiary. It was certainly so when the lower Tf volcanics of the Yaveufa Formation were laid down.

Bismarck Fault Zone

The Bismarck Fault Zone was named by Rickwood (1955). Its northwest extension was mapped by Dow (1961, 1962) and Dow et al. (1973) as far as the Sepik plains. We have found that the fault zone in the Chimbu valley (Fig. 55) is much wider and more complex than was shown by Rickwood (1955), and that the large number of southeasterly trending faults of small displacement that cross the Asaro River in the vicinity of Lufa constitute the southeast extension of the Bismarck Fault Zone in the Kubor area. However, the zone is not as well defined in the intervening country as in the Chimbu and Lufa areas. Near Mount Udon, the Bismarck Fault Zone appears to split, and a number of faults trend northwards towards the Jimi and Bundi Fault Zones (Dow & Dekker, 1964). Within the Kubor area, the Bismarck Fault Zone is 20 km wide, and consists of a highly disturbed zone of subparallel anastomosing faults and overturned tight folds. There is at least 3000 m of vertical displacement (north side up) spread over the width of the fault zone. This is clearly seen in the overturned northern limb of the Yaveufa Syncline, where the Kana Volcanics have been thrust over the Maril Shale, and the Balimbu Greywacke over the Chim Formation.

Large vertical movements probably occurred on only a few faults, such as that separating the Maril Shale and Miocene limestone and siltstone in the Chimbu River valley. Most faults are marked by steeply dipping or vertical shear zones up to several tens of metres wide. Many of the small faults in the Chimbu valley are thrust faults and are closely associated with overturned folds in the Chimbu Limestone. They probably developed as a result of sliding, folding, and overthrusting of the thin Tertiary limestone-siltstone sequence towards the south, within a tectonically active zone. Our map of the Chimbu area is largely a photogeological interpretation based on limited field data: field relationships are difficult to establish because most of the contacts are buried by limestone scree and shale landslips.

Although overprinted by the late Miocene-Pliocene deformation, the Bismarck Fault Zone appears to have been active since at least Cretaceous time (Fig. 56), as the Mesozoic sediments are more strongly faulted and deformed than the overlying Tertiary rocks. The major uplift of the northern block along the Bismarck Fault Zone exposed the middle Miocene Bismarck Intrusive Complex during the late Miocene or Pliocene. Dow et al. (1973) have suggested that considerable transcurrent movement may have occurred along the Bismarck Fault Zone, but we have found no evidence to support or disprove this contention.

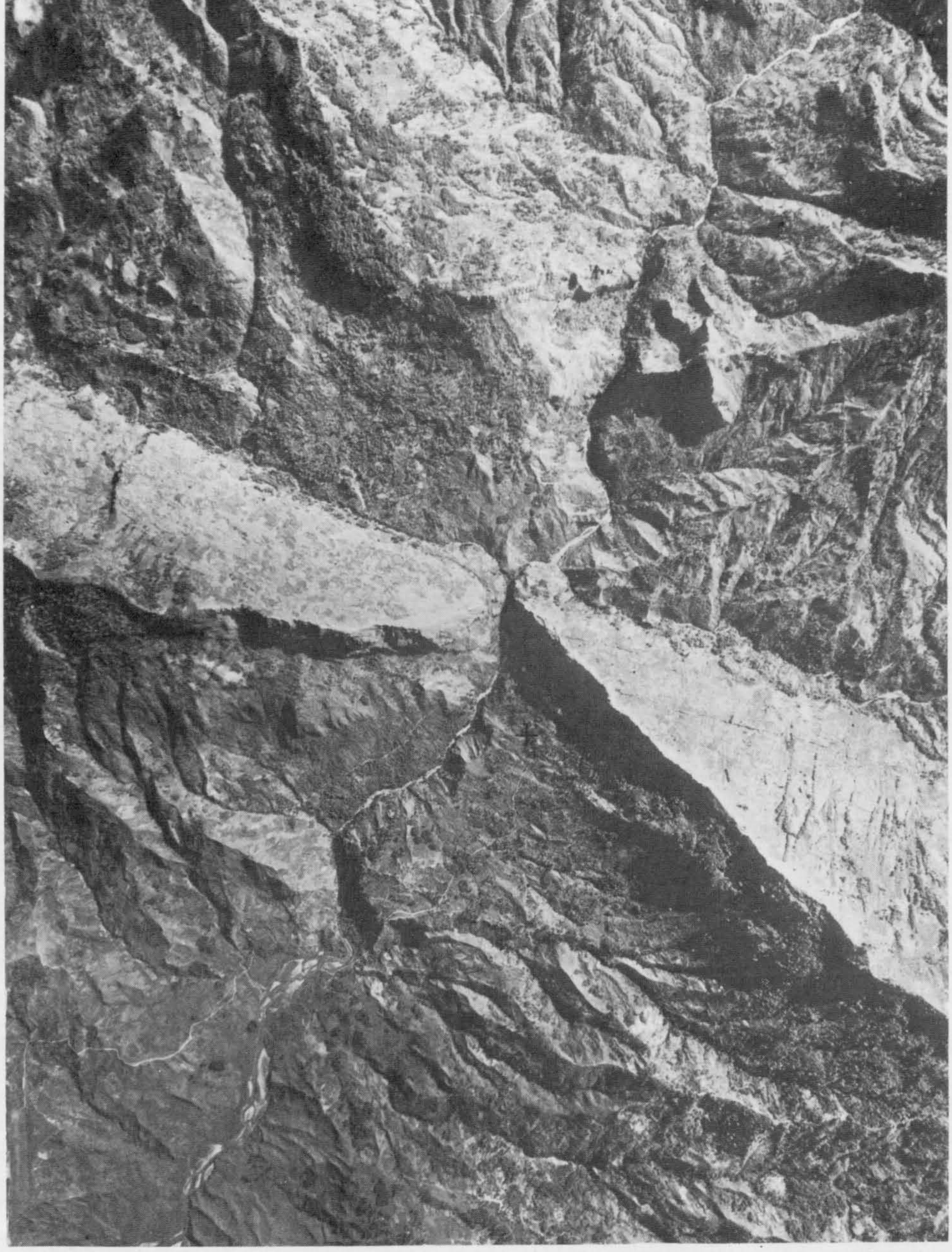


Figure 55. Part of the Bismarck Fault Zone in the lower Chimbu River gorge. The country to the north of the cuesta of Chimbu Limestone consists of faulted Movi Beds; the Chim Formation occupies the area to the south. Kundiawa lies in the lower left hand corner. Aerial photograph.

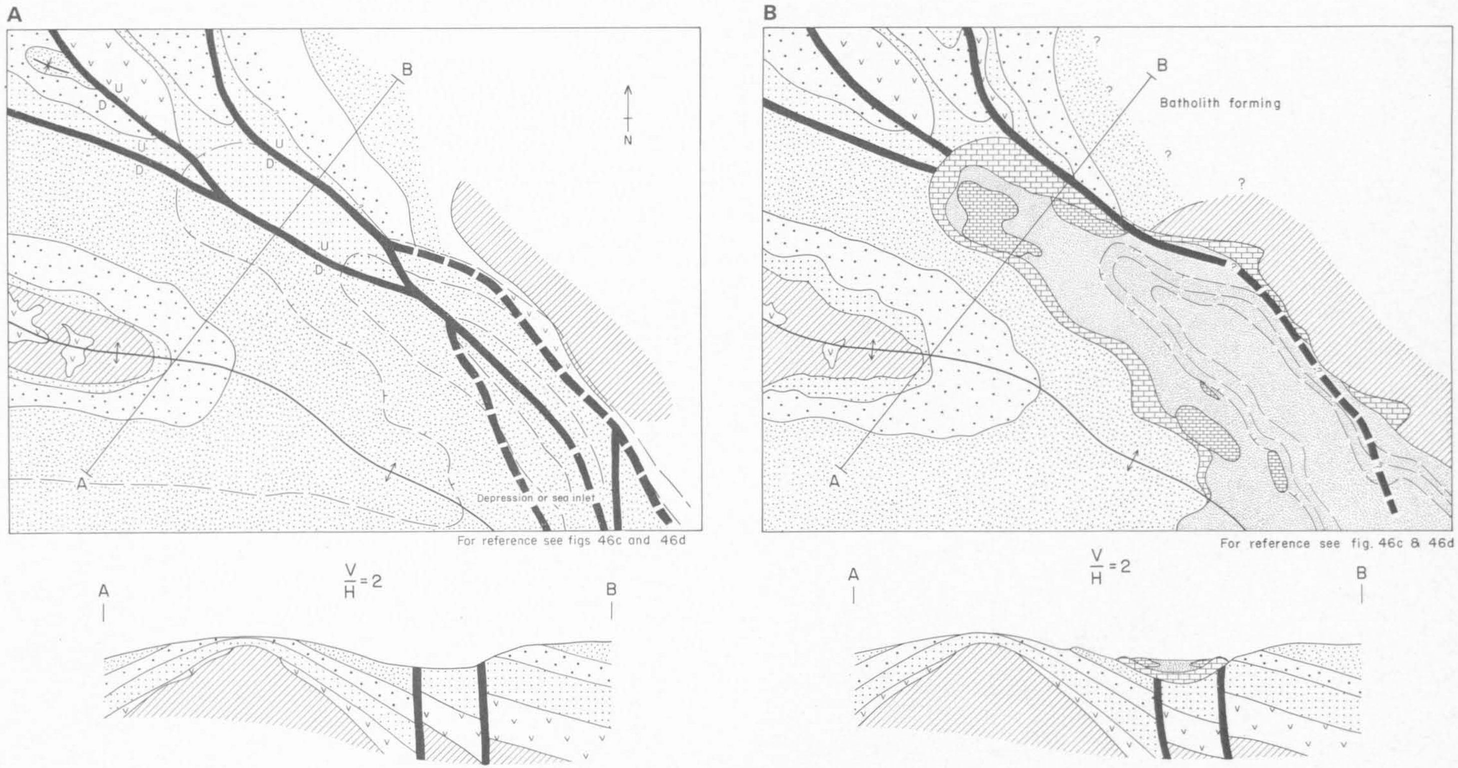


Figure 56. Development of the Bismarck Fault Zone.

(a) In late Cretaceous/early Tertiary times the Mesozoic rocks were faulted and a shallow depression (Yaveufa inlet of Aure Trough), open to the southeast, was formed along the line of faulting.

(b) In Eocene to middle Eocene times a sequence of limestone overlain by a pile of siltstone and limestone reefs, which thickens from 500 to 4000 m to the southeast, was laid down in the Yaveufa inlet.

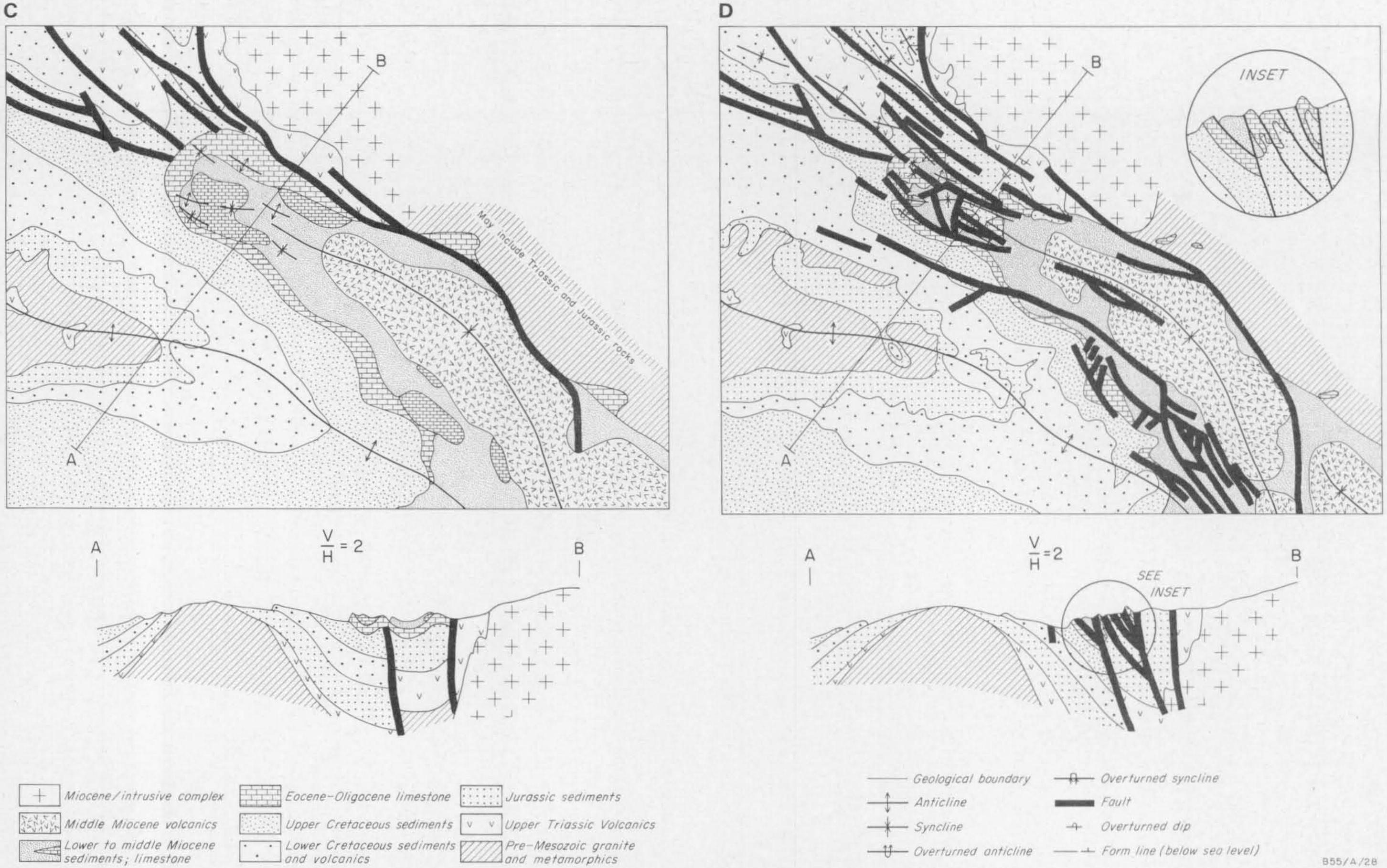


Figure 56. Development of the Bismarck Fault Zone.

(c) In the middle Miocene volcanics were erupted along the line of the Bismarck Fault Zone in the deeper part of the inlet, and most of the Bismarck Intrusive Complex was emplaced. During the reactivation of the fault zone the Tertiary rocks were folded and faulted and the Yaveufa Syncline formed.

(d) Reactivation of the fault zone and emplacement of the Bismarck Intrusive Complex were completed by the Pliocene. The Tertiary sediments near Kundiawa were folded into tight overturned folds and thrust southwards. Elsewhere most of the faults splay around the massive Miocene volcanics or are parallel to the margins of the Yaveufa Syncline.

GEOLOGICAL HISTORY
(Fig. 57)

The oldest rocks in the area are fine-grained Palaeozoic sediments and volcanics, which were laid down in deep water, and subsequently deformed and metamorphosed (Omung Metamorphics). In the Late Permian (about 244 m.y. ago), the metamorphics were intruded by composite plutons of acid to basic composition (Kubor Granodiorite), but within a period of about 10 m.y. the igneous and metamorphic rocks were uplifted and eroded, and the igneous intrusions exposed. This was the first stage in the development of a ridge in the Kubor area. Arkose and sandy limestone reefs (Kuta Formation) were laid down on and around the exposed igneous and metamorphic rocks in the Late Permian or Early Triassic * As uplift continued the basement complex and limestone reefs were further eroded.

The area was then submerged, and in the Late Triassic a number of volcanic islands were formed and a great thickness of dacitic and basaltic volcanics and volcanolithic sediments (Kana Volcanics) was laid down in the surrounding seas. The greatest thickness of volcanics accumulated in a northwesterly trending trough or basin to the north and northeast of the Kubor Range.

When the Kubor area was again uplifted and eroded in the Early Jurassic, most of the Kana Volcanics were removed and the resulting sediment was redeposited to the north as the Balimbu Greywacke. During the Middle Jurassic, basic volcanics (Mongum Volcanics) were extruded on a small area of the sea floor to the north of the Kubor landmass (Kol Syncline). Sedimentation was much more widespread in the Late Jurassic, when the shallow sea transgressed over most of the Kubor area, and up to 2000 m of pyritic black shale and minor arkosic sandstone (Maril Shale) was laid down.

In late Early Cretaceous time, uplift and erosion were followed by further subsidence and volcanism. Shale, siltstone, massive feldspathic and tuffaceous greywackes, and marine volcanics (Kondaku Tuff) were laid down unconformably on the Maril Shale. In the Late Cretaceous the volcanic material in the Kondaku Tuff was derived from a more northerly source, probably in the vicinity of the Bismarck Mountains and Schrader Range. In the Early Cretaceous, soon after the deposition of the Kondaku Tuff began, the Kubor area started to rise. Calcareous shale, siltstone, sandstone, and minor volcanics (Chim Formation) were laid down on the Kondaku Tuff, and lapped off the emergent area during the early Late Cretaceous. Deposition of siltstone around the Kubor landmass probably ceased in Cenomanian time, and did not resume until at least the late Palaeocene.

The Bismarck Fault Zone, which was active in Late Cretaceous/Palaeocene time, and possibly since the Triassic, resulted in vertical, scissor, and possible horizontal displacement of the Mesozoic sediments to the north of the Kubor Range (Fig. 56).

In the late Palaeocene, when the Kubor Range and Bismarck Mountains were being actively eroded, calcareous siltstone (mapped as part of the Chim Formation) was laid down in the Nebilyer valley area, and reworked Kondaku Tuff and Chim Formation (Pima Sandstone) were deposited to the south of the Kubor Range.

In Eocene-Oligocene times, shelf limestone (Nebilyer Limestone) was laid down at the west end of the Kubor landmass, while reef limestone (Chimbu Limestone) was formed in a marine inlet (Yaveufa Inlet, Fig. 56) along its northeast flank. Sedimentation within the Kubor area ceased in the late early Oligocene, possibly as a result of slight uplift.

In the late Oligocene and Miocene further subsidence occurred in the Yaveufa Inlet and to the west of the Kubor Range. The two basins were linked to the south by a shallow sea extending to the Torres Strait/Gulf of Papua area. The type of

* The Kuta Formation may not have formed until the Late Triassic—see p. 19.

sediment laid down during the early and middle Miocene varied according to the depth of water and the proximity to land and the volcanic centres (Fig. 39). A considerable thickness of bioclastic limestone (Darai Limestone) was laid down on the shallow shelf areas and calcareous siltstone, sandstone, and greywacke (Aure Group) in the basins.

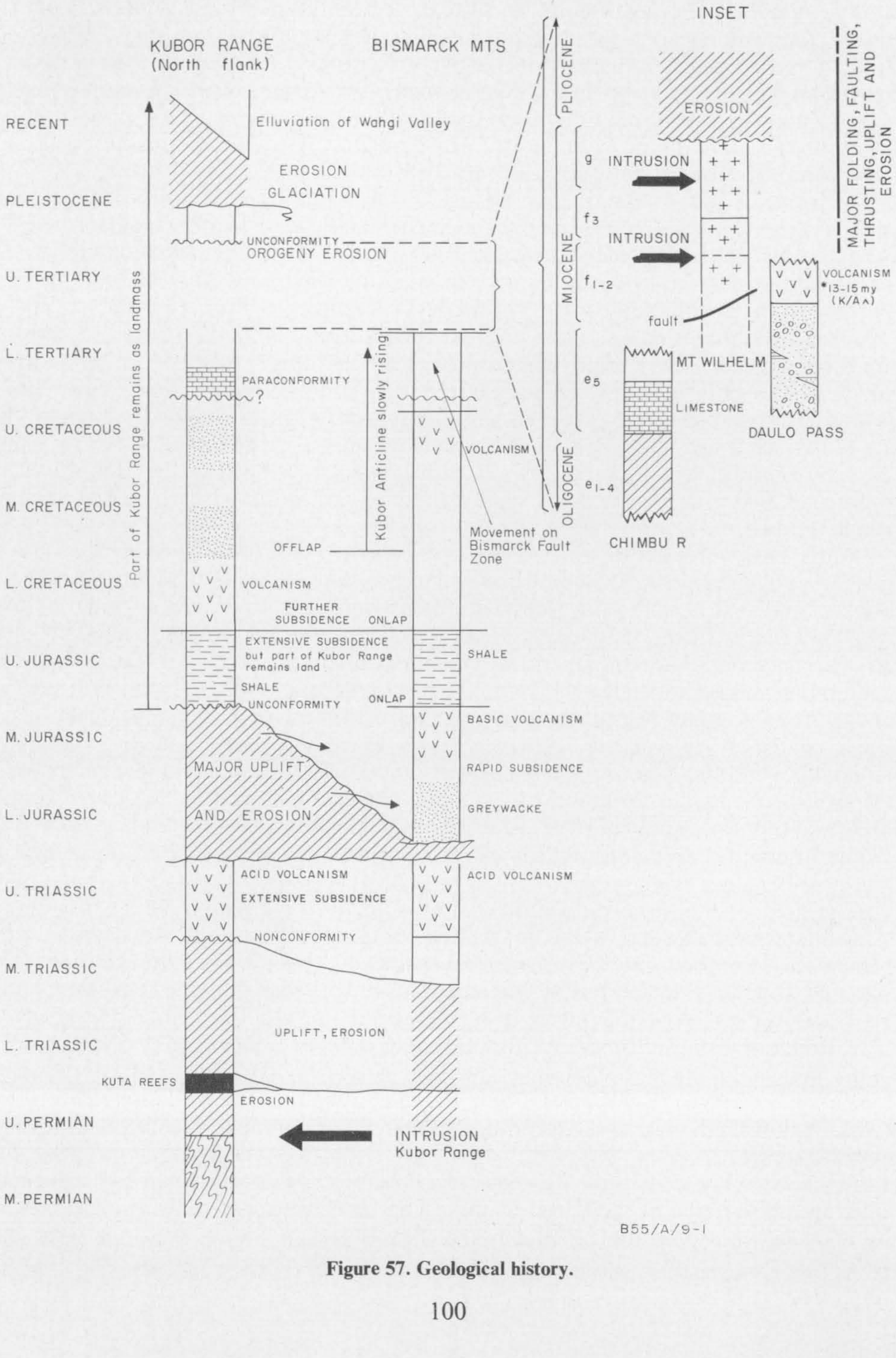


Figure 57. Geological history.

The Yaveufa Inlet continued to sink during upper Te and lower Tf times, and the calcareous volcanolithic beds (Movi Beds) were rapidly covered in the central part of the trough by a thick sequence of lavas, agglomerate, and volcanolithic sediments with lenses of limestone (Yaveufa Formation). During lower Tf time large composite plutonic bodies (Bismarck Intrusive Complex and Kimil Diorite) were emplaced to the north of the Kubor Range, and small hypabyssal equivalents of the Yaveufa Formation (Kenangi Gabbro) intruded the Movi Beds.

Starting in late Tf time, there followed a period of major folding, faulting, thrusting, uplift, and erosion that probably reached a peak during the Pliocene. This orogeny reactivated the Bismarck Fault Zone (Fig. 56), formed the Yaveufa Syncline, and further arched the Kubor Anticline. Gravity sliding and diapiric folding of the Tertiary and uppermost Cretaceous limestone and siltstone of the south flank of the Kubor Anticline resulted in the formation of a belt of thrust-faulted diapiric folds, 50 km wide, parallel to the axis of the anticline (Papuan Fold Belt—Bain, 1973). Numerous minor folds and faults were also formed in the Mesozoic and Tertiary rocks during this period, and a hypabyssal pluton (Michael Diorite) was emplaced in the southeastern nose of the Kubor Anticline (probably in the late Miocene). The whole region was uplifted and eroded in the late Pliocene and early Pleistocene.

In the south and west several large stratovolcanoes (highlands volcanoes) were formed in early Pleistocene time on a land surface as deeply eroded as that of the present day. One of the volcanoes (Crater Mountain) possibly started to form in the late Pliocene. The volcanoes are surrounded by extensive aprons of volcanic material which have been deeply gullied by Holocene erosion. The summits of the highest volcanoes and other mountain ranges over 3000 m have been modified by Holocene glaciation. Extensive alluvial fans and lacustrine deposits were laid down in the Wahgi valley when the river was dammed by eruptions from the Hagen volcanoes. Some of the sediment is probably of fluvioglacial origin. Recent uplift has resulted in dissection of the alluvial deposits and the formation of narrow slit gorges in the bottom of most of the valleys.

ECONOMIC GEOLOGY
(Fig. 58)

Gold

The auriferous gravels near Kuta, 8 km south of Mount Hagen, were discovered in 1932 by the Leahy brothers, who accompanied the first Government Patrol into the area. Between 1935 and 1949, about 87 kg of gold (fineness 753) valued at $71 366 were produced (Ward, 1959). Production has now all but ceased. The main workings extended for over a kilometre along the east bank of Kunimo Creek, but the other workings in Ambi, Ewunga, and Kuan Creeks were less extensive. The auriferous wash rests on tuffaceous sandstone, and contains pebbles and boulders of andesite, quartz, limestone, and sandstone. The wash is 10 cm to 2.4 m thick, and is overlain by soil and unconsolidated volcanic ash. Ward (1949) has suggested that the gold may have been derived from stringers and veinlets of quartz associated with small dykes and sills of diorite intruding the Kondaku Tuff near Kuta (see Benembi Diorite).

The alluvium filling the small valleys on the east side of the Nebilyer valley and the larger Kaip (or Gunia) valley east of Mount Hagen has been derived from much the same area as the auriferous deposits at Kuta, and may therefore contain some gold.

The small deposits of auriferous river gravel in the Jimi valley north of Banz provide a subsistence income for a small group of people. The gold was probably derived from the Kimil Diorite. Although these deposits lie outside the Kubor area there is good reason to believe that gold has also been shed southwards from the Kimil Diorite into the Wahgi valley. The alluvials in the streams draining the south side of the Jimi-Wahgi divide near Banz are therefore worth testing for gold.

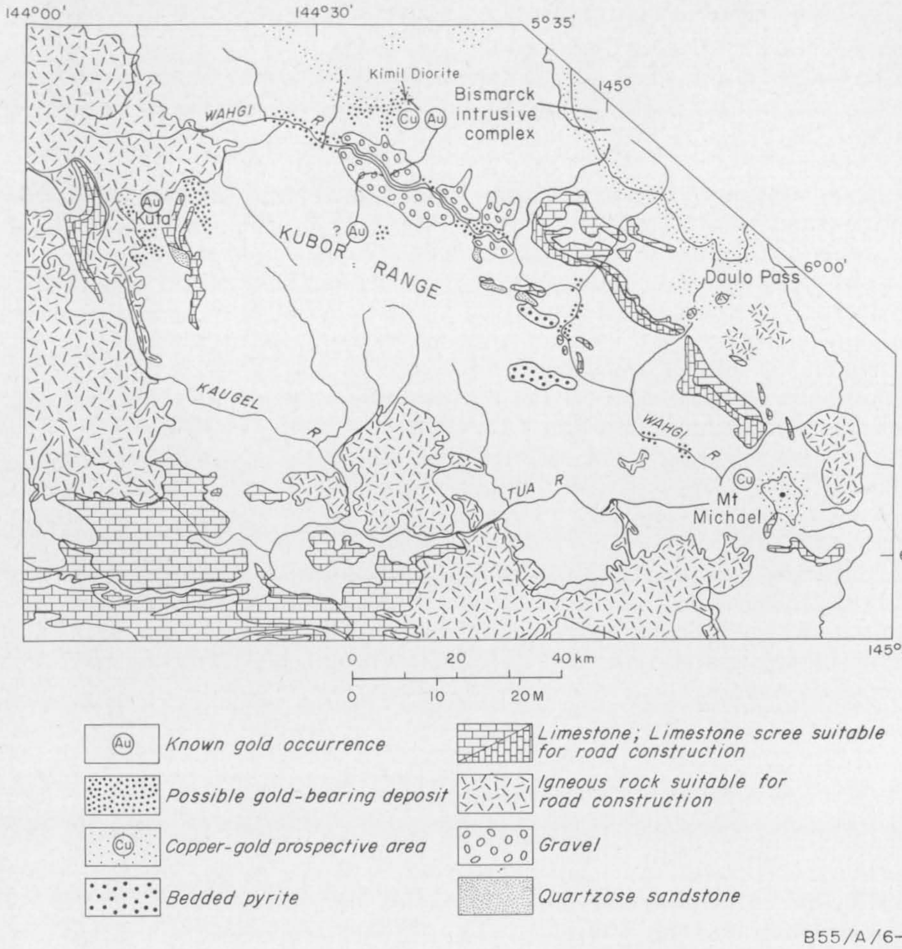


Figure 58. Distribution of minerals and rocks of economic importance.

Copper

Apart from a few flecks of chalcopyrite in the Kimil Divide, Bismarck Intrusive Complex, and Michael Diorite, no copper mineralization has been found. However, detailed mapping may possibly reveal significant zones of copper mineralization. The most prospective areas indicated in Figure 58 have been selected on the assumption that porphyry copper deposits are most likely to occur in association with hydrothermally altered hypabyssal or subvolcanic rocks, especially where they intrude volcanics. In the case of large composite batholiths, such as the Bismarck Intrusive Complex, hypabyssal rocks are most likely to be found near their margins (e.g. as at Yandera).

Mount Michael and the Benembi Diorite, 4 km due east of Togoba, are hydrothermally altered hypabyssal diorite porphyries. The Benembi plug is not well exposed, and pyrite is absent in the few specimens collected. However, it is believed to be related to the Tertiary intrusives from which the gold in the Kuta alluvial deposits was derived. Pyrite is widely distributed in the Michael Diorite, and as much as 2 or 3 percent is commonly present around the summit of Mount Michael. Some specimens (e.g. 21NG2645) also contain very small amounts of chalcopyrite. The extent of the mineralization is unknown, as the intrusion was not mapped in detail.

Massive pyrite and a trace of chalcopyrite occur in the contact zone of the Kimil Diorite where it intrudes Kana Volcanics in the headwaters of Banz Creek. This intrusive has also shed gold into the Jimi valley. Molybdenum, copper, and zinc sulphides and gold are localized in small quartz veins and shears throughout the contact zone of a small stock of Kimil Diorite intruding acid to intermediate Kana Volcanics in the Marramp River, about 30 km northwest of Banz (Jones, 1970). Other bodies of Kimil Diorite outside the Kubor area may also contain copper and gold. The southwest margin of the Bismarck Intrusive Complex, where it intrudes the Kana Volcanics, is a possible zone of copper and gold mineralization. Disseminated pyrite, chalcopyrite, and molybdenite occur in the basic gabbros, and andesitic and monzonitic porphyrites at Yandera. The mineralization is of the porphyry copper type and is being investigated by Kennecott Exploration (Australia) Pty Ltd. McMillan (pers. comm.) noted that gold-bearing reefs may occur near the margin of the Bismarck Intrusive Complex, where he observed much quartz veining and associated pyrite.

A number of small gabbroic intrusions, some consisting of Kenangi Gabbro, and some possibly related to the Bismarck Intrusive Complex, occur in and near the Yaveufa Formation in the headwaters of the Mai River. Closer examination is required to determine whether they are mineralized.

Bedded pyrite

Pyrite occurs as beds, nodules, and disseminations in the Maril Shale. Near Gumine and Genabona, the abundance of pyrite in the Maril Shale serves to distinguish it from the overlying Cretaceous shales.

Local concentrations of ovoid nodules and disseminated pyrite form up to 3 or 4 percent of the rock. Some of the nodules are hard and compact, but most of them are friable. Thin beds of friable pyrite occur only in the most pyritic areas. Near Genabona a large body of pyritic shale breccia (21NG2591) forms a waterfall 8 m high; the average pyrite content over a width of 12 m is about 10 percent. The breccia is cut by a vein, 25 cm wide, containing 70 percent pyrite; it contains negligible amounts of copper and gold.

Limestone

There are many large deposits of limestone in the Kubor area (Fig. 58), most of which are easily accessible by road, except in the south. Talus derived from the Chimbu Limestone, found to the east of the lower Wahgi River, is quarried and used for surfacing nearby roads. The reserves are over 40 million m^3. The Nebilyer and Kuta Limestones, and the limestones near Mount Michael and within the Maril Shale, are all suitable for use as road surfacing material. The Nebilyer Limestone also provides talus deposits similar to those found beneath the cliffs of Chimbu Limestone.

The pure white foraminiferal limestone at Mount Elimbari (Chimbu Limestone) appears to be eminently suitable as a building or cladding stone.

Stone axe quarries

Before 1940, the manufacture and export of stone axes was by far the most important indigenous industry (Hughes, 1969). The supply of raw material involved the earliest known mining operations in the highlands. Chappell (1966) has shown that almost all the stone used was quarried at five sites within the Kubor area and at eight sites in the adjacent Jimi valley. All the larger stone quarries are situated in contact metamorphic zones, generally in Maril Shale, but also in the Omung Metamorphics.

Only two of the large quarries—Abiamp and Dom—were located during our survey. The quarries have not been worked for about 30 years, and are now almost completely buried by landslips, or concealed by overgrowth. Chappell has shown that there was a major quarrying operation at Abiamp, and that the workings consisted of a series of aligned pits and drives from which over 2500 tons of rock were quarried with sharpened sticks for an estimated yield of 40 percent useful tool stone. The physical and petrographic properties of the tool stone from Abiamp and 12 other quarries are listed by Chappell (1966, p. 106). The rocks range from albite-epidote-actinolite hornfels to albitized fine-grained sediments containing quartz, prehnite, and stilpnomelane, and have a conchoidal fracture and a hardness of 5 to 7 (Mohs' scale). The quarries were also the site of manufacturing operations, although some raw materials were traded from the larger quarries (Chappell, 1966, p. 103). All the known accessible occurrences of albite-epidote and albite-epidote-actinolite hornfels in the Maril Shale within the central highlands have been quarried, as has the only known occurrence of actinolite-epidote-albite hornfels in the Omung Metamorphics which is sufficiently hard (6 on Moh's scale) for the manufacture of axes.

Road surfacing material and aggregate

The distribution of gabbros and formations containing basaltic and andesitic lavas suitable for use as road surfacing material or aggregate is shown on Figure 58.

Gravel

There are extensive deposits of stratified sand, clay, and gravel (Quaternary alluvial fans) in the Wahgi valley which are suitable for the construction of roads.

Quartzose sandstone

Soft to hard friable sandstone, ranging from white pure quartz sandstone to arkose (basal sandstone of the Maril Shale and Kuta Formation), may be useful as aggregate in the construction of bridges and culverts or in the townships of Kundiawa and Mount Hagen. The main deposits occur near Gurumugl, southeast of Kundiawa, and the smaller more feldspathic deposits to the southeast of Kuta.

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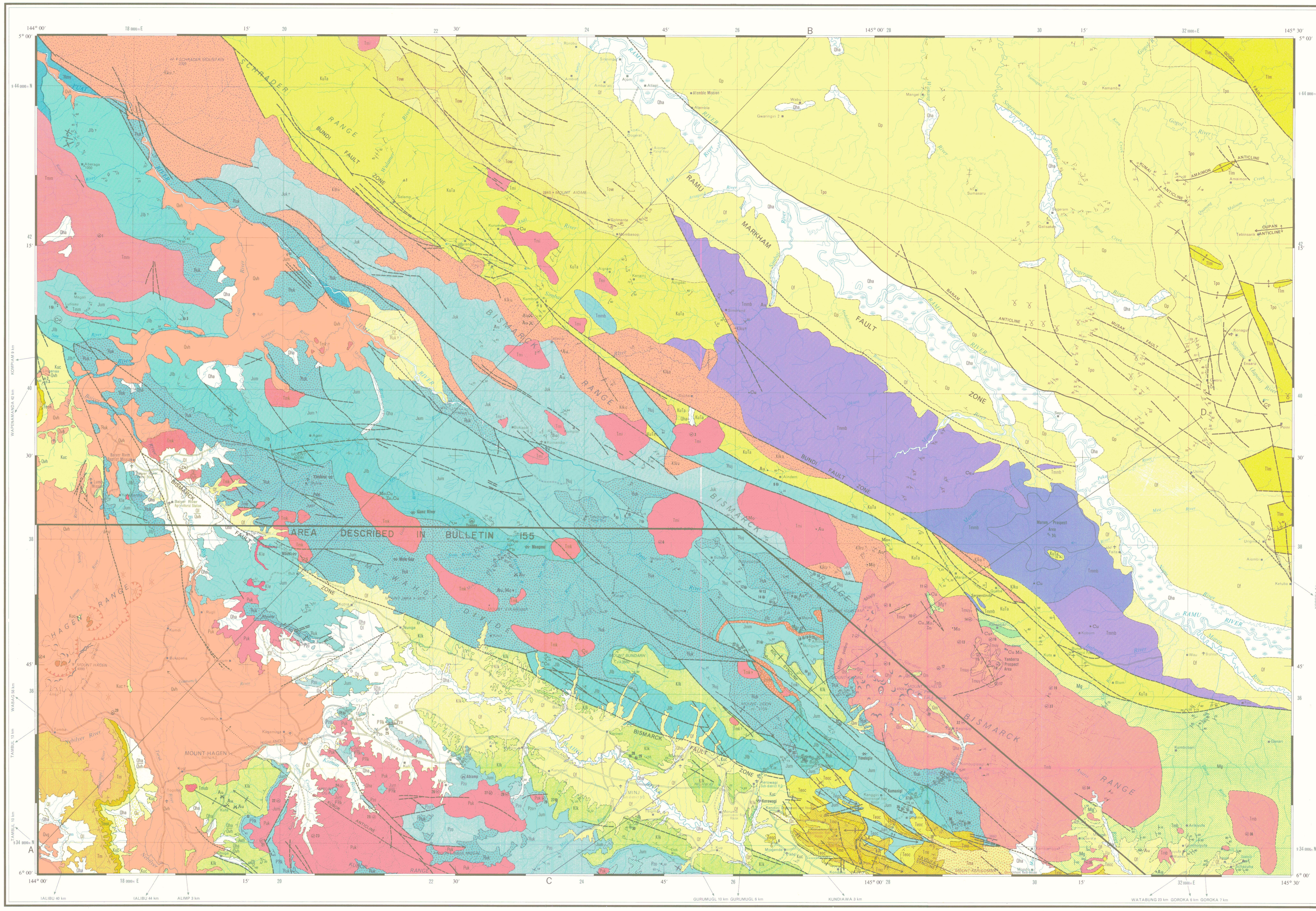
RAMU

Reference

- Geological boundary
- Anticline, showing plunge
- Syncline, showing plunge
- Overturned anticline, showing plunge
- Overturned syncline, showing plunge
- Fault (D, U indicate relative movement down, up)
- Fault, low-angle thrust (⊢— indicates upper plate)

Where location of boundaries, folds and faults is approximate, line is broken; where inferred, queried; where concealed, folds are dotted, faults are shown by short dashes

- Shear zone
- Strike and dip of strata
- Strike and dip of strata, unmeasured
- Vertical strata
- Horizontal strata
- Strike and dip of overturned strata
- Dip not measured } airphoto interpretation
- Dip 15°–45° } airphoto interpretation
- Trend of bedding } airphoto interpretation
- Joint pattern } airphoto interpretation
- Strike and dip of joint
- Vertical joint
- Strike and dip of foliation
- Strike and dip of cleavage
- Prevailing strike and dip of cleavage
- Vertical cleavage
- Platy flow, inclined
- Major eruptive centre with no recorded eruption
- Minor eruptive centre with no recorded eruption
- Crater wall
- Plant fossil locality
- 7 Macrofossil locality } number refers to data in Explanatory Notes
- 3 Microfossil locality } number refers to data in Explanatory Notes
- 14 Sample locality for isotopic age determination } number refers to data in Explanatory Notes
- •Au Minor mineral occurrence
- (Dt) Unworked deposit
- Mine, not worked
- Prospect
- Major stone axe quarry, not worked
- Stone axe quarry, not worked
- Alluvial workings
- Alluvial workings, not worked
- Au Gold
- Ba Barite
- Cp Clay, pottery
- Cu Copper
- Dt Diatomite
- Mo Molybdenum
- Ni Nickel
- Zn Zinc
- Gas seep
- Spring, salinity > 10 000 ppm
- Swamp
- Escarpment
- Cirque
- Highway
- Road
- Vehicle track
- Track
- Airport
- Landing ground
- Settlement
- Built-up area
- • 3750 Elevation in metres, approximate
- pa Position approximate
- abd Abandoned



Reference

CAINOZOIC – QUATERNARY	HOLOCENE		Qha	Clay, sand, silt, gravel; minor peat, soil: alluvium
			Qs	Boulder gravel, clay, soil: scree deposits
			Qf	Clay, sand, boulder gravel: alluvial fan deposits
			Ql	Clay, silt, sand, gravel, peat: lake deposits
			Qm	Gravel: moraine and fluvioglacial deposits
	PLEISTOCENE TO HOLOCENE	Hagen Volcanics	Qvh	Basaltic to dacitic lava, agglomerate, tuff, conglomerate, lahar deposits; Hypabyssal intrusives
		Giluwe Volcanics	Qvg	Shoshonitic agglomerate
	PLEISTOCENE		Qp	Carbonaceous mudstone, sandstone and siltstone, limestone; minor conglomerate
CAINOZOIC – TERTIARY	PLIOCENE Th *	Ouba Beds	Tpo	Mudstone; minor sandstone, siltstone, mudstone, conglomerate, limestone
	UPPER MIOCENE		Tmuy	Monzonite, porphyritic microdiorite, porphyry
	UPPER MIOCENE ?	Benembi Diorite	Tmub	Porphyritic microdiorite
	MIDDLE MIOCENE lower Tf *	Oipo Intrusives	Tmi	Gabbro, granodiorite, tonalite, diorite, pyroxenite, lamprophyre
		Bismarck Intrusive Complex	Tmb	Gabbro, diorite; minor tonalite, granodiorite, mangerite, granite, aplite, pegmatite, hornblendite, dunite, peridotite, anorthosite
		Kimil Diorite	Tmk	Diorite, gabbro, tonalite, granodiorite; andesite porphyry, dolerite and basalt dykes; minor trachyandesite
		Maramuni Diorite	Tmm	Diorite, microdiorite, granodiorite; minor gabbro, rhyodacite, porphyry, monzonite; andesite and dolerite dykes
		Yaveufa Formation	Tma	Andesitic to shoshonitic agglomerate; minor andesitic and basic lava, tuff, volcanolithic conglomerate
	LOWER TO MIDDLE MIOCENE upper Te to lower Tf *	Movi Beds	Tmo	Calcareous siltstone, shale and sandstone; minor conglomerate; Limestone
	UPPER OLIGOCENE TO MIDDLE MIOCENE lower Te to lower Tf *	Aure Beds	Tm	Calcareous mudstone and siltstone, greywacke; minor siltstone, limestone
	MIOCENE ?	Marum Basic Belt	Tmmb	Gabbro; minor norite, anorthosite; Dunite, serpentinite, minor pyroxenite
	OLIGOCENE ?	Wulamer Beds	Tow	Phyllitic shale and slate, sheared calcareous sandstone and conglomerate, agglomerate, siltstone; minor cherty mudstone; Limestone
	OLIGOCENE ? TO LOWER MIOCENE ?		Tlm	Sandstone, siltstone, mudstone, conglomerate, agglomerate
	MIDDLE EOCENE TO LOWER OLIGOCENE Ta_3 to Tc *	Chimbu Limestone	Teoc	Grey buff and white foraminiferal limestone, calcarenite
		Nebilyer Limestone	Teon	Calcarenite, limestone; minor argillite, siltstone
	UPPER CRETACEOUS TO EOCENE	Asai Shale	KuTa	Schistose phyllitic and carbonaceous shale, siltstone and mudstone; minor limestone, calcarenite, greywacke, conglomerate
MESOZOIC	LOWER CRETACEOUS ?	Kumbruf Volcanics	Klku	Basaltic agglomerate and pillow lava, volcanolithic conglomerate, amygdaloidal lava, indurated calcareous siltstone, lithic and feldspathic sandstone
			Kle	Microdiorite, dolerite, gabbro
	UPPER JURASSIC ?	Kompiai Formation	Juk	Siltstone, greywacke, schistose indurated and phyllitic shale, phyllite; minor indurated calcareous sandstone
	UPPER CRETACEOUS	Chim Formation (Wahgi Group)	Kuc	Shale, siltstone, sandstone; minor calcarenite, greywacke, conglomerate, tuff, altered volcanics
	LOWER CRETACEOUS	Kondaku Tuff (Wahgi Group)	Klk	Lithic sandstone or greywacke, tuffaceous sandstone, shale, siltstone; minor conglomerate, agglomerate, volcanic breccia, lava
	UPPER JURASSIC	Maril Shale (Wahgi Group)	Jum	Calcareous carbonaceous and pyritic shale and siltstone; minor sandstone, calcilutite; Basal rudite, arkose
	MIDDLE JURASSIC ?	Mongum Volcanics (Wahgi Group)	Jmm	Basaltic agglomerate and pillow lava, conglomerate, feldspathic greywacke
	LOWER JURASSIC	Balimbu Greywacke (Wahgi Group)	Jlb	Calcareous and volcanolithic greywacke, sandstone, siltstone; minor shale
	LOWER JURASSIC ?		Jlu	Granodiorite, diorite, aplite and dolerite dykes
	UPPER TRIASSIC	Kana Volcanics	Ŧuk	Multicoloured basic to intermediate agglomerate, fine volcanic breccia, volcanolithic sediments, acid to basic lava, tuff, conglomerate, greywacke, feldspathic sandstone; Calcarenite, recrystallized coral limestone
		Jimi Greywacke	Ŧuj	Greywacke, siltstone; minor shale, siltstone, feldspathic sandstone
	MIDDLE TO UPPER TRIASSIC	Yuat Formation	Ŧmy	Black shale; minor feldspathic sandstone
		Goroka Formation	Mg	Quartz veined schist, schistose carbonaceous and calcareous siltstone, phyllite, hornfels; minor gneiss, amphibolite; Marble
PALAEOZOIC	UPPER PERMIAN TO LOWER TRIASSIC	Kuta Formation	PŦk	Limestone, sandy limestone; minor arkose
	UPPER PERMIAN	Kubor Granodiorite	Puk	Granodiorite, tonalite; minor diorite, gabbro, aplite, pegmatite
	UPPER PALAEOZOIC	Omung Metamorphics	Pzo	Slate, phyllite, schist, indurated shale and siltstone; minor metagreywacke, basic metavolcanics, hornfels

* Tertiary letter stage

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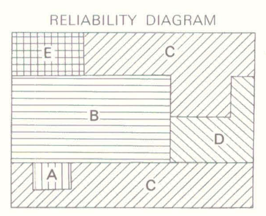
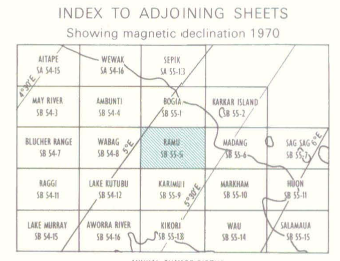
Base map compiled by BMR from topographic maps prepared by Division of National Mapping and Royal Australian Survey Corps, aerial photography, and uncontrolled side-looking airborne radar mosaics with horizontal control station data supplied by Division of National Mapping.

RELIABILITY DIAGRAM



Topography: A Army base; detailed, well controlled
B Slotted template assembly; detailed, semi-controlled
C Adjusted National Mapping bases; detailed, poorly controlled
D Army base; not detailed, poorly controlled
E Drawn from adjusted side-looking airborne radar mosaic at approximately 1:250 000 scale; not detailed, uncontrolled

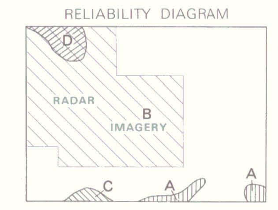
INDEX TO ADJOINING SHEETS
Showing magnetic declination 1970



Scale 1:250 000

GREY NUMBERED LINES ARE 10 000 METRE INTERVALS OF THE AUSTRALIAN MAP GRID, ZONE 55
TRANSVERSE MERCATOR PROJECTION

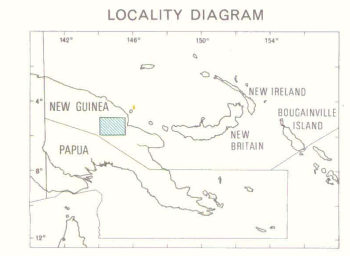
RELIABILITY DIAGRAM



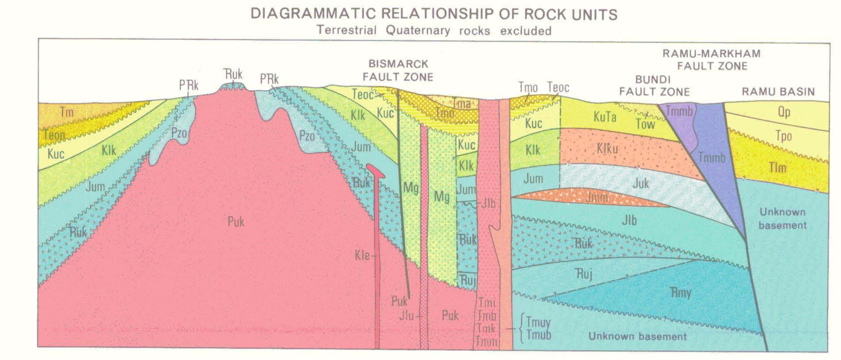
Geology: A Detailed mapping
B Detailed reconnaissance: numerous traverses, interpretation of airphotos and radar imagery
C General reconnaissance: few traverses, mainly interpretation of airphotos and some radar imagery
D Interpretation of airphotos and radar imagery

Geology 1956 by N. J. McMillan, J. E. Johnson; 1957 by E. J. Malone, K. K. Hughes
1962 by F. E. Dekker, D. B. Dow; 1967 by J. H. C. Bain, D. B. Dow, R. J. Ryburn
1968 by J. H. C. Bain, D. B. Dow, D. E. Mackenzie, R. W. Page, R. J. Ryburn, I. E. Smith
1970 by J. H. C. Bain, D. E. Mackenzie (BMR); Continental Oil Company of Australia Ltd
Kennecott Exp. (Aust.) Pty Ltd
Compiled 1971 by J. H. C. Bain, D. E. Mackenzie
Cartography by Geological Branch, BMR
Drawn by Cangraphics Pty Limited
Printed by Mercury–Walch Pty Ltd., Hobart, Australia

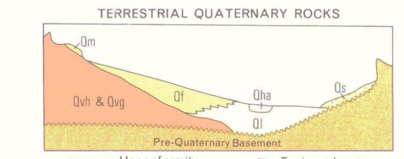
LOCALITY DIAGRAM



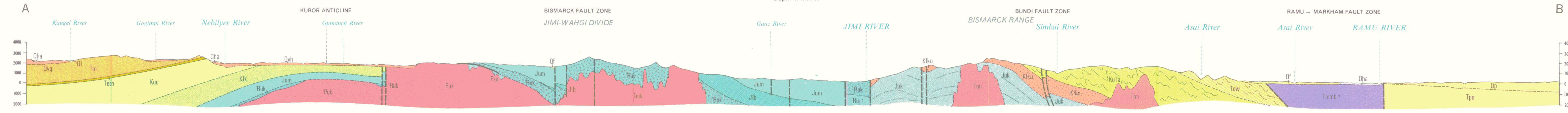
DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS
Terrestrial Quaternary rocks excluded

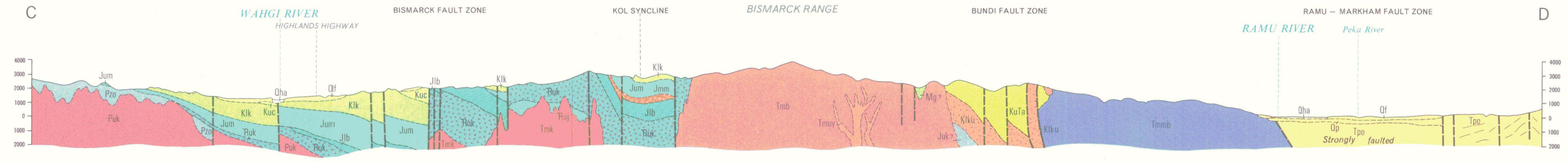


TERRESTRIAL QUATERNARY ROCKS



Sections
Scale: V/H = 1
Depth in metres





FIRST EDITION 1974

RAMU
SHEET SB 55-5

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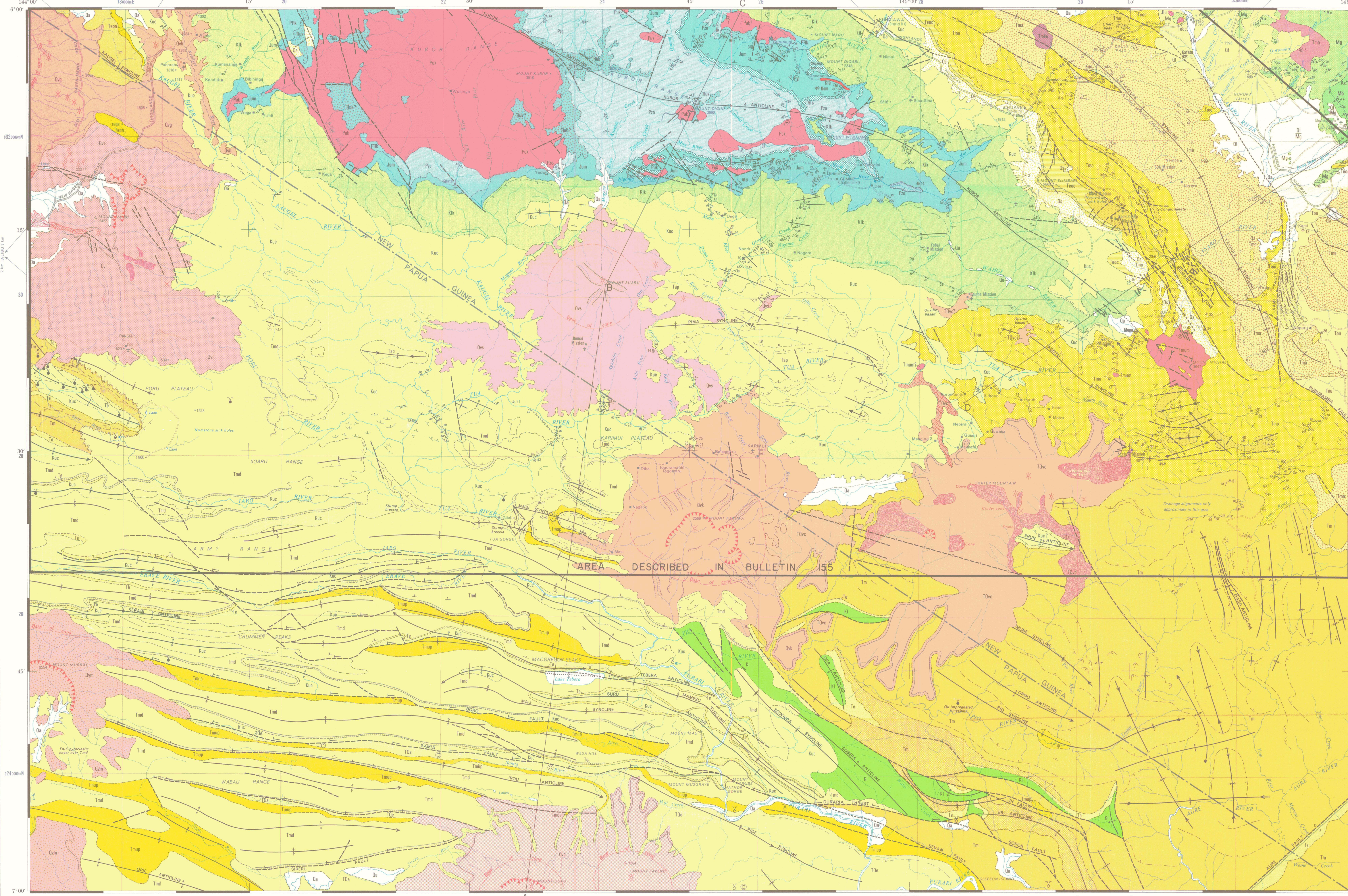
PAPUA NEW GUINEA 1:250,000 GEOLOGICAL SERIES

KARIMUI

SHEET SB 55-9



Reference

Geological boundary
Facies boundary
Anticline showing plunge
Syncline showing plunge
Monocline
Overturned anticline
Overturned syncline
Fault (D,U indicate relative movement down, up)
Fault, low-angle thrust (⊢ indicates upper plate)
Shear zone

Where location of boundaries, folds and faults is approximate, line is broken; where inferred, queried; where concealed, boundaries and folds are dotted, faults are shown by short dashes

Strike and dip of strata
Strike and dip of strata, unmeasured
Vertical strata
Strike and dip of overturned strata
Dip 5–15° (airphoto interpretation)
Dip 15–45° (airphoto interpretation)
Dip >45° (airphoto interpretation)
Dip not estimated (airphoto interpretation)
Strike and dip of overturned strata, dip not estimated (airphoto interpretation)
Trend of bedding (airphoto interpretation)
Strike and dip of foliation
Foliation with plunge of lineation

Major eruptive centre with no recorded eruption
Minor eruptive centre with no recorded eruption
Crater wall, caldera wall or other escarpment associated with volcano
Lava flow
Pyroclastic flow

Gas seep
Oil seep
Oil and gas seep or show
Macrofossil locality (Number refers to data in Explanatory Notes)
Microfossil locality (Number refers to data in Explanatory Notes)
Sample locality for age determination (Number refers to data in Explanatory Notes)
Dyke

•Au Minor mineral occurrence
© Unworked deposit
Au Gold
C Coal
Cu Copper
Py Pyrite
Sc Schungite
Stone axe quarry, not worked

Spring, salinity greater than 10,000 ppm

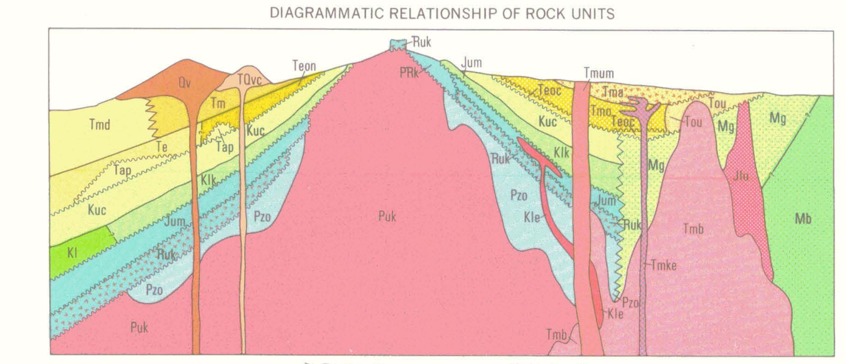
Escarpment
Cirque
Highway
Road
Vehicle track
Track
Airport
Landing ground
Town
Settlement
Trigonometrical station
• 1912 Elevation in metres, approximate

Reference

CAINOZOIC – QUATERNARY	HOLOCENE		Qa	Clay, sand, silt, gravel; minor peat, alluvial soils: alluvium
			Ql	Clay, silt, sand, gravel: lake deposits
			Qs	Boulder gravel, clay, soil: scree deposits
			Qf	Clay, sand, silt, boulder gravel: alluvial fan deposits
		Suaru Volcanics	Qvs	Basaltic and andesitic lava, agglomerate, tuff; minor derived sediments (shown as Qv in rock relationship diagram)
		Karimui Volcanics	Qvk	Basaltic and andesitic lava, agglomerate, tuff; minor derived sediments (shown as Qv in rock relationship diagram)
		Duau Volcanics	Qvd	Basaltic and andesitic lava, agglomerate, tuff; minor derived sediments (shown as Qv in rock relationship diagram)
		Mount Murray Volcanics	Qvm	Basaltic and andesitic lava, agglomerate, tuff; minor derived sediments (shown as Qv in rock relationship diagram)
		Ialibu Volcanics	Qvi	Basaltic and andesitic lava, agglomerate, tuff; minor derived sediments (shown as Qv in rock relationship diagram)
		Hagen Volcanics	Qvh	Basaltic lahar deposits, agglomerate, conglomerate; minor tuff, lava (shown as Qv in rock relationship diagram)
		Giluwe Volcanics	Qvg	Basaltic lava, ash, tuff, agglomerate (shown as Qv in rock relationship diagram)
CAINOZOIC	PLIOCENE TO HOLOCENE	Crater Mountain Volcanics	TQvc	Andesitic and basaltic lava; minor tuff, agglomerate, derived sediments
	PLIOCENE TO PLEISTOCENE Th*	Era Beds	TQe	Sandstone, siltstone, mudstone, coal
CAINOZOIC – TERTIARY	UPPER MIOCENE TO PLIOCENE Tg to Th *	Orubadi Beds	Tmup	Mudstone; some siltstone, sandstone; minor calcareous sandstone
	UPPER MIOCENE	Michael Diorite	Tmum	Porphyritic hornblende microdiorite
	MIDDLE MIOCENE lower Tf *	Kenangi Gabbro	Tmke	Gabbro, mangerite, granodiorite
		Bismarck Intrusive Complex	Tmb	Diorite; minor gabbro
		Yaveufa Formation	Tma	Agglomerate, welded tuff, andesitic and basaltic lava, tuff, conglomerate, greywacke; Calcarenite
	LOWER TO MIDDLE MIOCENE upper Te to lower Tf*	Movi Beds	Tmo	Volcanolithic and calcareous sandstone, siltstone and shale, conglomerate; some tuff; minor chert; Limestone
	UPPER OLIGOCENE TO MIDDLE MIOCENE lower Te to lower Tf *	Darai Limestone	Tmd	Limestone, calcarenite, calcirudite, marl
		Aure Beds	Tm	Siltstone; some shale, marl, conglomerate, greywacke, mudstone; Limestone
	UPPER OLIGOCENE lower Te*	Omaura Greywacke	Tou	Shale, siltstone, feldspathic sandstone; Sheared serpentinite
	MIDDLE EOCENE TO LOWER OLIGOCENE Ta_3 to Tc *	Chimbu Limestone	Teoc	Foraminiferal limestone, calcarenite
		Nebilyer Limestone	Teon	Grey limestone and calcarenite: minor argillite, siltstone
	EOCENE Ta_2 to Tb*		Te	Limestone, sandstone, sandy limestone; minor sandstone, siltstone, mudstone
	UPPER PALEOCENE TO EOCENE Ta_1 to Tb*	Pima Sandstone	Tap	Sandstone, tuff, siltstone, mudstone; minor conglomerate
MESOZOIC	LOWER CRETACEOUS		Kl	Lithic sandstone, interbedded siltstone and mudstone; minor greywacke and limestone
	LOWER CRETACEOUS?		Kle	Diorite, microdiorite
	UPPER CRETACEOUS	Wahgi Group – Chim Formation	Kuc	Massive shale; some laminated sandstone, siltstone and shale; minor tuff, altered volcanics, greywacke, calcarenite, conglomerate
	LOWER CRETACEOUS	Wahgi Group – Kondaku Tuff	Klk	Lithic sandstone, greywacke, tuffaceous sandstone, siltstone, shale; some conglomerate, agglomerate, volcanic breccia and lava
	UPPER JURASSIC	Wahgi Group – Maril Shale	Jum	Indurated shale and siltstone; some sandstone, limestone, shale; Arkose, breccia and conglomerate at base
	LOWER JURASSIC		Jlu	Granodiorite, diorite; aplite and dolerite dykes
	UPPER TRIASSIC	Kana Volcanics	Ruk	Lava, tuff, multicoloured agglomerate, volcanolithic and feldspathic sandstone
	MESOZOIC?	Goroka Formation	Mg	Schistose carbonaceous siltstone, schist, hornfels; minor recrystallized limestone, quartzite
		Bena Bena Formation	Mb	Schist; some indurated siltstone, greywacke and arkose; minor gneiss, quartzite, hornfels
PALAEOZOIC	UPPER PERMIAN TO LOWER TRIASSIC	Kuta Formation	PRk	Limestone, sandy limestone; minor arkose
	UPPER PERMIAN	Kubor Granodiorite	Puk	Granodiorite, tonalite; minor diorite, gabbro, aplite, pegmatite
	UPPER PALAEOZOIC	Omung Metamorphics	Pzo	Slate, phyllite, schist, indurated siltstone and shale; some metagreywacke, basic metavolcanics, hornfels

* Tertiary letter stage

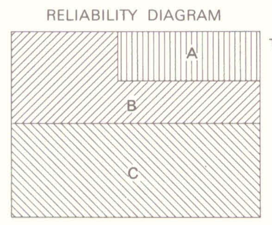
DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



Facies change   Unconformity

Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of Minerals and Energy. Issued under the authority of the Hon. R. F. X. Connor, M.P., Minister for Minerals and Energy.
Base map adapted from topographic maps prepared by Division of National Mapping and Royal Australian Survey Corps with additional compilation by BMR 1971, from Commonwealth Aerial Photography and uncontrolled side looking airborne radar mosaics with horizontal control station data supplied by Division of National Mapping.

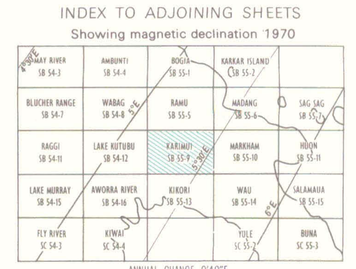
RELIABILITY DIAGRAM



Topography
A Adjusted National Mapping bases; detailed, poorly controlled
B Photo mosaics partly adjusted to U.S. Army Map Service and Division of National Mapping bases; detailed, poorly controlled
C Traced from adjusted side looking airborne radar mosaic at approximately 1:250,000 scale; not detailed, uncontrolled

INDEX TO ADJOINING SHEETS

Showing magnetic declination 1970



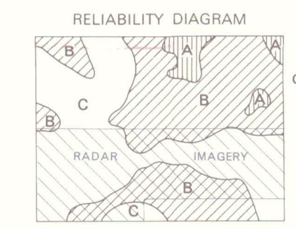
Scale 1:250,000

5 0 5 10 15 20 25 KILOMETRES

5 0 5 10 MILES

GREY NUMBERED LINES ARE 20,000 METRE INTERVALS OF THE AUSTRALIAN MAP GRID, ZONE 55
TRANSVERSE MERCATOR PROJECTION

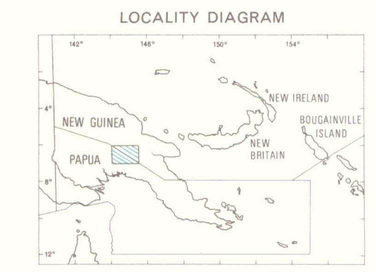
RELIABILITY DIAGRAM



Geology
A Detailed mapping
B Detailed reconnaissance: numerous traverses, interpretation of air-photos and radar imagery
C General reconnaissance: some traverses, interpretation of air-photos and radar imagery

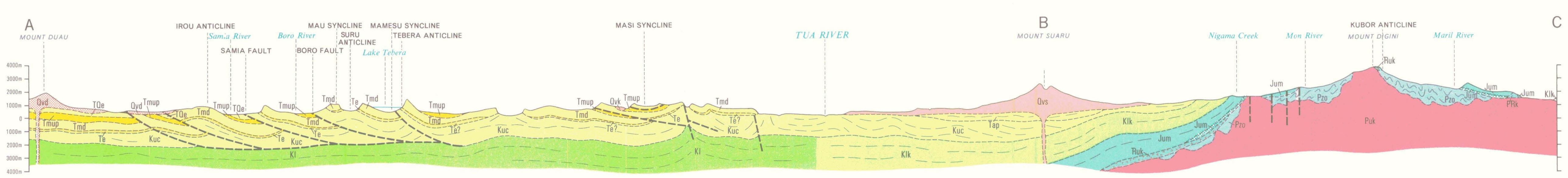
Geology 1947–1955 by W. D. Mott, K. Llewellyn, F. K. Rickwood, J. S. Paterson, P. E. Kent (APC Pty Ltd & IEC Pty Ltd); 1956–1957 by N. J. McMillan, J. E. Johnson, E. J. Malone, K. K. Hughes (BMR); 1968 by S. H. Buchan, G. P. Robinson (BP Pet. Dev. (Aust.) Pty Ltd); 1968–1970 by J. H. C. Bain, D. E. Mackenzie, R. J. Ryburn, R. J. Tingey, D. B. Dow, R. W. Page, I. E. Smith, G. Cifali, D. J. Belford (BMR)
Compiled 1971 by J. H. C. Bain, D. E. Mackenzie
Cartography by Geological Branch, BMR
Drawn by Cartographic Drafting Services, Bendigo, Vic.
Printed by Mercury–Walch Pty Ltd., Hobart, Australia

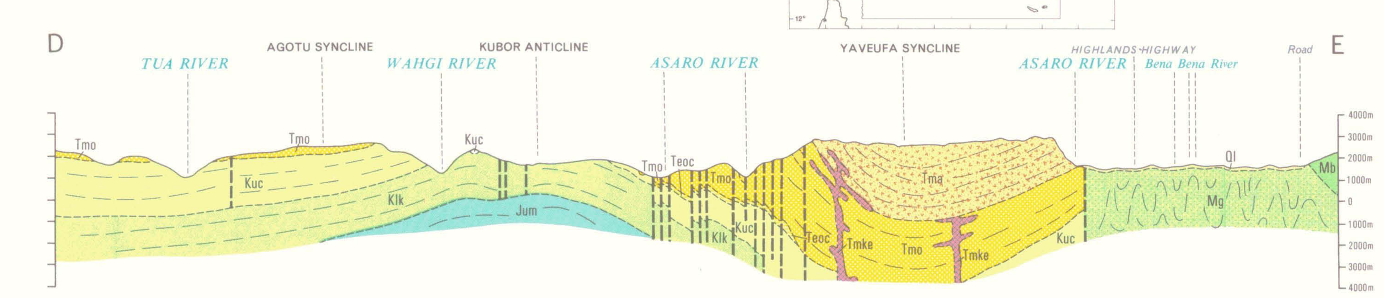
LOCALITY DIAGRAM



Sections

Superficial sediments omitted





FIRST EDITION 1974

KARIMUI

SHEET SB 55-9

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