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Geology of the Kubor Anticline - Central Highlands of New Guinea

by

J.H.C. Bain, D.E. Mackenzie, and R.J. Ryburn

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SUMMARY

The Kubor Anticline is situated in the Goroka-Mount Hagen area of the central highlands of Papua-New Guinea. It is a mountainous region with peaks up to 4,500 m, drained by the Kaugel and Wahgi River systems which flow to the Gulf of Papua via the Purari River. The area was mapped as part of a continuing programme of regional mapping by the Bureau of Mineral Resources. Field work was carried out in 1968 (four months) and 1970 (two months). Regional geology is shown at 1:500,000 scale (Plate 1), and all detail at 1:100,000 scale (Plates 2-17). About 450 thin sections and 250 palaeontological samples were examined; their locations are shown on the 1:100,000 maps.

The Kubor Anticline is a large double plunging basement arch (60 x 125 km) which exposes metamorphic, igneous, and sedimentary rocks ranging in age from Palaeozoic to upper Tertiary. The core of the anticline consists of low grade (greenschist) metamorphics of Palaeozoic age intruded by late Permian composite plutons of acid to basic composition. Unconformably overlying the basement core are small remnants of Upper Permian to Lower Triassic reef limestone, and Upper Triassic dacitic and basaltic volcanics. About 7000 m of folded and faulted Upper Jurassic to Upper Cretaceous fine clastics and volcanolithic sediments unconformably overlie the basement complex, the Permian-Triassic limestone, and the Triassic volcanics; the Jurassic and Cretaceous rocks form the topographically prominent limbs of the anticline. The volcanolithic sediments, which have been buried to depths of 4500 m or more, contain lime zeolites, prehnite, pumpellyite, and zoisite.

Two slightly smaller synclinal folds that flank the eastern end of the anticline are developed in Tertiary rocks which surround the Kubor Anticline on all but the northern side. Upper Palaeocene clastics occur only south and west of the anticline. Eocene-Oligocene shelf and reef limestone overlie Palaeocene and Cretaceous rocks west, south, east, and northeast of the anticline. The limestone is overlain by lower and middle Miocene volcanolithic sediments and volcanics east and west of the anticline, and by extensive Oligocene to middle Miocene shelf limestone south of the anticline. The Miocene volcanics east of the Kubor Anticline contain under-saturated, high-potash lavas; those to the west are of more normal andesitic composition. About 50 km south of the anticlinal axis there is a 50 km-wide zone of overthrust diapiric folds (long axes parallel to the Kubor Anticline) developed in the Tertiary and uppermost Cretaceous sediments. The folds and thrust faults are believed to have resulted from southward gravity sliding off the Kubor Anticline. The Mesozoic and Tertiary rocks on the northern flank of the Kubor Anticline are cut by an extensive 300 km-long by 10 km-wide fault zone (Bismarck Fault Zone) which lies within the New Guinea Mobile Belt and is thought to mark the northern margin of the Palaeozoic Australian continent. Tertiary limestone and sediments caught in the fault zone have been strongly folded, faulted, and overthrust, and the northern block has been elevated at least 3,000 m relative to the southern block. Middle Miocene composite plutons of acid to basic composition intrude the Bismarck Fault Zone and the area to the north, and there is an upper Miocene porphyry stock in the eastern nose of the Kubor Anticline. The southern and western flanks are dominated by Pleistocene strato-volcanoes, and Pleistocene to Recent alluvial fans partly fill the Wahgi Valley on the northern flank.

The Kubor Granodiorite plutons, emplaced in the Omung Metamorphics during the late Permian, were uplifted, eroded, and exposed within a period of 5 m.y. after emplacement. This was the first development of a topographic high in the Kubor area. During Permian to Triassic time reef limestone developed on and around the exposed Kubor Granodiorite. Episodic sedimentation, volcanism, and erosion continued in the Kubor area from Upper Triassic until Cenomanian time, although at least part of the Kubor area remained above sea level from Lower Jurassic time onwards. In Lower Cretaceous time, the Kubor area began to rise (first stage in the development of the Kubor Anticline), and the source of volcanic material in the sediments moved northwards. The Bismarck Fault Zone became active during late Cretaceous to Palaeocene time, resulting in vertical scissor and possible horizontal displacement of the Mesozoic sediments north of the Kubor Range. Sedimentation recommenced to the south and west of the Kubor area during the upper Palaeocene, and became more extensive to the west, south, and east during middle Eocene to early Oligocene time. Two basins developed in lower and middle Miocene time to the east and west of the Kubor area. They were connected to the south by an extensive shallow sea in which shelf limestone formed. Andesitic volcanism occurred in the basins during middle Miocene time, and numerous large and small plutonic bodies were emplaced to the north of the Kubor area. Commencing in the late middle Miocene there followed major orogenic events which probably reached a peak during the Pliocene: the Bismarck Fault Zone was reactivated, the Yaveufa Syncline formed, and the Kubor Anticline was further arched. Numberous minor folds and faults formed and a hypabyssal pluton was emplaced in the eastern nose of the Kubor Anticline. The Tertiary limestone on the southern flank of the Kubor Anticline slid southwards over the Cretaceous shale, and a 50 km-wide belt of overthrust diapiric folds resulted. The whole region was further uplifted and eroded during late Pliocene and early Pleistocene time. Several large stratovolcanoes then formed to the west and south of the Kubor Anticline. The summit areas of volcanoes and mountains above 3000 m were glaciated during late Pleistocene to Recent time.

Only small traces of metallic mineralization have been found; alluvial gold in the Wahgi Valley, disseminated copper-gold-molybdenum mineralization in the Jimi-Wahgi divide, and to a lesser degree disseminated copper-gold in the Michael Diorite and Bismarck Intrusive Complex areas, appear to offer the best prospects for exploration. Large quantities of stone suitable for road metal, aggregate, or building stone, and unconsolidated gravel suitable for road construction are present in the map area.

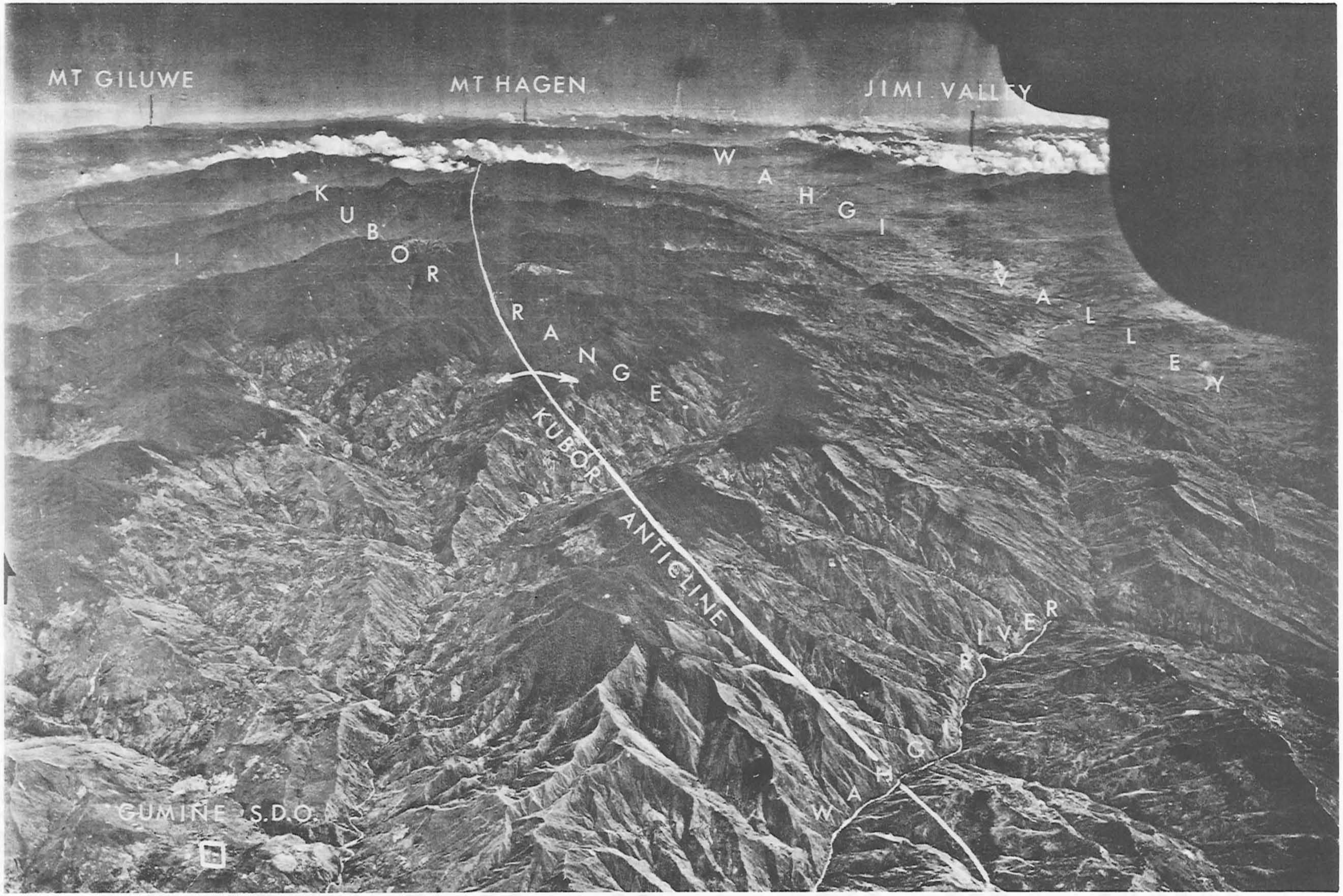

Fig. 1 The Kubor Anticline, forming the Kubor Range and Wahgi Valley.
View to W.N.W. 5RT-5RGL M718 338RS, 1948 6" 25,000 feet CPC 7614.

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INTRODUCTION

The Kubor Anticline forms a mountain range (Kubor Range) 75 km long in the central highlands of New Guinea between 144°E and 145°E. The range is rugged, forest-covered, and almost uninhabited; the crest is above 3000 m, and a number of peaks have glacial landforms and alpine vegetation. The surrounding country forms part of a high, deeply dissected, southward sloping plateau (Purari Plateau), the northern part of which is mostly grass-covered, supports more than a quarter of a million inhabitants and is served by numerous roads, tracks and airstrips; the southern part is forested and sparsely populated.

The Kubor Anticline was mapped in the course of producing Ramu and Karimui 1:250,000 scale geological sheets; a part of the Bureau of Mineral Resources' programme of regional mapping at 1:250,000 scale in the Territory of Papua and New Guinea.

Field work from June until October 1968 was carried out by J.H.C. Bain, D.E. Mackenzie, and R.J. Ryburn, who were assisted during helicopter operations by D.B. Dow, R.J. Tingey, I.E. Smith, G. Cifali, and R.W. Page. Detailed follow-up work was carried out by Bain, Mackenzie, and D.J. Belford during 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 Karimui and Crater volcanoes. The southeastern portion of the Plateau extending to the Aziana and Lamari Rivers was also mapped (but is not discussed here).

This report deals only with the Kubor Range and the area immediately adjacent to it. It incorporates the unpublished results of some traverses made by D.B. Dow and F.E. Dekker in 1964, but does not include data from the Lamari River area.

The Ramu and Karimui 1:250,000 scale geological sheets and a comprehensive report on the geology of the combined sheet areas are in preparation.

Physiography

The map area covers the greater part of the Purari Plateau as defined by Spinks (1935). It is a rugged area with mountain peaks up to 4,500 m, deeply incised gorges, and spectacular limestone cliffs.

The Purari Plateau slopes gently southwards from an average elevation of about 2,000 m near Mount Hagen town to about 800 m in the southwestern part of the map area (Fig. 7). Mountain ranges and divides all but encircle the map area, and it is only in the southwestern corner that they are absent. The Purari Plateau is drained through this gap. The bordering ranges on the northern and eastern boundaries of the map culminate in the northeastern corner where Mount Wilhelm (4509 metres) rises some 3,000 metres above the Wahgi Valley (Fig. 2).

Dominant on the Purari Plateau in the central part of the map area, is the Kubor Range which rises to over 3,500 metres above sea level at a number of places along its 75 km length (Fig. 1). The centre of the range is the Palaeozoic core of the Kubor Anticline, and its foothills are the Mesozoic limbs. To the west, where the range is widest (35 km), and composed largely of granitic rocks, the drainage is more complex, and the topography more rugged, than at the tapering eastern end. Deeply eroded, flat-lying outliers of volcanic rocks cap the highest points on the range (Fig. 3), and commonly form sharp, rugged, bare rock peaks such as Mount Sigul Mugal (Fig. 4). Elsewhere the range is bush covered, and is everywhere devoid of human habitation.

A late Pleistocene glaciation has modified the landscape above 3,200 metres elevation, and cirques are developed at a number of places on the Kubor Range and on Mounts Giluwe, Hagen (just west of the map area), Michael, and Wilhelm (Löffler, 1970). Small moraine deposits remain at a few places on Mount Giluwe and on the flanks of Mount Wilhelm, and fanglomerate deposits, in part of probable fluvioglacial origin, cover the floor of the central Wahgi Valley.

A prominent limestone cuesta (Chimbu Limestone) with cliff faces up to 300 m high, runs for 60 km southeast of Kerowagi. It presents an almost impenetratable barrier to eastwest travel except where it is cut by the southwesterly flowing Chimbu and Mai Rivers. The Chimbu River forms a spectacular pass; it flows from a small tarn high on the slopes of Mount Wilhelm, falls steeply to the east, then swings southwestwards 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 dipslope near Kundiawa. It dissipates much of its energy in a short stretch of broad, flat-floored valley before joining the Wahgi River.

The main river in the map area, the Wahgi River, starts its course as a small youthful stream on the steep eastern slope of Mount Hagen. In a short distance it changes to a mature meandering river on the flat floor of the upper Wahgi Valley (Figs. 42, 43). This flat area probably formed as a result of damming of the ancestral westerly flowing Wahgi River by the Mount Hagen volcano and the subsequent formation and infilling by sediment of a shallow lake (Haantjens, 1970). Stream capture then reversed the flow of the Wahgi River to its present course. About 12 km due south of Kerowagi the Wahgi drops into a deep gorge, at least 600 m deep (Fig. 21), which extends past the junction of the Wahgi and Asaro rivers.

There are terraces at various levels in the Wahgi Gorge; the main terrace is at the base of the Kondaku Tuff, the next near the base of the Maril Shale, another cut into the Maril Shale and Omung Metamorphics, and yet another of very limited extent in the base of the gorge. Numerous tributaries, also deeply incised, enter the gorge by waterfall, because most valleys have been left 'hanging' by the more rapid incision of the larger stream.

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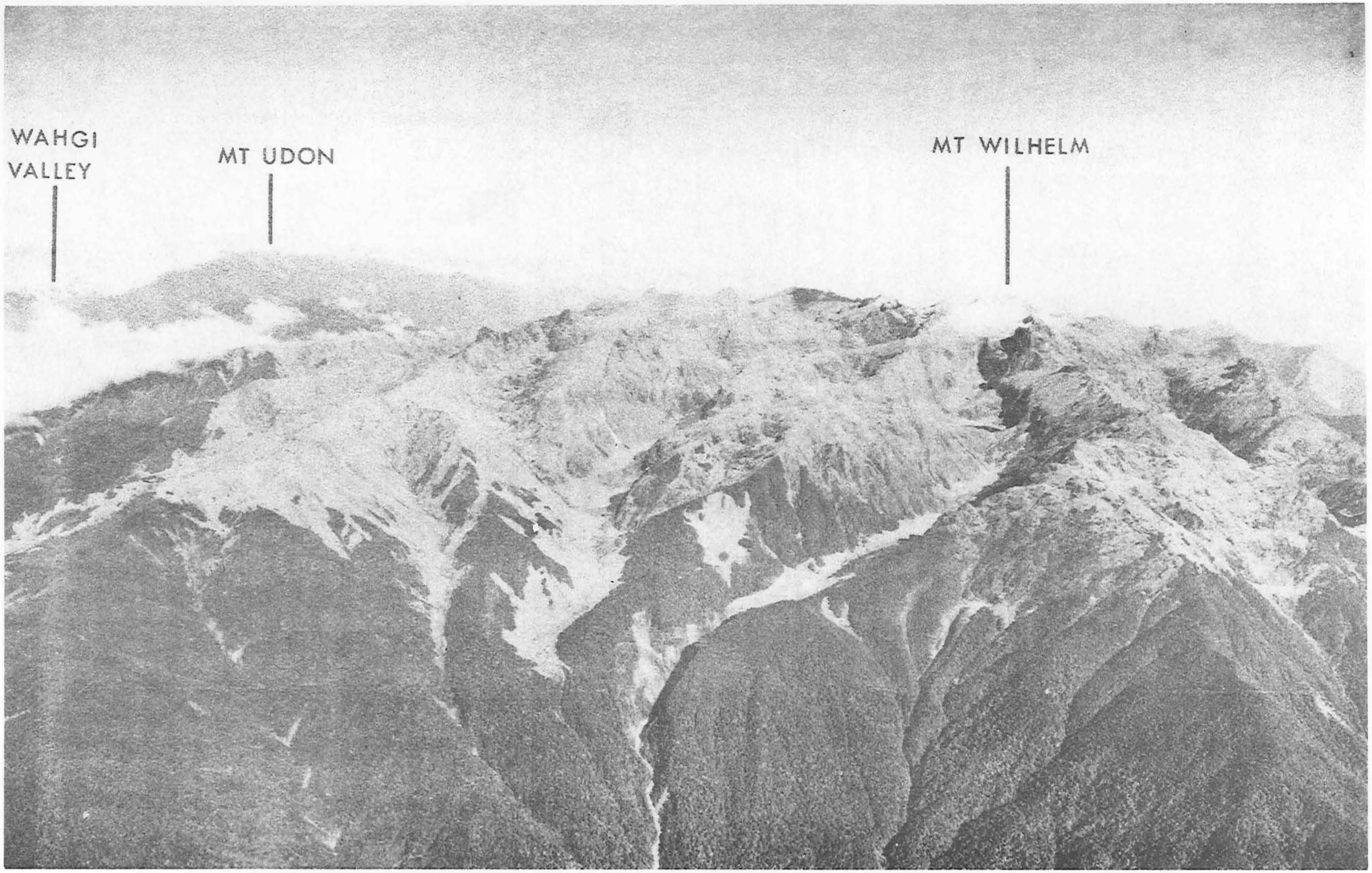


<u>Fig. 2</u> Glaciated summit area of Mount Wilhelm, viewed from the south east. Note seasonal snow cap. Altitude 4500 metres above sea level.

QASCO NG 25/11.

Fig. 3 Kubor Range (approx 4000 metres ASL) showing massive flat-lying Kana Volcanics capping Omung Metamorphics and Kubor Granodiorite. Local Relief is about 2000 metres. Neg. GA1233

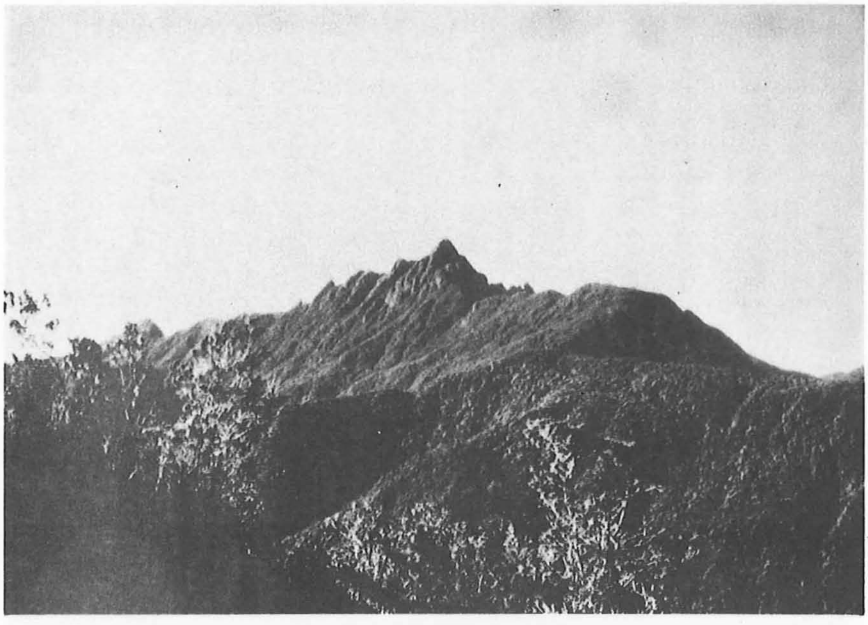


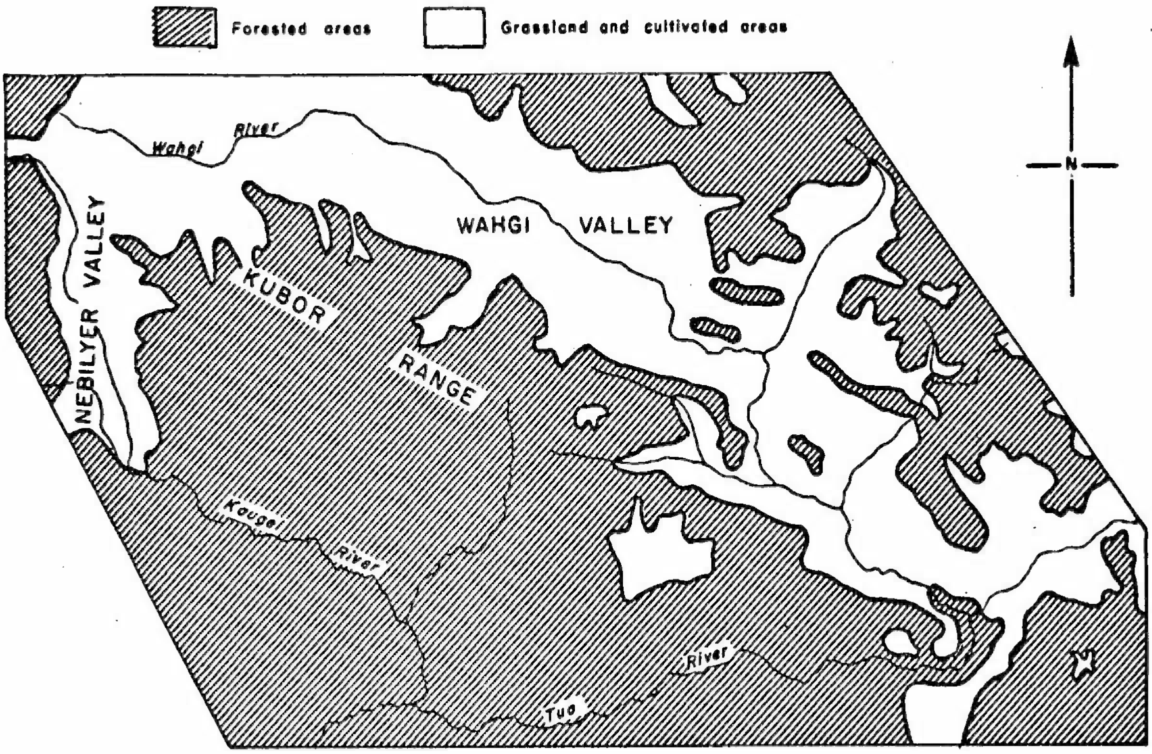
Fig. 4 Mount Sigul Mugal (approx. 4000 metres ASL), one of the peaks of the Kubor Range viewed from the NW at 3,000 metres ASL. The mountain is largely granite with a capping of volcanic rocks (Kana Volcanics). Neg. GA2390

Fig. 5 View to the north-west from near the summit of Mount Sigul Mugal. Flat-topped hill in the centre middle distance is Mount Oga with the upper Wahgi Valley behind. Neg. GA1265.

Fig. 6 Glaciated Kana Volcanics on the rest of the Kubor Range (4000 ± metres ASL). Neg. GA1263

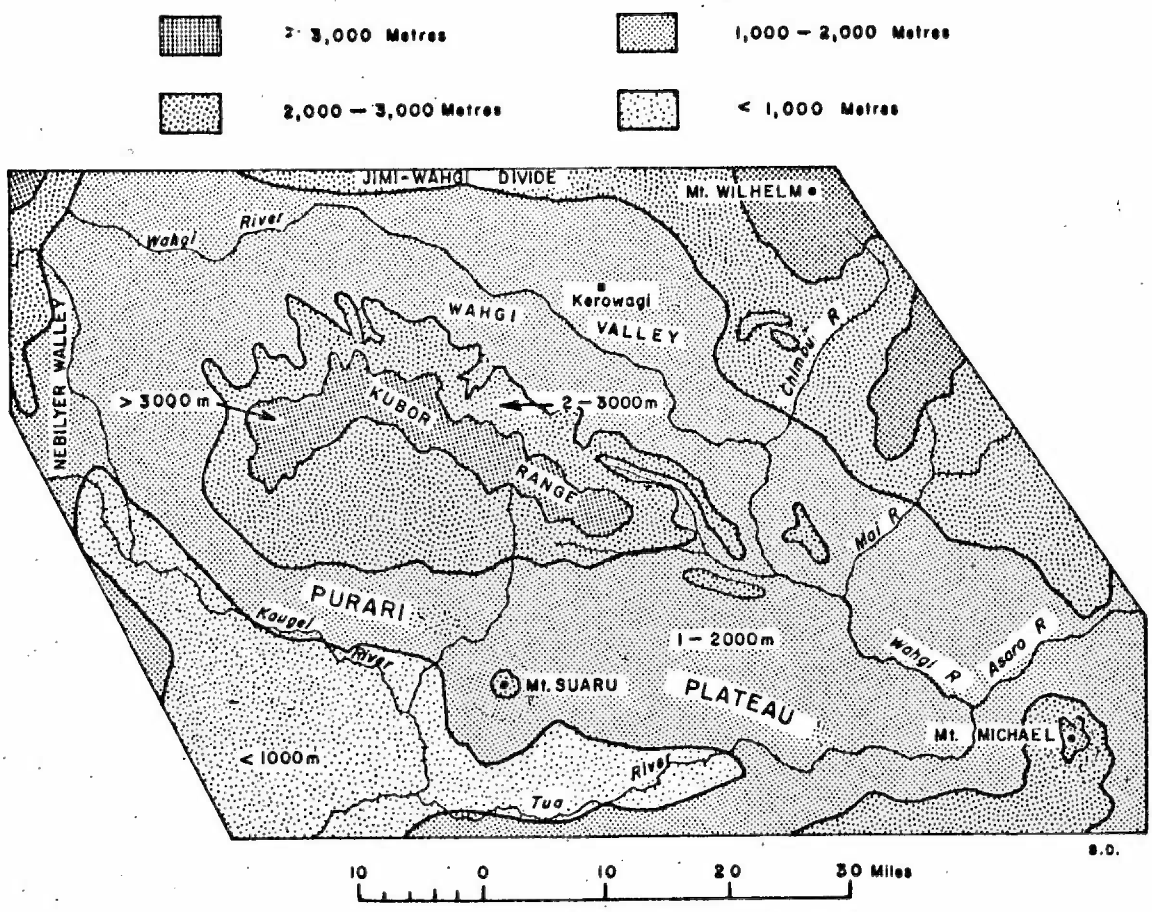
Fig. 7

VEGETATION



PHYSIOGRAPHY

Height above sea level



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The Kaugel River enters the westerly flowing Tua (Wahgi) River southwest of Mount Suaru and the resultant much swollen Tua flows south out of the map area where it is joined by the Erave River, and becomes the Purari River.

On the deeply dissected land surface described above are superimposed a number of large stratovolcanoes, surrounded by thick and extensive gently sloping volcanic aprons, which have been deeply gullied by recent erosion. Lavas and lahar deposits from the larger volcanoes (e.g., Mount Hagen) have filled deep valleys (e.g., Nebilyer) and changed the courses of numerous streams.

Climate

On the Purari Plateau mean annual rainfall is about 2,500 mm and there is a pronounced 'dry' period during the season of southeast winds (May-October); annual rainfall is lower in sheltered areas, and higher (probably up to 3,800 mm) in more exposed areas. More rain (in the order of 3,800-5,000 mm per year) falls on the southern flanks of the Kubor Range, and Crater and Karimui volcanoes where there is a poorly-defined wet season during the southeast trades.

During the survey (June-September) temperatures recorded at Gumine base camp (1700 m a.s.l.) in 1968 ranged between mean maxima and minima of 26.8°C and 12.8°C. These figures show a greater diurnal range than would be expected for the more humid remainder of the year. Occasional night frosts are known to occur at ground level in cold air pockets down to as low as 2000 m a.s.l.

Bik (1967) described a very similar climate for part of the Western and Southern Highlands.

Brookfield and Hart (1966) show that great variations in weather conditions prevail in different parts of the Wahgi Valley at the same time of day, and they contend that the climate of the enclosed Highlands valleys is affected by local circulations that operate independently of all but the most dominant of general conditions.

Airphotographs and Basemaps

Airphotographs from Qasco, Adastra, RAAF, and other sources afford almost complete coverage of the area (Plate 18). Most have been taken from about 7,600 m a.s.l., with a 152 mm focal length lens, and some from 4,500 m a.s.l. (Qasco). In all cases 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 prints make geological interpretation difficult. Adastra and RAAF trimetrogon photos were flown prior to 1960, and therefore show none of the recently made roads. Most of the recent Qasco airphotographs (flown in 1968, and received 6 months after completion of field work) cover the trackless bush area to the south of the Kubor Range.

Geological data were plotted on 1:50,000 scale topographic bases. For the northern part of the map area these were obtained by enlarging 1:63,360 scale Planimetric Series (uncontoured) Preliminary Edition maps prepared by the Division of National Mapping. Bases for the southern half of the area were obtained by assembling the airphotographs in uncontrolled mosaics, and tracing off the major streams. These maps were then reduced to 1:50,000 scale, and adjusted so that on further reduction to 1:250,000 scale the drainage would approximately match the generalized stream data on the Royal Australian Survey Corps 1:250,000 scale topographic maps. U.S.A.F. Aeronautical Approach Charts (1:250,000 scale) with hill shading and some form lines were also available, but as the Army Survey maps contained the same stream data and more complete cultural data they were used in preference to the Approach Charts. The 1:50,000 scale geological sheets have been photographically reduced to 1:100,000 scale (Plates 2-17).

Access and Method of Working

The Lae-Mount Hagen road runs through the area, and there are numerous poorly formed roads in the Wahgi Valley between Mount Hagen and Goroka. Many of these minor roads, however, become impassable after heavy rain. There are nineteen airstrips within the mapped area, although all but three are open only to light aircraft (Figs. 8 and 9).

In 1968, a base camp, with access to Omkalai airstrip (Figs. 8 and 9), was established near Gumine. Roads were traversed using four-wheel-drive vehicles, and the intervening country mapped by one and two-day traverses along streams and walking 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 south of the Kubor Range. An inflatable rubber raft was used during mapping of a 65 km section of the Tua River.

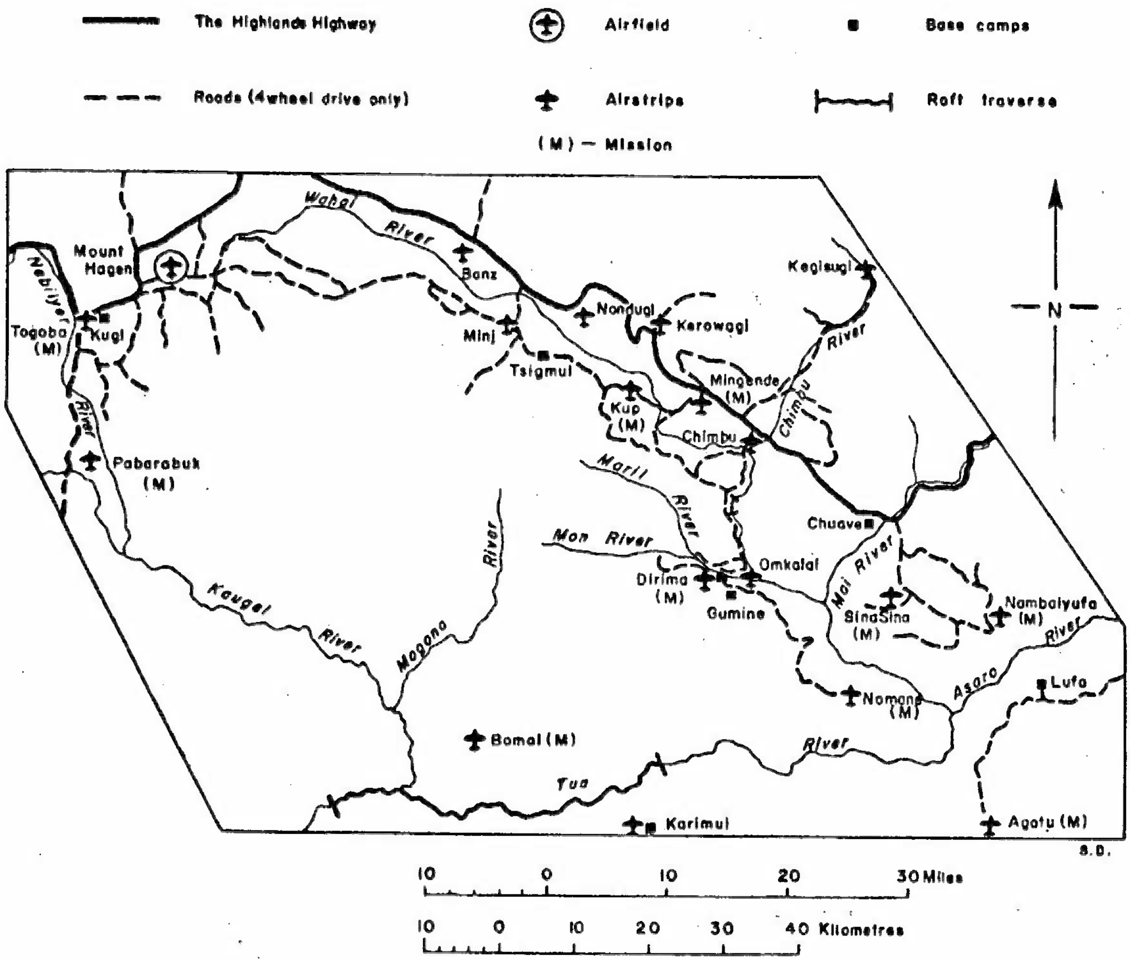
In 1970 four-wheel-drive vehicles were again used to position ground traverse parties for detailed mapping and collecting. A helicopter, working from a base at Baiyer River was used during reconnaissance mapping in the Jimi Valley.

Helicopter operational methods in 1968 were based on experience obtained in the South Sepik region in 1967 (Dow et al., 1968; Davies and 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 map area is complex, and photo-interpretation between spot observations could not be made with confidence, it was frequently necessary for traverse parties positioned by helicopter to walk for up to four days to cover the more inaccessible parts. Occasionally traverses lasted 7 to 8 days. The paucity of landing sites meant that economical usage of the helicopter could best be obtained by a combination of the following practices:

(1) Spot observations - a necessary prelude to the planning of traverses.

Fig. 8

ROADS AND AIRSTRIPS



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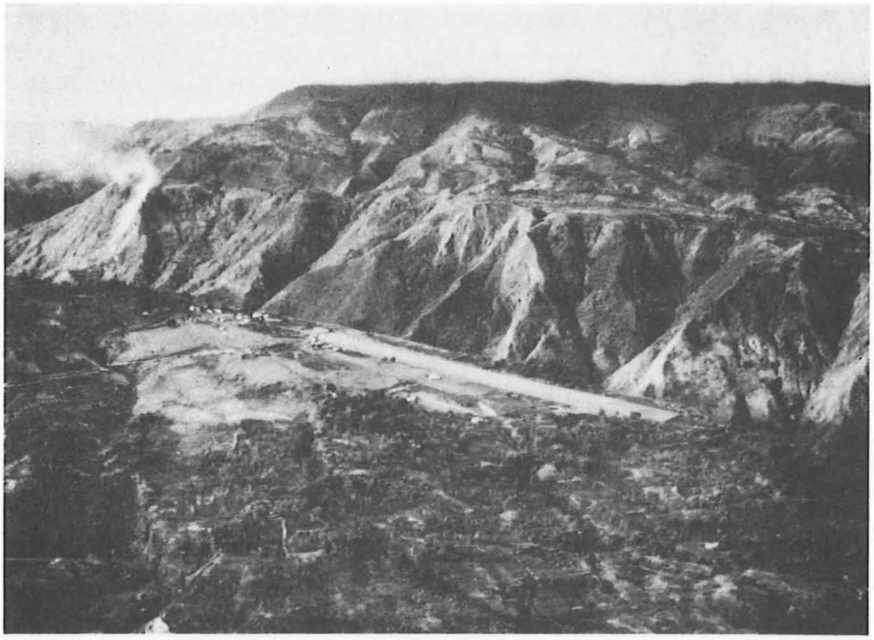


Fig. 9 Omkalai airstrip (restricted B category) on a dipslope (13°) of Maril Shale. The Wahgi River flows from left to right in the 600 metres deep gorge just beyond the airstrip. Hills mantled by clouds are composed of Kondaku Tuffs.
Neg. GA2393.

(2) Geologist and native assistant placed in the field in the morning, and picked up the same afternoon. (This method is economical only whilst working close to the helicopter base, i.e., within 30 km).

(3) Geologist and three carriers positioned for traverse of up to four or five days' duration.

The helicopter base was moved twice to ensure that the machine operated only within its most economical range (50 km radius). Light aircraft were used to provide rapid and economical movement of personnel and equipment between base camps. To make full use of the helicopter it was found imperative that the party consist of at least five or six geologists. The party leader generally remained in base as co-ordinator, and made use of any free time on the helicopter with reconnaissance and one day traverses. His duties were to ensure the smooth and efficient functioning of the helicopter programme which had to be as flexible as possible to accommodate contingencies such as bad weather, unexpected geological problems, or sickness of party members.

PREVIOUS GEOLOGICAL INVESTIGATIONS

N.H. Fisher, Government Geologist, visited the Highlands in 1937. His brief reconnaissance followed earlier 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 Mesozoic and Tertiary rocks exposed in the Chimbu River, and collected specimens from this section and from the limestone at Kuta. Laboratory studies of these specimens were made by Edwards and Glaessner (1953), and Crook (1961). In 1949 Australasian Petroleum Company (A.P.C.) geologistsG.A.V. Stanley, K.M. Llewellyn, and M.F. Glaessner (Stanley, 1950) made a reconnaissance of the Central Highlands from Aiyura (east of Kainantu) to Mount Hagen. The Miocene rocks east of the Chimbu Limestone were described, and the Kuta limestone resampled. Subsequent palaeontological examination of the Kuta limestone by Glaessner et al. (1950) established its age as Permian. The Kubor granite and metamorphic rocks, which are unconformably overlain by the limestone were therefore thought to be Palaeozoic, and the oldest known rocks in eastern New Guinea.

In December, 1950, F.K. Rickwood (1955) mapped the area from Chuave to Wabag, including the Kubor Range and the Wahgi Valley. Unfortunately he and earlier workers had no base maps or airphotographs of the area, and consequently much of their data is not easily referable to existing maps or airphotographs. However, Rickwood recognized the broad structure of the area, and mapped and defined the formations proposed by Edwards and Glaessner (1953). Petroleum exploration geologists then regarded the geological knowledge of the Highlands as adequate for the purposes of oil exploration in Papua. Rickwood and other A.P.C. geologists (Rickwood and Kent, 1956) subsequently mapped the area to the south of Mount Michael and the Tua River (Pio-Purari Survey), but without accurate base maps.

In 1956 Bureau of Mineral Resources geologists (McMillan and Malone, 1960) commenced regional mapping of the eastern part of the Central Highlands using airphotographs and semi-controlled detailed topographic base maps prepared by the Division of National Mapping. In 1962 Dow and Dekker (1964) mapped the Bismarck Mountains which lie immediately north of the area covered in this report. Their base map was prepared from an uncontrolled mosaic of airphotographs; because the area is one of extreme relief, streams and geological boundaries on their map are as much as 8 km out of position.

Since 1962, engineering geologists, including J.R. Read from the Resident Geological Branch, Port Moresby, have made geological observations along the line of the Highlands Highway in the course of road alignment investigations. Several large mining companies, notably Kennecott Explorations (Australia) Pty Ltd, have made brief reconnaissances throughout the area, and collected stream sediments for analysis. More recently, Dow and Harding (BMR) in 1966, followed by Page (BMR) and McDougall (ANU) in 1967, have collected a large number of specimens for isotopic age determination (Page, 1971; Page & McDougall, 1970a; 1970b).

OUTLINE OF GEOLOGY

The Kubor Anticline is a basement fold on what was the northeast margin of the Australian continental block during Palaeozoic time. It is bounded on the north by the New Guinea Mobile Belt (Dow et al. 1968), a tectonically active zone within younger continental crust which accreted to the northern edge of the continent during Mesozoic time. Uplift of the northern edge of the older continental block resulted in gravity sliding which has strongly deformed the uppermost layers of the overlying Mesozoic and Tertiary sediments. The lower layers of this sedimentary sequence are only broadly folded and faulted (e.g., Kubor Anticline). Within the Mobile Belt these sediments have been strongly deformed and intensely faulted.

The oldest rocks exposed in the map area are low-grade regionally metamorphosed (greenschist facies) sedimentary and volcanic rocks of probable Palaeozoic age called the Omung Metamorphics. These are exposed only in the core of the Kubor Anticline, where they are intruded by large composite plutons and small stocks of acid to basic composition (Kubor Granodiorite) which are thought to be of late Permian age.

Unconformably overlying the Kubor Granodiorite at the western and northeastern extent of the basement core are small patches of sandy limestone and arkose (Kuta Formation) of Upper Permian - Lower Triassic age. Also unconformable on the metamorphic and plutonic rocks, but not seen in contact with the Kuta Formation, are Upper Triassic dacitic and basaltic volcanics (Kana Volcanics) which form flat outliers on the crest of the Kubor Range and overturned fault wedges on the southern and western slopes of Mount Wilhelm. To the north of the Anticline the Kana Volcanics are unconformably overlain by Lower Jurassic greywacke (Balimbu Greywacke) and Middle Jurassic basic volcanics (Mongum Volcanics). In the map area these formations are present only as small fault wedges in the Jimi-Wahgi divide and Bismarck Mountains.

Unconformably overlying the basement core, the Kuta Formation, and the Kana Volcanics, and forming the prominent limbs of the Anticline, is a thick (about 7,000 m) sequence of Upper Jurassic to Upper Cretaceous clastic and volcanic rocks. This sequence consists of three formations: Upper Jurassic Maril Shale which is predominantly shale; Lower Cretaceous Kondaku Tuff which is mostly volcanolithic sandstone, shale, and basic volcanics; and Upper Cretaceous Chim Formation which is again largely shale. The lowermost beds in the Maril Shale everywhere contain a very high proportion of clasts derived from the immediately underlying rocks, and constitute a distinctive stratigraphic marker unit.

The southern and western limbs of the Anticline are overlain with paraconformity by Upper Palaeocene mudstone and sandstone (Pima Sandstone), and Eocene/Oligocene limestone (Nebilyer Limestone), respectively. At the eastern 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 basal unit of the Yaveufa Syncline. The Eocene/Oligocene limestone units are everywhere overlain by Miocene limestone or clastics. The Nebilyer Limestone at the western closure of the Kubor Anticline is overlain by fine clastics, interbedded limestone, marl, and mudstone (undifferentiated Aure Group) which grade southwards into massive shelf limestone (Darai Limestone). The Miocene limestone has slid southwards off the flanks of the Kubor Range, and now rests with marked unconformity on highly disturbed Upper Cretaceous shale.

Unconformably overlying the Chimbu Limestone in the Yaveufa Syncline is a sequence of siltstone, tuffaceous sandstone, conglomerate, and limestone (Movi Beds), and volcanic and volcanolithic rocks (Asaro Formation and Daulo Volcanic Member) which thicken towards the southeast.

Intruding the Mesozoic formations in the Jimi-Wahgi divide and Bismarck Mountains are large composite plutons of middle Miocene age (Kimil Diorite, and Bismarck Intrusive Complex). A large hypabyssal diorite stock (Michael Diorite) forms Mount Michael, and is of upper Miocene age. Numerous small intrusive bodies (Kenangi Gabbro) in the vicinity of the Daulo Volcanics, and a small stock (Benembi Diorite) near Kuta, are probably also of Miocene age.

The northern limb of the Kubor Anticline is cut by the extensive Bismarck Fault Zone which marks the southern margin of the New Guinea Mobile Belt. The Bismarck Fault Zone is a 20 km-wide, highly disturbed zone of subparallel anastomosing faults, thrust faults, and tight overturned folds. There is at least 3,000 m of vertical displacement (north side up) spread over the width of the fault zone in the vicinity of Mount Wilhelm.

PRE-PERMIAN

Omung Metamorphics

Name

The oldest rocks in the Central Highlands are low-grade metasedimentary rocks which form part of the pre-Permian basement exposed in the core of the Kubor Anticline. These rocks were first described by Rickwood (1955, p.68) who named them the Omung Metamorphics (from the Omung River on the northeast flank of the Kubor Range; 6°00'S, 144°43'E).

Distribution

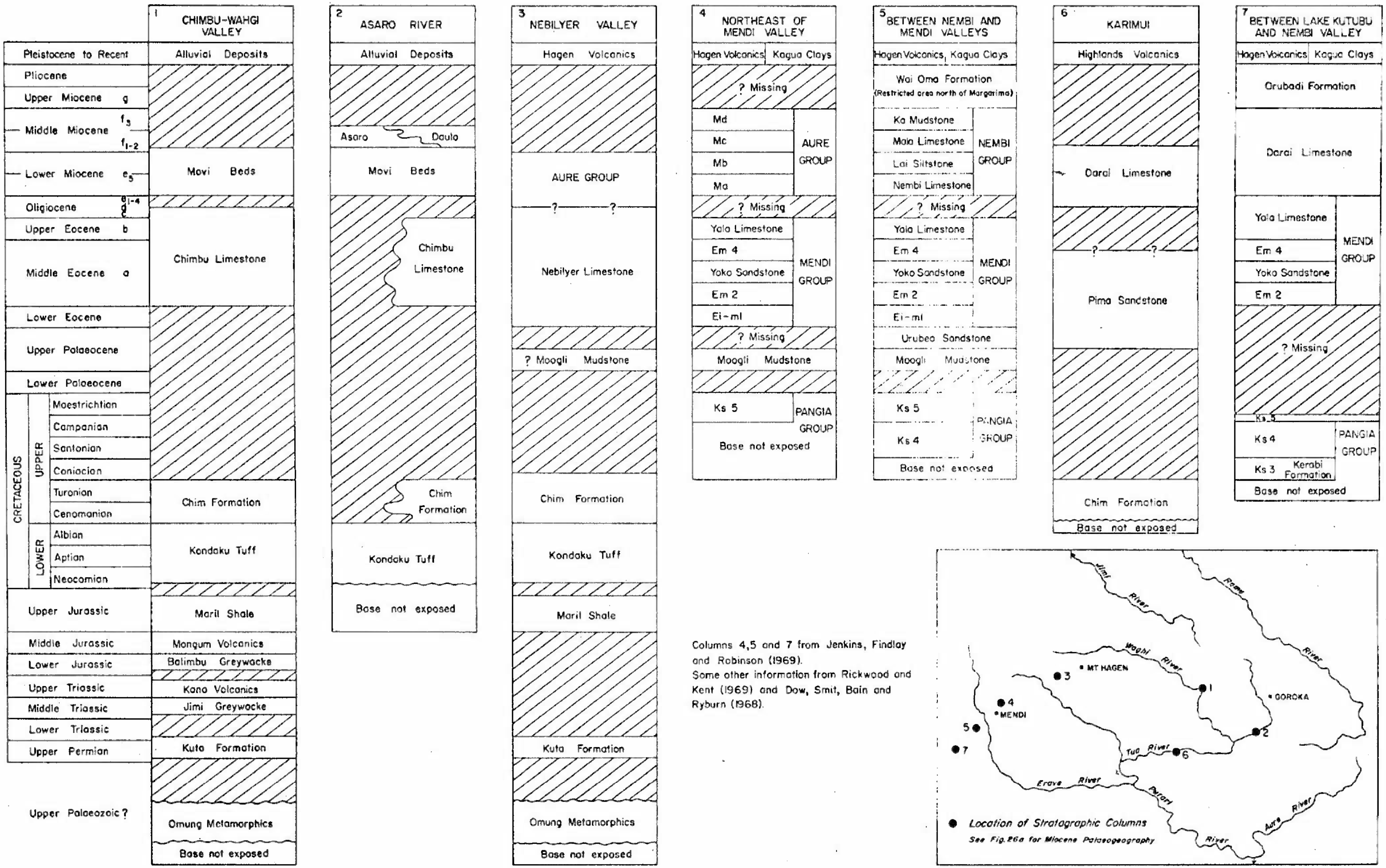
The Omung Metamorphics crop out mainly in the eastern half of the core of the Kubor Anticline where they are intruded by some bodies of Kubor Granodiorite. The western half is occupied by a large pluton of Kubor Granodiorite with subordinate exposures of metamorphics. A small area of metamorphic and plutonic basement is also exposed at the head of the Wahgi Valley, 15 km northeast of Mt Hagen. Rocks in the Chimbu River which Rickwood correlated with the Omung Metamorphics are now known to be Upper Triassic Kana Volcanics (Dow et al., 1968, p.25).

Age

The Omung Metamorphics are of pre-Permian age. Around the western end and northeast flank of the Kubor Anticline, Kubor Granodiorite and in some places Omung Metamorphics are unconformably overlain by

Fig. 10

SUMMARY OF STRATIGRAPHIC UNITS



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limestones of the Kuta Formation which are the oldest known fossiliferous rocks in eastern New Guinea. On the basis of microfossils these limestones were thought to be Permian (Rickwood, 1955), but macrofossils collected in 1970 indicate an age close to the Permian-Triassic boundary (see Kuta Formation). Elsewhere the metamorphics are overlain by Upper Triassic Kana Volcanics or by Upper Jurassic Maril Shale.

Lithology

The most characteristic and abundant rock types are shale and siltstone that have undergone varying but generally slight degrees of metamorphism. In many areas the formation is composed mainly of dark grey, massive "argillite" (indurated shale or siltstone) with blocky jointing and poorly developed cleavage. In other areas somewhat greater metamorphism has produced slate, phyllite, and sericite schist. Quartz veins are common. Spotted slate and hornfels are developed mainly in narrow aureoles surrounding Kubor Granodiorite intrusions.

Metagreywackes are much less abundant. Characteristically they are hard and grey, bluish-grey, or green, with blocky jointing but without discernible cleavage. They occur as massive beds or thin interbeds within finer-grained rocks. Graded bedding and fine current bedding are locally present in some outcrops of the thinly bedded type. Rarely present are intraformational breccias consisting of angular argillite flakes in greywacke matrix.

Green or sometimes red metavolcanic rocks are conspicuous as boulders in many of the streams draining the Kubor Range. Their relationship to the metasediments is uncertain as they are not common in outcrop. Possibly they occur as thin flows and feeder dykes within the metasediments. They are usually massive, and commonly contain relict amygdales and plagioclase phenocrysts.

The bulk of the formation has been subjected to low-grade regional metamorphism, the effects of which vary according to locality and lithology. Slaty or phyllitic cleavage is present only in the finer-grained rocks, and commonly parallels bedding where bedding is seen. In some outcrops of phyllite, notably on Mount Digini and in the Maril River, a secondary strain-slip cleavage (Fig. 11) gives rise to small folds and crenulation lineations on main cleavage surfaces. Slates and phyllites in the north branch of the Maril River display tightly folded bedding with axial plane cleavage. Post-metamorphic chevron folds and kink bands are also to be seen in phyllite outcrops on Mount Digini and in the Maril River.

Owing to the scarcity of bedding and the absence of distinctive marker units, the macrostructure of the Omung Metamorphics is obscure. On a regional scale, bedding 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 in several places in the vicinity of Dek. The tendency for cleavage to parallel bedding suggests that the formation may be isoclinally folded. Broad anticlinal warping associated with the development of the Kubor Anticline is probably superimposed on an earlier, more complex structure. The thickness of sediments involved is probably more than 2,000 m.

Petrography

In thin section the fine-grained metasediments are seen to be poorly sorted, notably quartzose silty shales and matrix-rich siltstones that have undergone various degrees of metamorphic reconstitution. In relatively unmetamorphosed examples, clastic texture is largely preserved, and the detritus is predominantly quartz with progressively smaller amounts of albitized plagioclase, muscovite, chloritized and epidotized ferromagnesian minerals, biotite, sphene, epidote, and zircon. The matrix material in all cases is largely recrystallized to fine-grained sericite, quartz, chlorite, and albite(?) with much disseminated opaque material. Cleavage in the matrix is marked by preferred orientation of micaceous minerals. With increasing metamorphic reconstitution, recrystallization and directional structure become more pronounced but some relict detrital grains are present in all specimens. Fine-grained, metamorphic biotite is present in some phyllite specimens. Many thin sections are transected by veinlets of quartz, albite, and chlorite.

Metagreywackes consist of angular poorly sorted grains of quartz (about 60%), albitized plagioclase, muscovite, potash-feldspar (microcline and orthoclase), intermediate to basic volcanics, biotite, sphene, opaques, epidote, apatite, and zircon in a matrix similar to that of the finer metasediments. Shearing and cataclasis are apparent in many specimens. As in the phyllites, metamorphic biotite (or in some cases possibly stilpnomelane) is present in some of the more highly metamorphosed specimens.

Most of the metavolcanic rocks appear to have been lavas of basic or intermediate composition, but are now largely recrystallized to greenschist facies assemblages made up of albite, chlorite, epidote, actinolite, quartz, and calcite, not all of which are necessarily found in the one rock. Accessory sphene and opaques are ubiquitous. Albitized plagioclase laths are commonly preserved in relict subophitic texture (sometimes flow-aligned), and relict phenocrysts of plagioclase and augite are also common. Metamorphosed hypabyssal equivalents of the lavas with relict porphyritic or doleritic texture are also found. Two specimens which consist of finely crystalline albite, epidote, chlorite and calcite may have been tuffs.

Rocks from the contact-metamorphic zones surrounding Kubor Granodiorite intrusions show evidence of only slight thermal metamorphism. The most common effect is the growth of biotite or andalusite porphyroblasts in pelitic rocks. For example, a hornfelsed siltstone from within a few metres of a plutonic contact on Mount Digini (21NG2753) contains biotite as spongy brown porphyroblasts and also as fine green flakes in the recrystallized matrix, but still retains clastic texture. Spotted slates have also been noted in areas devoid of intrusions; an example is a spotted slate from the Mogono River (21NG1355) in which the "spots" are muscovite-biotite aggregates.

Andalusite was identified in three specimens. The most spectacular example is hornfelsed siltstone from the Gumine-Kundiawa Road (21NG1138) which contains perfectly euhedral crystals of sericitized andalusite up to 2 cm long (Fig. 12). Biotite is also present. Smaller andalusite crystals with well developed chiastolite crosses were noted in

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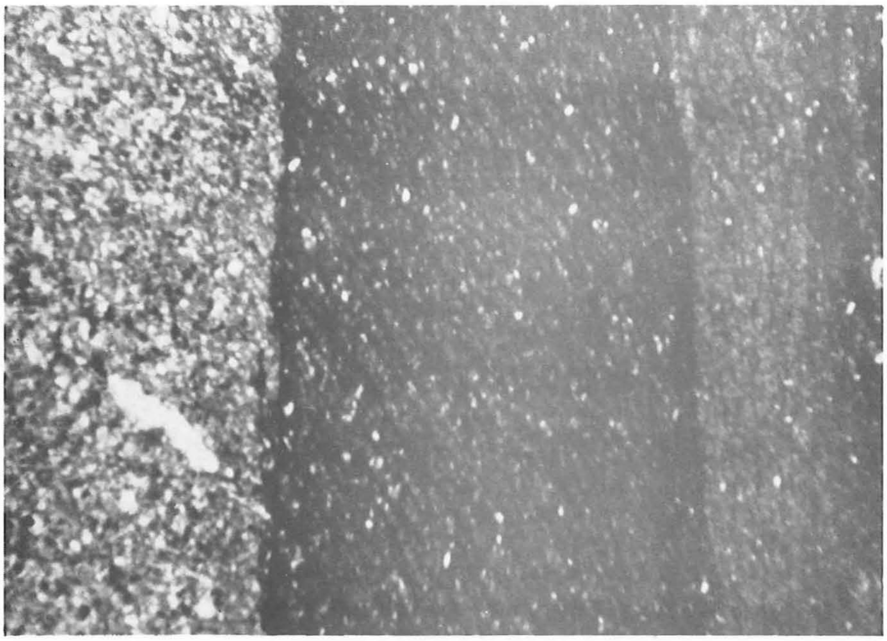

Fig. 11: Strain slip cleavage at an angle to bedding in finely interbedded slaty shale and siltstone of the Omung Metamorphics. Specimen (21NG0523) from the Kundiawa-Gumine road. X 40, plane polarized light.

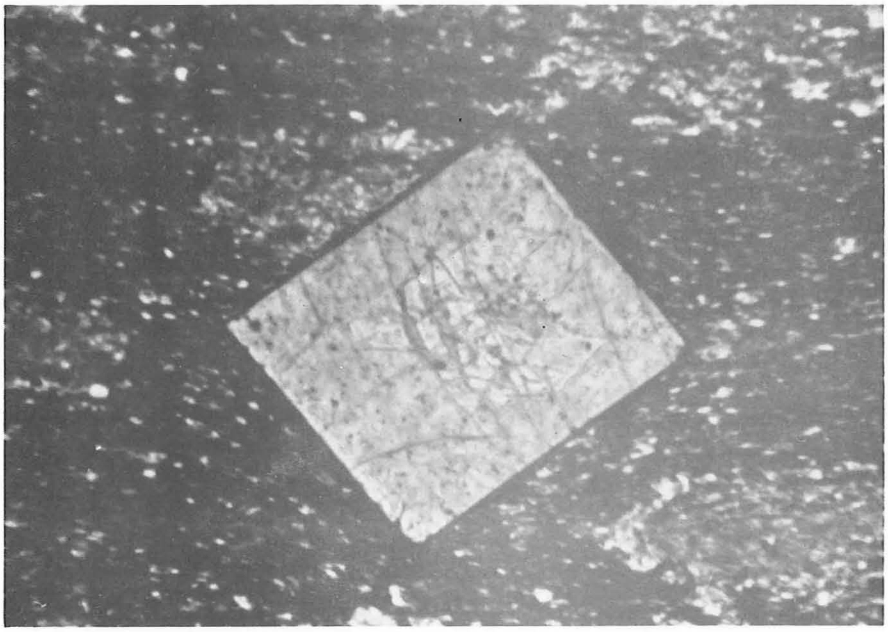

Fig.12: Basal section of sericitized andalusite in pelitic hornfels of the Omung Metamorphics. Specimen (21NG1138) from the Kundiawa-Gumine road. X 40, plane polarized light.

a similar rock from a contact aureole on Mount Digini (21NG2571). A spotted slate from the Omung River (21NG2805) has composite porphyroblasts of radiating andalusite prisms and also contains fine biotite.

Scapolite was tentatively identified in an unusual metavolcanic rock cropping out beneath the Kuta Formation in Momai Creek near Kuta (20NG1287). The (?)scapolite occurs as small stumpy prisms in radiating spherical aggregates that could represent original spherulites. Relict quartz and plagioclase phenocrysts suggest that the rock was originally a dacite.

Other minerals of probable contact metamorphic or metasomatic origin include accessory garnet in a metavolcanic hornfels from the Gumine-Kundiawa Road (21NG0520), and tourmaline as a vein mineral with albite and chlorite 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. The other two exposures, 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), are of granitic rocks only. Granitic basement is also known from 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.

Possible correlatives of the Omung Metamorphics are the Goroka and Bena Bena Formations of the Eastern Highlands (McMillan and Malone, 1960). These formations consist largely of low-grade metasediments broadly similar to the Omung Metamorphics. However, these formations probably include rocks of Mesozoic age, and their age of metamorphism may be considerably younger than that of the Omung Metamorphics, possibly Lower Tertiary.

The Omung Metamorphics were originally deposited as relatively deep-water marine sediments. The observed sedimentary structures, notably graded bedding, fine cross laminations, and intraformational breccias, are of types commonly found in turbidite sequences and suggest a geosynclinal environment of deposition. The predominance of fine-grained sediments, and the absence of shallow-water conglomerates, limestones and fossils are supporting factors. The main relict detrital minerals are quartz, plagioclase, biotite, and muscovite. Granitic and crystalline rocks of the Australian proto-continent to the south-west are the most likely source of these.

The metamorphism that resulted in the development of cleavage throughout much of the formation was probably coeval with folding. It is thought that intrusion of Kubor Granodiorite plutons and consequent development of hornfelses was a later event. This is indicated by the narrowness of the contact aureoles containing the hornfelses, and by the absence of metamorphic minerals and textures in the bulk of the Kubor Granodiorite.

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UPPER PERMIAN or TRIASSIC

Kuta Formation (name varied)

Definition

Rickwood (1955, p.69) used the name "Kuta Group" for a sequence of Permian? (Glaessner et al., 1950) calcareous arkoses, limestones, and shales which unconformably overlies the Kubor Granodiorite and Omung Metamorphics. The unit is overlain by Upper Jurassic Maril Shale and/or Lower Cretaceous Kondaku Tuff. The type area of the "Kuta Group" is near Kuta village (145°13'11"E, 5°55'00"S), at the western closure of the Kubor Anticline. No attempt was made by Rickwood to map any sub-units within the "Kuta Group", nor was any subdivision of the unit made in the 1968 BMR mapping. Therefore the Permian limestone and arkose are here renamed Kuta Formation in accordance with the Australian Code of Stratigraphic Nomenclature.

Distribution and thickness

The largest exposure of the Kuta Formation is along the crest of the range from just east of Kuta south to latitude 6°10'S, at the western end of the Kubor Anticline. Smaller exposure have been mapped on Mount Oga (Figs. 5 and 44), and at three localities on the southern 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 (144°45'E, 5°59'S), and near Gurumugl in the upper Wahgi Gorge, 20 km west of Kundiawa.

The Kuta Formation attains a maximum thickness of about 250 m in the area southeast of Kuta; elsewhere it ranges in thickness from about 30-40 m near the Korman River, to about 100 m in the Gurumugl area (west of Kundiawa). Limestone makes up the bulk of the unit; arkose and shale total only a few metres in thickness.

Stratigraphic relationships

The Kuta Formation rests with marked angular unconformity on the Kubor Granodiorite and Omung Metamorphics. The base of the formation contains or is entirely made up of detritus from the underlying rocks. Upper Jurassic Maril Shale in part overlies the Kuta Formation, which has an irregular upper surface. At various places, such as in Tobe Creek (21 km SE of Mount Hagen) and on the Wahgi River, 10 km west of Kundiawa, the Jurassic is missing, and the Lower Cretaceous Kondaku Tuff overlies or abuts against the Kuta limestone.

Age

Microfauna from the limestones near Kuta were reported by Glaessner to be Permian (Glaessner et al., 1950). The foraminifera

Pachyphloia and

Geinitzina

were identified.

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Fauna collected by Rickwood (1955) from the Kuta Limestones at various localities included:

Dielasma cf. *elongatum* (Schlotheim)

Dielasma cf. *itiatubense* Derby

Dielasma sp.

Spiriferina sp.

Rhynchonella sp.

Streptorhynchus cf. *pyramidalis* King

Marginifera sp.

Fistulotrypa sp.

Pseudomonotis sp.

Gastropod gen. et sp. indet.

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., 1970) has identified the foraminfera

Geinitzina and

Robuloides

from locality 21NG2571, near Gurumugl Rest House (144°47.5'E, 6°3'S), and places them tentatively in the Upper Permian. A rhychonellid brachiopod from the same locality is considered by K.S.W. Campbell (pers. comm., 1970) to be Triassic or Permian. Although he likens it to a New Zealand Triassic species, he does not consider it diagnostic. A collection of fauna from the Kuta Formation, made in June 1970, included a variety of brachiopods, ammonites, corals, polyzoa, and gastropods. From a preliminary examination, K.S.W. Campbell, J.M. Dickins, S.K. Skwarko, and D.L. Strusz conclude that the fauna has a time range which straddles the Permian-Triassic boundary.

Lithology

In the Kuta-Mount Oga area, the Kuta Formation consists largely 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 upward into limestone; in other places the basal basalt is missing. At point 20NG2688, 10.4 km SSE of Mount Hagen town, the Kuta Formation consists of massive pale grey crystalline limestone which dips west at about 5°. In Momai Creek, southeast of Kuta (about 13 km SSE of Mount Hagen), Kubor Granodiorite, hornfelsed Omung Metamorphics and red to multicoloured volcanic rudites are unconformably overlain by coarse arkose which grades upward 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 The limestone dips at 45° to the west, and is overlain by Kondaku Tuff which dips at 38° to the southwest; this limestone bed was downfaulted into the granitic basement before deposition of the Kondaku Tuff.

On the western side of the Kaip Valley, 10 km east-southeast of Mount Hagen, a bed of massive, dark grey limestone which dips northwest directly overlies granodiorite, and is overlain by dark grey shale and siltstone, probably of the Maril Shale.

Across the valley, on Mount Oga, the Kubor Granodiorite and the Omung Metamorphics are overlain by about twenty feet 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 south road, close to the Wahgi River, is made up of pale grey to buff, coarse to fine-grained crystalline limestone which contains scattered sandy granitic detritus. A larger exposure, on the eastern side of the Wahgi River is fossiliferous, very pale grey to buff fine-grained limestone. Five kilometres farther east, also close to the main road, is a small exposure of buff to grey medium to fine-grained crystalline limestone with scattered granitic detritus and small brachiopod remains.

Several prominent limestone masses on the northeast flank of the Kubor Anticline, between the Omung River and Neragaima Mission (144°47'E, 6°02'S), were mapped by Rickwood (1955) as lenses within the Upper Jurassic Maril Shale. However, detailed examination in 1968 revealed that these masses are biohermal reefs which rest on a layer of arkose unconformably overlying Kubor Granodiorite, and are overlain by Maril Shale. The limestone is grey and compact, similar to that at the type locality.

Near Minj, calcareous arkose and limestone typical of the Kuta Formation grade laterally into calcareous breccias containing fragments of metamorphic rocks (Rickwood, 1955). A thin shale (or phyllite) breccia unit, which immediately underlies the Maril Shale where it laps over the Omung Metamorphics, was correlated with the Kuta Formation by Rickwood. It is more likely that this is a basal part of the Maril Shale, derived from the underlying Omung Metamorphics and Kubor Granodiorite. If the breccia were Permian or Triassic, the outcrop pattern of such a thin unit would be discontinuous as a result of the extensive erosion which has removed most of the Kana Volcanics from the Kubor Anticline. However, the breccia is almost continuous beneath the Maril Shale, with no intervening Kana Volcanics.

Structure

Generally, the Kuta Formation is gently dipping and only slightly folded. Near Kuta, on Mount Oga, and in the Gurumugl area, dips are less than 10°; on the western side of the Kaip valley and farther south along the range, faulting has steepened the dips to as much as 45°.

Origin

The presence of coarse basal arkose, brachiopods, gastropods, corals, polyzoa, crinoids, foraminifera, and granitic detritus in the limestone all indicate shallow-water or shelf deposition. Both near Kuta

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and near Gurumugl, the limestone covers an irregular granitic basement. The Kuta Formation does not occur at elevations greater than 2,750 m in the Kubor Range, and it is concluded that the limestone was deposited as fringing reefs on granitic wash and on breccia derived from the adjacent Palaeozoic basement.

Kana Volcanics

Nomenclature

Dow and Dekker (1964, p. 12) proposed the name 'Kana Formation' for Upper Triassic sediments of volcanic derivation exposed in the headwaters of the Jimi River to the north of the map (Plate 1). In that area the formation consists of at least 600 m of interbedded feldspathic arenite and tuffaceous siltstone together with some beds of dacite pebble conglomerate and minor quartz arenite and limestone. It conformably overlies the Jimi Greywacke, also of Upper 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 an Upper Triassic age (Skwarko, 1967, p. 46).

The formation was subsequently renamed Kana Volcanics by Dow et al. (1968, p. 24) who recognized the high volcanic content of the unit in areas outside the Jimi River headwaters, notably the Yuat River area and near Tabibuga in the Jimi Valley. We have retained the name Kana Volcanics as our mapping has confirmed that the unit as a whole is characterized by volcanic rocks.

Distribution and thickness

The greater part of the Kana Volcanics crops out to the north of the map area in the Jimi Valley and on the Jimi-Wahgi divide. The formation is exposed extensively but discontinuously from the Jimi River headwaters along the length of 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 map area. Dow and Dekker (1964, p. 23) described basic volcanics on Mount Udon at the eastern end of the Jimi-Wahgi divide, which they were unable to relate to other formations. We have tentatively correlated these with the Kana Volcanics on the basis of their description.

Volcanic rocks, almost certainly correlatives of the Kana Volcanics, form conspicuous cappings on the summit ridges of the Kubor Range between Mounts Digini and Sigul Mugal. Outliers have also been photo-interpreted on some of the southern spurs of the range.

The formation is 3,500 m thick in the Chimbu River type section and at least 2,500 m thick in the area north of Banz. On the Kubor Range the thickness ranges between 200 m and 700 m.

Lithology

The Kana Volcanics encompass a variety of rock types ranging from lavas and pyroclastics to epiclastic sediments of volcanic derivation. Lavas and pyroclastic rocks are largely of andesitic and dacitic composition, although there is an overall range from basaltic to rhyolitic types.

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Sediments appear to be composed mainly of intermediate to acid volcanic detritus. In general, lavas and pyroclastic rocks (encluding breccia and agglomerate) are subordinate to epiclastic rocks but the proportion varies widely from one area to another.

In many areas the Kana Volcanics can be recognized by an abundance of red and green rocks. The most widespread of these are tuffs or fine-grained, tuffaceous sediments, whose colours may be described as brick-red, maroon, purple, purplish-red, or pink. Green or greenish-grey equivalents are also rather common. Volcanic breccias and agglomerates may be green, red, or a mixture of red and green clasts; volcanolithic conglomerates are characteristically red or brown. Lavas are commonly green owing to secondary alteration to chlorite and epidote but red hematitic varieties are also present.

The Chimbu River section was described by Dow et al. (1968, p. 26) who nominated it as the type section. The sequence in stratigraphic order is as follows (after Dow et al., 1968).

TOP

600 m — 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 dacitic rocks in a reddish-purple tuffaceous matrix. Some rare basaltic pebbles. Grades upwards into green and reddish-purple feldspathic sandstone containing rounded pebbles of porphyritic andesite and some calcareous nodules. Medium-bedded. Contains some beds of red tuffaceous siltstone and dacite-pebble conglomerate similar to the underlying beds. Top probably faulted against Balimbu Greywacke.

180 m — Red tuffaceous siltstone and shale. Small quartz and feldspar grains can generally be distinguished in the coarser varieties. Massive, jointed, unbedded, band of dark grey sheared phyllite near top.

180 m — Green basaltic agglomerate and interbedded basalt-pebble and cobble conglomerate. Basalt green and highly epidotized in places.

1820 m — Mostly well bedded crystal tuff and tuffaceous sandstone consisting of graded beds 5 to 60 cm thick grading upwards into light-coloured shale and siltstone. Appear to be mostly acidic. Some dacitic lavas and agglomerate, and rare dacite pebble conglomerate. Intruded by dolerite and gabbro.

750 m — Poorly exposed and intruded by many dykes of altered dolerite and gabbro, so original rock type not readily apparent. Some green, highly altered fine-grained basic rocks which are probably basaltic lava flows. Only other rock seen is bedded andesitic crystal tuff similar to the overlying volcanics. Intruded by the Bismarck Intrusive Complex; bottom of sequence may be absent.

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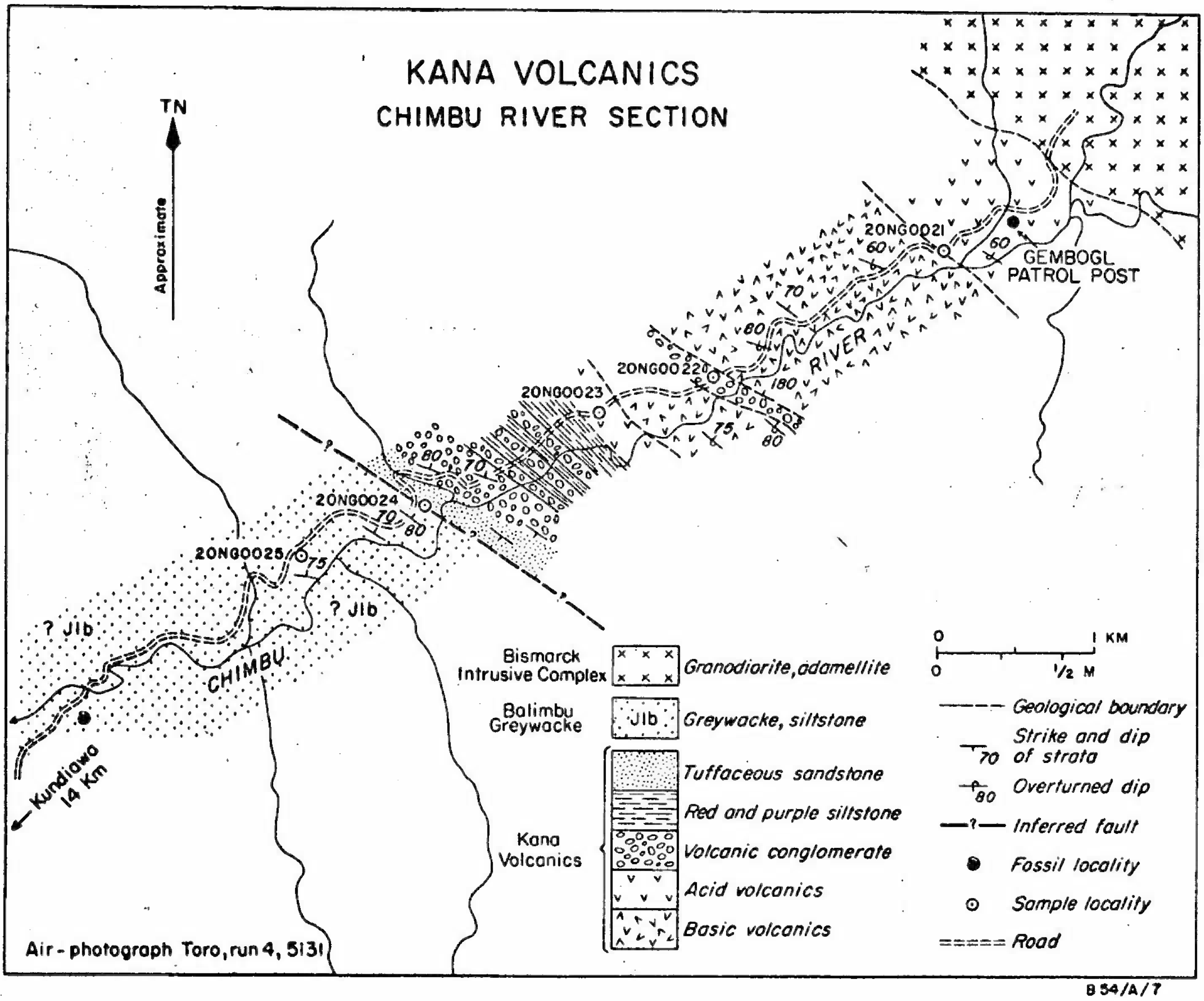
KANA VOLCANICS
CHIMBU RIVER SECTION
TN
Approximate
20NG0021
20NG0022
20NG0023
20NG0024
20NG0025
GEMBOGL
PATROL POST
RIVER
CHIMBU
? Jlb
Kundiawa
14 Km
Air-photograph Toro, run 4, 5131
Bismarck Intrusive Complex
Granodiorite, adamellite
Balimbu Greywacke
Greywacke, siltstone
Kana Volcanics
Tuffaceous sandstone
Red and purple siltstone
Volcanic conglomerate
Acid volcanics
Basic volcanics
0 1 KM
0 1/2 M
Geological boundary
Strike and dip of strata
Overturned dip
Inferred fault
Fossil locality
Sample locality
Road
B 54/A/7

FIGURE 12a

A stream section through part of the formation 7 km southeast of the Chimbu River section exposes volcanolithic, feldspathic and tuffaceous sediments. Much of the section consists of hard, grey, green, or pink sandstone interbedded with red or grey tuffaceous siltstone and shale. These rocks may be massive or thinly interbedded and finer lithologies exhibit graded bedding in some places. The sandstones contain rare calcareous beds up to 10 cm thick, and in two of these, poorly-preserved bivalves, gastropods, and brachiopods were found. In places, the sequence contains massive beds of volcanolithic conglomerate which consists of well rounded pebbles and cobbles of porphyritic andesite and dacite in a grey or red tuffaceous matrix. Green, massive andesite was found in one outcrop near the top of the sequence, but lavas are otherwise absent. Also noted were 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; red limestone and fossiliferous red shale were also seen. No outcrop was seen in the headwaters of the Koro River, but abundant float indicates that the formation is present. Farther downstream in the same river, green lavas of the Kana Volcanics crop out over a short section. On Mount Udon, Dow and Dekker (1964) reported 600 m of dolerite with some andesite grading upwards into 600 m of basalt, agglomerate, greywacke, and siltstone.

Intermediate lavas and pyroclastics predominate on the Kubor Range; outcrop on Mount Digini is mainly fine-grained grey or green lava and minor agglomerate. In the vicinity of Mount Kubor, agglomerates and massive flow-banded or brecciated lavas are extensively chloritized and epidotized. One outcrop of agglomerate appeared to contain fractured remnants of pillow lava, suggesting subaqueous eruption. Other rock types include epiclastic volcanic breccia, volcanolithic and feldspathic sandstone, and fine-grained grey or green tuff. In hand specimen many lavas from the Kubor Range appear to be amygdaloidal. In thin section the 'amygdales' are commonly seen to be patches of an unidentified white mineral replacing plagioclase laths.

Stratigraphic relationships and age

To the north, in the Jimi and Yuat Rivers, the Kana Formation conformably overlies slightly older Triassic sediments. In the Jimi River headwaters, Dow and Dekker (1964) found that the base was usually marked by volcanolithic conglomerate, and that where the conglomerate was absent there was a downwards transition into Jimi Greywacke lithologies. 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 by the Lower Jurassic Balimbu Greywacke or its equivalent, and the relationship is thought to be unconformable.

Within the map area, similar stratigraphic relationships appear to hold to the north of the Wahgi Valley, although the structure there is complex. The Chimbu River section is overturned; the base of the formation is intruded by the Bismarck Intrusive Complex, and the top appears to be faulted against overturned Balimbu Greywacke (Fig. 12a).

In the Kubor Anticline, the volcanics rest unconformably on Kubor Granodiorite and Omung Metamorphics. Upper Jurassic Maril Shale overlies the formation 20 km north of Mount Hagen, and possibly on the southern limb of Kubor Anticline, west of the Mogono River.

Fossils collected from a few localities in the Bismarck Fault Zone were too poorly preserved, or were otherwise unsuitable for precise dating. Skwarko (1967, p. 43) recorded Costatoria cf. melanesiana, Rhaphistomella? kumbrufensis and Spiriferina cf. abichi from locality H590 (of Dow and 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 units on palaeontological grounds, and thus the age of the Kana Volcanics is given as Upper Triassic.

Petrography

Specimens from the Chimbu River type section include lava, agglomerate, tuff, volcaniclastic sediments, and a microdiorite porphyry. The composition of volcanic constituents ranges from basaltic to rhyolitic, but is predominantly dacitic to rhyodacitic. All specimens have suffered low-grade metamorphism, and in most the original feldspar is albitized. Chlorite and epidote are common; calcite, actinolite, biotite, and muscovite are less so. The metamorphic grade decreases from epidote-amphibolite facies close to the Bismarck Intrusive Complex to lowermost greenschist facies at the downstream contact of the section. This suggests that metamorphism accompanied intrusion of the adjacent plutonic mass. A chloritized augite andesite pebble and a biotite dacite cobble from a volcanolithic conglomerate were identified from Geirinigl Creek (Plate 7).

Specimens from north of Banz include volcanic breccia and arenite. The breccia is composed of poorly sorted, angular, and commonly vesicular lava fragments ranging from finely comminuted sandy matrix material to clasts of 10 cm diameter or more. The clastic volcanic material is principally andesitic and dacitic; most primary textures are preserved but feldspars are albitized and the rocks as a whole are altered to chlorite, albite, epidote, and calcite. Some clasts appear to have had glassy rims (e.g., 20NG0608). In specimens with 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 extensive recrystallization to greenschist mineral assemblages, the original compositions of lavas from the Kubor Range are somewhat uncertain. Most appear to have been andesite but some were probably basalt or dacite. Plagioclase laths are albitized, and commonly define a subophitic or trachytic texture. Quartz is abundant in examples that were probably dacitic or rhyodacitic, and sericite is present where the rock originally contained potash feldspar. Olivine phenocrysts, now altered to ?chlorite, were tentatively identified in basaltic specimens from Mount Digini (21NG2752) and Mount Kubor (21NG0024). Specimens of volcanolithic and tuffaceous sediments from the Kubor Range are similar to those already described, although some contain metasedimentary clasts.

Provenance and depositional environment

The Kana Volcanics are composed almost entirely of the products of basic to acid volcanism, and include both primary source rocks and transported derivatives. Most, if not all, of the epiclastic sediments were deposited in a marine environment, but some lavas and pyroclastics were subaerial. The presence of massive beds of volcanolithic conglomerate points to subaerial erosion, although the beds may have been laid down offshore. Features such as glassy rims on volcanic clasts and pillow forms in agglomerate suggest that some volcanism may have been submarine.

The Kana Volcanics were probably deposited in and around volcanic islands that were built up on the northern margin of the Australian continent in the Upper Triassic.

JURASSIC

Balimbu Greywacke

The name Balimbu Greywacke was proposed by Dow and Dekker (1964, p. 14) for interbedded greywacke and siltstone of Lower Jurassic age which crops out in the headwaters of the Jimi River to the north of the map area. The type section is exposed in Balimbu Creek on the northern limb of the Kol Syncline. There, the formation is about 300 m thick. Balimbu Greywacke unconformably overlies 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; and report in prep.).

Within the map area, rocks correlated with the Balimbu Greywacke have been mapped in three areas to the north of the Wahgi Valley: in the Chimbu River, in the Koro (Kworu) River, and along the southern fall of the Jimi - Wahgi divide between Banz and Nondugl. All three areas lie within the Bismarck Fault Zone. Balimbu Greywacke also crops out above Kana Volcanics and directly beneath Maril Shale on the northern side of the Jimi-Wahgi divide between the Tsau River and Gai River (north of the map area). Lower Jurassic fossils from the divide between the Yuat and Maramuni Rivers suggest that the Balimbu Greywacke may crop out up to 140 km northwest of the type area (Skwarko, in prep; Dow et al., in press).

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

The Koro River sequence was re-examined in 1968. The principal rock types are dark blue-grey sandstone*, dark grey siltstone, and shale.

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* The term sandstone is used in preference to greywacke as the rocks are not particularly matrix-rich, and do not display turbidite structures.

The sandstone is typically well bedded, indurated, and moderately jointed. Detritus is predominantly lithic-feldspathic, and appears to be largely of volcanic origin. Grainsize ranges from fine sand to grit. Carbonaceous fragments are common, if not characteristic. Thinly bedded to massive shale and siltstone are interbedded with the sandstone; they make up less than half the sequence. In some outcrops the finer lithologies have a tuffaceous appearance.

A very large (about 20 cm long), but poorly preserved belemnite was found in shale near Bogo Rest House (20NG2635), close to the Koro River ammonite locality (H549) of Dow and Dekker (1964). This was subsequently examined by G.R. Stevens, of the New Zealand Geological Survey, who was unable to provide a positive identification. However, similar large belemnites are known from the Lower Jurassic in other parts of the world. Also noted were sinuous worm trials on a bedding plane in sandstone.

The Koro River sequence appears to overlie the Kana Volcanics to the southwest and to underlie the Maril Shale to the northeast without the interposition of the Mongum Volcanics. One or both contacts may be faulted, and the sequence as a whole is structurally complex with numerous faults and divergent bedding attitudes. From available data it seems that the Koro River sequence is a southeastern extension of the Balimbu Greywacke on the southern limb of the Kol Syncline. The probable minimum thickness is 1500 m.

Rocks correlated with the Balimbu Greywacke crop out in the Chimbu River 15 km northeast of Kundiawa (Dow et al., 1968, p. 25). Greywacke, siltstone, and shale form a 1500 m thick, overturned sequence dipping steeply northeast. The sequence is faulted against overturned Kana Volcanics to the northeast, and overlies overturned Maril Shale to the southwest. Apart from incipient metamorphism, the rock types are similar to those exposed in the Koro River. Siltstone and shale are strongly cleaved. In places the sequence is intruded by dolerite dykes up to several metres thick. Bivalves and a poorly preserved ammonite were collected from within 200 m of the contact with the Maril Shale (20NG0561), but these have proved to be indeterminate.

On the southern side of the Jimi-Wahgi Divide, the Balimbu Greywacke has been interpreted as occupying a fault bounded strip trending southeast from north of Banz towards Kerowagi. Lithologies are similar to those of the Balimbu Greywacke elsewhere but, in the absence of fossils and clear stratigraphic relationships, the correlation is somewhat tentative. Conceivably, other Mesozoic formations may also be present. The strip is faulted against Cretaceous rocks to the south and against Kana Volcanics to the north. Strata dip moderately to steeply northeast, and the thickness is of the same order as that estimated for the Koro and Chimbu River sequences.

The formation is absent within the Kubor Anticline. This is probably due to emergence of this area during the Lower Jurassic, as evidenced by the fact that the Maril Shale rests unconformably on the Kana Volcanics and older rocks. Alternatively, but less probably, the unfossiliferous lower portion of the Maril Shale in this area could be equivalent to the Balimbu Greywacke.

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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. Detritus was derived largely from pre-existing volcanic rocks (Kana Volcanics?) and possibly from contemporary volcanism, as some rocks appear to be tuffaceous.

Mongum Volcanics

The Mongum Volcanics were first described by Dow and Dekker (1964, p. 15) from the Kol Syncline, in the headwaters of the Jimi River. In that area the formation overlies the Lower Jurassic Balimbu Greywacke, and underlies the Upper Jurassic Maril Shale. The type section is on the northern limb of the Kol Syncline, 2 km north of Mongum Village. According to Dow and Dekker, the formation comprises green basaltic agglomerate and pillow lavas interbedded with pebble-cobble conglomerate and tuffaceous greywacke; it is 250 m thick in the type area. From its stratigraphic position, Dow and Dekker inferred a Middle Jurassic age but Lower or Upper Jurassic ages are also possible*. Fossils from the type area were too poorly preserved to be identified.

The Mongum Volcanics crop out on both limbs of the northwest-trending Kol Syncline. Only a small part of the exposure on the southern limb occurs within the map area - to the northeast of Mount Udon. Here the formation dips steeply northeast and appears to be no thicker than in the type area. Its boundaries are interpreted from airphotos and from field observations by Dow and Dekker in 1962; the area was not revisited in 1968.

The Mongum Volcanics do not appear in the Koro River sequence, which is an extension of the southern limb of the Kol Syncline. This is probably due to thinning or faulting-out 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 basic volcanics underlying Maril Shale in the Maramuni River (Dow et al., 1968; in press) the Mongum Volcanics appear to be restricted to the Kol Syncline.

Maril Shale

Definition

Following Noakes' (1939) tentative subdivision of the Chimbu River-Wahgi Gorge sequence, Edwards and Glaessner (1953, p. 97) proposed the name 'Maril Shales' for the basal unit of 'siliceous and calcareous shales'. Fossils collected by Noakes had been examined by Glaessner (1945), who identified the Upper Jurassic bivalve 'Buchia' malayomaorica. Rickwood (1955) subsequently mapped the 'Maril Shales' around the eastern end and northern flanks of the Kubor Anticline.

In earlier descriptions, the formation's upper and lower boundaries were not specifically defined. In the Wahgi Gorge type section,

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

we place the bottom at the unconformity with the underlying Omung Metamorphics and the top at the incoming of volcanolithic sediments characteristic of the overlying Kondaku Tuff. We have used the name Maril Shale (singular) in line with current practises of stratigraphic nomenclature, and following the usage of Dow and Dekker (1964).

Distribution and thickness

Recent mapping by the Bureau of Mineral Resources (e.g., Dow and Dekker, 1964; Dow et al., 1968) has shown that the Maril Shale crops out in a zone extending from the Kubor Anticline, 220 km northwest to the Maramuni River in the South Sepik region. Within the map area, the Maril Shale is exposed mainly around the basement core of the Kubor Anticline and in the Bismarck Fault Zone to the north of the Wahgi Valley.

The Maril Shale is thickest at the eastern end of the Kubor Anticline. Proceeding westwards along the northern limb, the thickness diminishes from 1200 m in the Wahgi Gorge to about 400 m in the Omung River; it remains roughly the same in the Minj, Tuman and Korman (Komun) Rivers and lenses out beneath the Kondaku Tuff 8 km southeast of Mt Hagen. On the southern limb, the formation is about 1500 m thick in Olefa Creek, 7 km west of Gumine; it thins to an estimated 1000 m in the Mogono River, and pinches out altogether 30 km farther west. It reappears surrounding a small window of Kubor Granodiorite in the Wembo River, 25 km south of Mt Hagen, but is otherwise absent at the western end of the anticline. Small outliers cap the summits of Mt Oga and Mt Mani at the northwestern end of the Kubor Range.

The Maril Shale also crops out overlying older rocks at the northwestern end of the Wahgi Valley. Only a small part of this occurrence falls inside the map area: the main exposure lies to the northwest in the Kuni and Muga Rivers (corresponding to the 'Kileng Hill' area of Rickwood, 1966), where the thickness is at least 1200 m.

In the Bismarck Fault Zone, a belt of Maril Shale extends from Gorgme, in the Chimbu River, to the Kol Syncline north of Mt Udon. The stratigraphic thickness is uncertain owing to extensive faulting, but Dow and Dekker (1964) gave a figure of 1000 m for the formation in the nose of the Kol Syncline, just north of the map 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 area of exposure lies to the north and northwest of the map area. A broad, almost continuous belt extends from the Tsau River, along the southern side of the middle Jimi Valley, and across the Gai River to the Maramuni River, a total distance of 180 km. In the Tsau River the thickness exceeds 2000 m. A similar thickness is reported in the Maramuni area (Dow et al., 1968).

Topography

Areas occupied by Maril Shale generally have a well developed strike-ridge and dip-slope topography. Dip slopes are particularly prominent on the northern flank of the Kubor Anticline where an arkose member forms V-shaped 'flat irons'. Resistant parts of the formation tend to be scarp-forming in areas of subhorizontal or gentle dips.

Lithology

The Maril Shale is typified by dark-grey, moderately-indurated shale and siltstone with variable mica and carbonate content. Outcrops may be either massive or well-bedded, but they commonly have two well developed sets of joints at a high angle to bedding and to each other. Flaggy parting parallel to bedding is also common. A characteristic feature of the calcareous shale and siltstone is the tendency of weathered surfaces to disintegrate into small blocky fragments.

Parts of the Maril Shale (especially 8 km west of Gumine and 2 km south of Neragaima) include pyritic and carbonaceous shale and siltstone. Pyrite occurs as concretions up to 30 cm in diameter, as thin lensoid masses, or finely disseminated grains. Where pyritic, the sediments are usually dark and carbonaceous. A 2 cm thick, lensoid mass of schungite, a vitreous carbon mineraloid with a high TiO_2 content, was collected from the Maril River by inhabitants of the Gumine area.

The formation also contains subordinate beds of fine to medium-grained sandstone up to 2 m thick, but commonly about 10 cm thick. Minor beds of grey to dark grey calcilutite occur widely, and red or green shales have been noted at various localities.

In the Kubor Anticline, the base of the Maril Shale is generally marked by up to 20 m of breccia-conglomerate (see also p. 16), poorly sorted, angular to subrounded clasts of slate, phyllite, metagreywacke, and granodiorite derived from the underlying basement, as well as clasts of shale, greywacke, quartz, sandstone, chert, limestone, and volcanic rocks. The matrix may be siltstone, sandstone, grit or limestone. The basal rudite grades locally into coarse arkosic sandstone where the formation overlies Kubor Granodiorite.

Between the Wahgi Gorge and Omung River on the northern limb, up to 200 m of arkose forms a resistant member in the middle part of the formation. This consists mainly of hard, light grey, arkosic sandstone which may be either massive, or well bedded. Ripple marks, cross-bedding, plant fragments, and worm trails are locally present. The arkose is interbedded with minor shale, calcareous sandstone, and calcarenite.

At a number of localities on the northern limb, the Maril Shale contains isolated small brecciated flows of green or grey, amygdaloidal lava interbedded with the sediments. Pillow lavas were noted at one point on the road between Gurumugl and Neragaima mission (Locality 21NG2581). Thin beds of volcanic breccia and fine tuff commonly occur in proximity to the flows, and feeder dykes were also noted.

In the Wahgi Gorge, the formation is intruded by a 15 m thick sill of diorite (Kera Sill p. 68), and similar sills are also known to intrude the Maril Shale 20 km northeast of Mt Hagen and in the Tsau River (north of the map area). These may be related to the small flows.

The basal parts of the formation at the eastern end of the anticline include some large lenses of limestone up to 70 m thick. Boulders derived from a large lens west of the Gumine-Kundiawa road consist of fine-grained dark grey limestone with conspicuous echinoid plates. Some boulders are crowded with phyllite clasts derived from the underlying metamorphic rocks.

Stratigraphic relationships and age

In most places around the Kubor Anticline, the Maril Shale rests unconformably on the Omung Metamorphics or Kubor Granodiorite. At the northwestern end, the formation locally overlies thin limestone of the Permian-Triassic Kuta Formation, and in the Gurumugl area, 15 km south of Kerowagi, it abuts partly exhumed biohermal reefs of the Kuta Formation. It unconformably overlies 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, in some areas with apparent conformity, but in others with slight angular unconformity.

In the Kol Syncline, the Maril Shale conformably overlies the Mongum Volcanics and is overlain, possibly unconformably, by Kondaku Tuff (Dow and Dekker, 1964, p. 16). To the southeast in the Koro and Chimbu Rivers, the Mongum Volcanics are absent, and the Maril Shale rests with probable unconformity on Lower Jurassic Balimbu Greywacke, although the relationship is not known with certainty.

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

Rickwood (1955) recognised '*Buchia*' *malayomaorica* (= *Malayomaorica m.*) from a number of localities along the northern flank of the Kubor Anticline. His supposition that these represented a single horizon within the formation was not supported by our observations. However, fossils from this area commonly occur in a distinctive red calcareous siltstone in the middle of the formation (cf. Edwards and Glaessner, 1953, p. 98) which quite probably represents a discrete time horizon. Elsewhere in the Kubor Anticline the fauna has been noted at a number of localities in the middle and upper parts but not from lower in the formation. Thus there is a possibility that the base of the formation may be Middle Jurassic or even older.

Petrography

A representative suite of thirty five specimens from the Maril Shale was examined in thin section.

The shale and siltstone that form the bulk of the formation contain poorly sorted, angular to subrounded grains of quartz, feldspar, muscovite, biotite, fine-grained volcanic rocks, and chert, in order of decreasing abundance. Much material is too fine-grained to be identified but calcite, sericite, clay minerals, and opaque matter are usually present.

Carbonate mud, bioclastic debris, and calcareous microfossils are present in various amounts. With increasing carbonate content, the fine-grained sediments grade into impure calcilutite.

Arenite specimens are typically quartzo-feldspathic or arkosic. Arkose specimens from the northern limb of the Kubor Anticline are very compact, and consist of angular to rounded quartz and feldspar clasts in approximately equal proportions (60-80% of total), muscovite, biotite, rock fragments, and very little matrix. Feldspars are sodic plagioclase, orthoclase, and microcline. Rock fragments are mainly fine-grained basic to intermediate volcanics and fine-grained metasediments (phyllite and slate). Minor detritus includes myrmekite, epidote, zircon, hematite, sphene, and opaques. Burial metamorphism has resulted in some recrystallization of quartz and plagioclase (albitization) and the growth of sericite and possibly stilpnomelane(?). Sandstones from elsewhere in the formation are generally similar but tend to be quartzo-feldspathic rather than arkosic, and the proporation of matrix and rock fragments is high in many specimens.

In thin section, the minor lava flows from the northern limb of the Kubor Anticline appear to be andesite and dacite, but most are very altered. In less altered examples the plagioclase is oligoclase-andesine, and some potash feldspar may be present. Augite occurs in two specimens, but in most the feromagnesian minerals are completely altered to epidote, chlorite, and calcite, and the plagioclase is albitized. Calcite commonly occurs as patches replacing feldspars: up to 70 percent of the rock may consist of calcite, which may have been introduced from the surrounding sediment during diagenesis. Quartz phenocrysts have been identified in two specimens that may have been dacites. Amygdales are filled with chlorite or calcite.

Two specimens of fine-grained vitric tuff from close to an intermediate lava flow on the northern limb of the Kubor Anticline (11 km southwest of Kundiawa) were found to consist largely of devitrified glass shards, with some detrital quartz and feldspar. The shards have been altered to chlorite, albite, calcite, leucoxene, and opaques; calcite makes up 40 percent of one specimen.

Edwards and Glaessner (1953, p. 109) described two radiolarian cherts from the upper third of the Maril Shale in the Wahgi Gorge, but no chert samples were collected by us.

The Maril Shale is relatively unaffected by burial metamorphism. Laumontite and prehnite, which are abundant in the volcanolithic and tuffaceous sediments of the overlying Kondaku Tuff and Chim Formation (page 32) have not been recognized in the Maril Shale. This is probably due to the general paucity of volcanic detritus in the Maril Shale, and also 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

Detritus in the Maril Shale appears to have been derived largely from granitic and metamorphic rocks, but there has also been some contribution from pre-existing volcanic rocks (Kana Volcanics, Mongum Volcanics). The most likely source is the pre-Mesozoic basement of the Highlands and Western

Papua which is locally represented by the Kubor Granodiorite and Omung Metamorphics. In contrast with the overlying Cretaceous sediments, contemporary volcanism has played only a minor part.

The fine-grained calcareous sediments of the Maril Shale were deposited in a marine shelf environment during a period of relative tectonic and volcanic quiescence. Except for the basal breccia-conglomerate and arkose lenses in the vicinity of the Kubor Anticline, coarse sediments are generally absent, suggesting that the bulk of the formation was deposited at some distance from land, or that land, if present, was of subdued relief. The axis of the Kubor Anticline may have been emergent in places. The arkose member on the northern limb contains terrestrial plant fragments, cross-bedding, and ripple marks suggestive of a partly terrestrial environment. This may indicate subaerial erosion of emergent islands of Kubor Granodiorite.

Sedimentation was very extensive in the Upper Jurassic. Apart from the areas of Maril Shale, Upper Jurassic sediments appear to underlie much of the Western Highlands and Western Papua where they have been located in petroleum exploration wells (Australian Petroleum Company, 1961). In the Western Highlands, fine-grained marine sediments containing <u>Malayomaorica</u> have been reported from the Wok Feneng, a tributary of the Fly River (Kuabgen Group; Osborne, 1945) and also from the Strickland Gorge (D. Jenkins, British Petroleum Australia, pers. comm.). Thick marine sediments in the Telefomin area contain ammonites of Upper Jurassic age (Australasian Petroleum Company, 1961) and <u>Malayomaorica</u> occurs in the Sitipa Shale in the April River area (Dow et al., 1968).

CRETACEOUS

Kondaku Tuff

Definition

The name 'Kondaku Tuffs' was first used by Edwards and Glaessner (1953) for the basal sandy part of the Cretaceous in the section along the Wahgi and Chimbu Gorges which Noakes (1939) measured. 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 is here amended to Kondaku Tuff to conform with the Australian Code of Stratigraphic Nomenclature. The base of the unit is distinguished from the Maril Shale by the occurrence of volcanic detritus in green sandstone, the top by a massive tuffaceous sandstone bed overlain by dominantly shaly sediments. The formation contains fossils of Lower Cretaceous age.

The Kondaku Tuff is characterized by prominent ridges and dip-slopes formed on resistant sandstone and tuff beds. These beds have exercised some control over drainage, resulting in areas of well developed rectilinear stream patterns.

Distribution and thickness

The Kondaku Tuff is exposed continuously around the periphery of the Kubor Anticline. The formation extends from the foothills (about 2,200 m a.s.l.) outwards into the Wahgi, Nebilyer, and Kaugel valleys, south into Mount Suaru area, and southeast to the Asaro River. Kondaku Tuff is exposed in two areas in the Jimi-Wahgi divide, one to the northwest and the other to the northeast of Kerowagi. Both are small masses caught up in the Bismarck Fault Zone, and surrounded by older (Triassic and Jurassic) rocks.

Noakes (1939) estimated the thickness of Lower Cretaceous in the Chimbu measured section at 2,000 m, and this estimate was supported by Rickwood (1955). However, more accurate mapping of the Chimbu section in 1968 showed the thickness to be about 2,450 m, and this is a maximum for the formation. The average thickness elsewhere is about 2,000 m, but in many areas the unit is partly repeated by faulting (Wahgi Valley) or folding (southern flanks of the Kubor Range).

Stratigraphic relationships and age

The Kondaku Tuff is underlain by Upper Jurassic Maril Shale. In some places there is clear evidence of angular unconformity; in others there is a paraconformable relationship. In the Wilde River area, on the south-western flanks of the Kubor Range, Kondaku Tuff directly overlies Kubor Granodiorite and Omung Metamorphics. The unit grades upwards into Upper Cretaceous Chim Formation; the contact is marked by the disappearance of massive lithic sandstone beds.

The Kondaku Tuff is probably of Lower Aptian to Albian age; no Cenomanian fossils have been found. Edwards and Glaessner (1953) list the following fauna collected by G.A.V. Stanley near Kundiawa:

Deshayesites n. sp. (Lower Aptian),

Cymatoceras sp.,

fragment of a large phragmacone of

"Belemnites" sellheimi Tenison-Woods, and

Pleuromya sp.,

all of which are Lower Cretaceous. Stanley also collected the following suite of Albian fossils from a locality 18 km southeast of Kundiawa:

Puzosia sp.,

Cymatoceras sp.,

Aucellina gryphaeoides hugendenensis (Etheridge), and

foraminifera, incl. 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 these fauna and flora are similar to those in the Lower Cretaceous Purari Formation of northern Papua.

Rickwood (1955) reported Glomospira sp., Ammodiscus sp., Dorothia sp., Cibicites sp., and Gyroidina sp. from red shales near the base of the Kondaku Tuff.

During the 1968 survey, abundant Ostrea, coiled gastropods, and charred plant remains were found in compact but friable tuffaceous sandstone at numerous localities within the upper parts of the formation.

At localities 20NG2625 and 2626, 18 km west-northwest of Kerowagi, on the Highlands Highway, gastropods, bivalves and belemnites were found in tuffaceous sandstone.

Lithology

The Kondaku Tuff consists largely of grey-green, coarse-grained lithic sandstone or greywacke, tuffaceous sandstone, and dark grey or green-grey shale and siltstone. Conglomerate, amygdaloidal lava, agglomerate, and volcanic breccia make up about 10 percent of the formation, and are concentrated in the lower 500-1000 m of the unit.

Shale and siltstone are the most common but the least prominent rock types in the Kondaku Tuff because of their soft, fissile nature and consequent low resistance to erosion. Interbedded shale and siltstone occur as beds ranging from 1 mm partings in sandstone, to beds up to 100 m thick which contain minor sandstone layers. Shale beds are commonly massive and uniform, though there is some layering in 1 cm bands or 1 mm laminations. Silty beds are mostly banded, in 1-3 cm bands, or finely laminated, with laminae as thin as 0.2 mm. Soft sediment slump deformation is common in these fine-grained beds, and has affected sequences up to 30 m thick. Dark grey to black, fine-grained calcareous nodules (Fig. 15) occur in shale and siltstone, but are larger and less common than similar nodules in the Chim Formation; a few of the nodules contain fossils. The calcareous nodules are ellipsoidal or lenticular, 3-60 cm long (most commonly 15-20 cm), and in many cases display surficial polygonal desiccation cracks and deep gashes filled with white, coarsely-crystalline calcite. Less common features are small (10 to 30 cm long, and 3 to 7 cm thick) lenses of light, powdery buff-coloured material, probably diatomite, and beds of impure limestone up to 20 cm thick. Vague dark streaks and traces of worm(?) burrowings outlined by dark, organic (faecal?) material are also a characteristic feature of the upper 400 m of the Kondaku Tuff. Most of the shale and siltstone consists of clays, feldspar (mainly plagioclase), quartz, and fragments of volcanic rock and altered glass. Calcareous shale containing foraminifera is also common, and contains a high proportion of the calcareous nodules. The shales within the Kondaku Tuff may be distinguished from the otherwise similar Maril Shale by the lesser degree of deformation and induration, the presence of calcareous rather than pyritic nodules and layers, and the abundance of volcanic detritus in the younger shales.

Green or grey-green, spheroidal-weathering lithic and tuffaceous sandstone make up the bulk of the remainder of the Kondaku Tuff. They are more abundant in the lower half of the unit than in the upper, and are also more common in the north of the map area than in the south. Immediately south of the Kubor Range, sandstones make up about 35 percent of the formation. The sandstones form laminated to massive beds from 3-4 mm to 6-7 m thick, and sequences of beds up to 150 m thick. Thinner (1-5 cm) beds are usually regularly interbedded with layers of shale and siltstone of a similar thickness; thick sequences (up to 50 m) of such rhythmically-bedded shale and sandstone are characteristic of the Kondaku Tuff. Thin (1-5 m) pebble-rich layers, scattered angular to rounded black shale fragments (5 mm-10 cm), and sparsely distributed grey limestone clasts (2-7 cm) are commonly seen within the thicker sandstone beds.

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TABLE 1. ESTIMATED COMPOSITIONS OF SAMPLES OF KONDAKU TUFF

Sample Number	Rock type	Quartz (%)	Plagioclase (%)	Potash Feldspar (%)	Rock Fragments (%)	Augite (%)	Hornblende (%)	Biotite (%)	Opaques (%)	Glauconite (%)	Chlorite (%)	Epidote (%)	Calcite (%)	Zeolite (%)	Prehnite (%)	Matrix (%)	Height above base (m.)	Notes
Tuffaceous/volcanolithic sediments																		
21NG 1035B	Tuff. felds.-lith.arenite		20(Ab)	tr.	5	1		tr.	tr.		5(gl)	tr.			40		0	Trace of muscovite
20NG 1254G	Tuffaceous arenite/grit	1	5		5+	1-2			3						10		0	2% glass
21NG 0548A	Felds.-lith. greywacke	tr.		tr.	60(?)	tr.					tr.		5				2,500±	
21NG 1151	" " labile arenite(T)	2-3	15(Ab)		55	5			tr.		5-10(gl)		tr.		10		1,000	
20NG 0599	" " "arenite(T)	2-3	20		60				tr.		10(gl)		2				?	5% leucoxene
21NG 2584A	" " "arenite	7	20	5(S)	55	8-10	3-4		tr.				tr.				1,400	
21NG 1024C	" " "arenite	10	10(Ab)	20	40	20		tr.	tr.							15	0	
20NG 1212A	Qtz.- feldslithic labile arenite(T)	10	15	5	45-50				8		5(gl)		2				top	5-10% leucoxene
21NG 1035C	Felds-lithic greywacke	15	25(Ab)		20	alt.			tr.		15	tr.			20		0	5% tourmaline
20NG 1239	Felds-qtz lithic arenite	15	5		60				1-2	tr.			15				0	
20NG 1254A	Tuff.labile lithic siltstone	15	5-10		50	tr.			10-15		tr.		tr.				0	10-15% alt. glass
21NG 1050A	Tuff. lithic greywacke	15	25		(25)*	20			tr.		25(gl)			2	10	5	0	
20NG 2626A	Calc.lithic labile arenite	15	5		35-40				2	3			35-40				?	
20NG 1254L	Qtz-felds-lithic labile arenite	20	20		55				tr.						5		0(?)	
21NG 1087A	" " " arenite	20	10(Ab)	3	37			1	10	3	1		15				top	
Feldspathic sediments																		
20NG 1295A	Tuff. felds.-lith. labile arenite	3	30(An_{0-30})		40	2	tr.	tr.			5(gl)				20		300	
21NG 1024A	Tuff. felds.-lith.greywacke	5(2°)	40(Ab)	8	10				10		10(gl)		2		15		0	
21NG 1024D	Litho-felds (sublabile) greywacke	10(2°)	60(01)		10	5					5				10		0	
Quartzose arenites																		
20NG 0597	Qtz lithic labile arenite	40	10		40		2	tr.	1-2		5(gl)						?	Trace of sphene
21NG 2610A	Felds.-lith. sublabile arenite	60	15(01-And)	2-3	15				1	2			1				900	
20NG 1295B	Qtz lithic labile arenite	40	10(")		35	5	1		2		5		tr.		1		300	
20NG 1297	" " " arenite	50	10(")		20	2		1	1		1-2		1-2				30	1-2% muscovite
21NG 0607A	Qtz felds.-lith. labile arenite	30	25		25				tr.		10(gl)		5				1,300	Rare zircon
21NG 1101	Calc.felds.qtz arenite	35	3(Ab)	10	tr.			tr.	10	5			35				300-600	Trace apatite
21NG 0544B	Qtz lithic labile arenite	50			30			tr.		tr.			10				1,200	Minor tourmaline
21NG 0544A	Calc.qtz lith.labile "	50	tr(01)		20				2				25			tr.	1,200	Minor muscovite
21NG 0555	" " " " arenite	50	tr(01)		15			tr.		tr.			30				900	Trace muscovite
21NG 1285	Tuff. " " " arenite	50	tr(Ab)		38(glass)				10,	2							600	Trace muscovite

TABLE 1. ESTIMATED COMPOSITION OF SAMPLES OF KONDAKU TUFF (contd)

Sample number	Rock type	Quartz (%)	Plagioclase (%)	Potash feldspar (%)	Rock fragments (%)	Augite (%)	Hornblende (%)	Biotite (%)	Opaques (%)	Glauconite (%)	Chlorite (%)	Epidote (%)	Calcite (%)	Zeolite (%)	Prehnite (%)	Matrix (%)	Height above base (m.)	Notes
Coarse-grained sediments																		
21NG 0558A	Volcanic conglomerate																top	
21NG 1321	Lithic grit	25	5	10	60		tr.			tr.	tr.					tr.	2,200	Trace of garnet
Tuffs																		
21NG 0548B	Zeolitized tuff	tr.	ab(Ab)		alt.	ab.								ab			near top	5 percent brookite
21NG 1366	Altered tuff	25	5(Ab)		5(glass)				tr.		15						900	
21NG 1289	Altered tuff	20	20(Ab)		60(glass)							tr.			10		600	
21NG 1109	Vitric-crystal tuff	5(2°)	35		2-3(glass)				2		25(gl)		30				450	
21NG 1050E	Altered tuff.	25	5(Ab)		5				5		25(gl)				30		0	
21NG 1304A	Altered tuff	tr.	5	5	5(glass)	tr.					10(gl)	1			60		0	
21NG 0531	Altered tuff	15	15	tr.	60(glass)			tr.	2		5		3				0	
Lavas																		
20NG 2612A	Augite andesite		80(An_{33})		—	19			2		5						1,200	Trace apatite; 2% leucoxene
20NG 2612B	Augite andesite		60(An_{28-30})		—	10			3				1				1,200	
20NG 2612C	Augite andesite } Similar to 2612B																	
20NG 2612D	" " }																	
20NG 2610C	Augite andesite " " "																	
20NG 2610B	Altered amygdaloidal lava		40(Ab?)						5-7		3		40				900	
20NG 1167	Met. augite rhyodacite	20	15			10					30	1	2		5		600-900	15percent actinolite
20NG 1169	Met. augite basalt	5	20(Ab)								50		5				300	

Abbreviations used: Ab - albite; ab - abundant; alt. - altered; And. - Andesine; Calc. - calcareous; Felds.-qtz - Feldspathic-quartzose; Felds.-lith. - Feldspatholithic; gl - after volcanic glass; Met. - metamorphosed; Ol. - oligoclase; Qtz - quartzose; Qtz-felds.- Quartzo-feldspathic; S - sanidine; Tuff, T - tuffaceous; 2° - secondary.

Diatomite(?) lenses, layers of lapilli and pumice fragments, highly irregular, contorted sandstone clasts, and, near the top of the unit, layers rich in carbonized plant remains (e.g., locality 21NG1074) or shelly fossils were also recorded. Hornblende fragments up to 1 cm across occur in some coarser-grained sandstones.

Sedimentary structures in sandstone are many and varied. Small-scale cross-bedding in laminated sandstone is common, as is graded bedding in coarser, banded sandstone. Many sandstone beds have irregular lower contacts with shale, and contain fragments of underlying shale. Some outcrops show areas of highly disturbed laminated sand which appears to have undergone solifluction. A less common structural feature is intraformational breccia consisting of angular or subangular sandstone fragments in a matrix of sand of a slightly different colour, grain-size, and composition; in some instances the sandstone clasts have been rotated relative to one another. This structure may be the result of solifluction and injection of sand into fractures in more compacted sandstone beds.

Lithic labile and sublabile sandstones are by far the most common of the arenaceous sediments in the Kondaku Tuff. A little less than half of these are tuffaceous, and contain fresh or altered volcanic glass. Rock fragments, largely of fine-grained basic volcanic and minor fine-grained sedimentary rocks, make up 5 to 60 percent of the rock. Plagioclase clasts, commonly altered to albite, make up 5 to 25 percent, and quartz, mostly as angular or subangular fragments, but some secondary, makes up 1 to 60 percent (Table 1). Clasts of pale green-brown augite and potash feldspar (both orthoclase and sanidine) occur in about a quarter of the samples, in amounts ranging from less than 1 percent to 20 percent. Small pellets of bright green, fine-grained glauconite occur in about 10 percent of the samples. Other minor constituents are biotite, muscovite, hornblende, opaque minerals (iron oxides), tourmaline, zircon, apatite, and sphene. Chlorite is a common secondary phase in these rocks; it has replaced most of the volcanic glass and, in many examples, much of the volcanic rock fragments, and constitutes from less than 1 percent to 25 percent of the rock. Other secondary minerals are prehnite and calcite, which are discussed below.

Tuff beds are concentrated in the lowermost and, more notably, the uppermost parts of the Kondaku Tuff; in the upper parts of the unit they contain abundant charred plant remains. The tuff beds consist of glass (which in some specimens is partly chloritized) angular plagioclase (usually albite) fragments, angular chips of quartz, opaque minerals and, in most cases, secondary chlorite. About half of the samples contain prehnite, and most of the others contain calcite. One sample is extensively invaded by fibrous laumontite.

Grit and conglomerate in the Kondaku Tuff are commonly seen in outcrop, but make up only 3 to 5 percent of the unit by volume. Beds range from a few centimetres to about 10 m in thickness, and are very hard and massive. Sorting is generally fair to good; there is little matrix, and zeolite and/or calcite cement is commonly developed. The grits and conglomerates are composed of subangular to rounded granules or pebbles of greenish, grey, and reddish fine-grained volcanic rocks, dark grey slate, black chert, pale grey limestone, coarse-grained diorite/granodiorite, yellow-brown quartzite, and rare fragments of brachiopod and gastropod shells. Volcanic rock fragments dominate over other clasts, and some conglomerates are made up entirely of greenish-grey, fine-grained lava clasts.

Eight samples of lava were collected from the Kondaku Tuff, all from between 300 and 1,200 m above the base of the unit, and all from the area between Kundiawa and Minj. Five of the samples are almost unaltered augite andesite made up of oligoclase-andesine (80%), brown augite (10%), opaque minerals, and some chlorite and calcite. Two samples are spilites; made up of albite, calcite and chlorite; one contains 5% quartz and 20% relict augite. The remaining sample (20NG1167) is an altered augite rhyodacite porphyry, consisting of plagioclase and sanidine (15%), augite (10%), chlorite (30%), prehnite (5%), and a little calcite and epidote. This rock also contains ovoid amygdales filled with quartz (20% of the rock) and fine, fibrous, pleochroic green actinolite (15%).

Edwards and Glaessner (1953) carried out some detailed petrological work on a small number of samples from the Kondaku Tuff. Apart from features included in the above descriptions, they recorded a wide variety of heavy minerals, including topaz, tourmaline, zircon, apatite, rutile, ilmenite and rare sulphides. Enstatite was found in one of the samples of tuff.

Provenance and depositional environment

Volcanic detritus and volcanic rocks make up the bulk of the Kondaku Tuff. The abundance of volcanic rock and glass fragments, lava and agglomerate in the Kondaku Tuff decreases markedly southwards away from the Wahgi Valley. As Edwards and Glaessner (1953) inferred, this indicates a source of the volcanic detritus and lava to the north of the Wahgi Valley, probably in the area of the Jimi-Wahgi divide. Some quartzose sandstones in the Kondaku Tuff contain granitic detritus, including a variety of heavy minerals which are not found in volcanic rocks. This granitic detritus was probably derived from exposed parts of the ancestral Kubor Range.

Rock types and sedimentary structures are compatible with deposition in a shallow subsiding trough (cf. Edwards and Glaessner, 1953) close to the source of volcanic detritus. The occurrence of coarse conglomerates, pebble bands, lavas and agglomerates, and small-scale cross-bedding are all indicative of shallow water deposition. The decreasing importance of conglomerate and lava upwards in the succession implies deepening of the trough, culminating in the deposition of the Chim Formation in moderately deep water.

Burial metamorphism

Crook (1961) recognized the effects of burial metamorphism in the Kondaku Tuff after examining samples collected by Noakes (1939) and described by Edwards and Glaessner (1953). He calculated the depth of burial of the base of the unit to have been about 10,500 m. In the top 900 m of the Kondaku Tuff, plagioclase, which was stated to be albitized throughout the formation, was also reported to be replaced by laumontite. In the bottom 900 m of the unit, Crook reported that prehnite had replaced plagioclase and formed a cement in many samples. He assumed that a temperature of 300°C and a pressure of at least 1450 bars were required for the formation of prehnite.

On the basis of the more detailed mapping carried out in the 1968 survey, it has been estimated that the depth of burial of the base of the Kondaku Tuff is about 5,500 m, made up of 2,500 m of Kondaku Tuff and 3,000 m of Chim Formation. It is unlikely that there was a significant thickness of Eocene-Miocene cover over the area of Kondaku Tuff that is now exposed. A liberal estimate of the total depth of burial could be no more than 6,300 m, even if the Eocene-Miocene cover did extend to the Kubor Range.

Zeolitization was noted in only two samples collected in 1968, while prehnite was found to be abundant in the lowermost 100 m of the Kondaku Tuff. This lower part of the formation is rich in volcanic detritus, lava and agglomerate. With few exceptions, prehnite does not occur in samples which contain calcite. Coombs et al. (1970) have pointed out that under conditions of high partial pressure of CO_2 in burial metamorphism, lime zeolites, prehnite, pumpellyite, and zoisite can all be suppressed in favour of calcite and chlorite. This is probably the explanation for the absence of prehnite in calcareous rocks in the lower part of the Kondaku Tuffs, and in all but a few samples of the underlying Maril Shale.

Effects of burial metamorphism have been manifested at a depth of only 4,500 m in the Wahgi sequence in contrast to 7,000 m for the Southland, New Zealand sequence, and 4,900 m for the Tamworth Trough sequence (Crook, 1961). This is probably due to the lithology of the rocks involved. A thick pile of largely basic volcanic detritus, basic lava and agglomerate, and interbedded siltstone and shale would probably retain some magmatic heat, and would generate an appreciable amount of radiogenic heat. Volcanic and volcanic-derived rocks would also be chemically susceptible to diagenetic change, relative to pelitic, quartzo-feldspatic or siliceous sediments which are more stable at the low temperatures of burial metamorphism.

Structure

In the Wahgi Valley area, the Kondaku Tuff dips regularly at 20 to 35 degrees to the northeast, and is disturbed only by a small number of faults. Small faults (such as in Fig. 15) have juxtaposed different lithologies within the formation, while larger faults have either repeated large 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. 13) and minor faults have disturbed the unit. South of the Kubor Range, stronger folding about closely spaced, non-parallel axes has taken place, and dips are irregular. Generally the Kondaku Tuff, with its thick, massive sandy beds, has behaved as a competent unit. There has been some penecontemporaneous soft-sediment slumping in the thicker shaley interbeds, mostly on a scale of a few metres to a few tens of metres. Jointing is blocky, with rectilinear joints 10 cm to about 1 m apart separating regularly-shaped blocks of sandstone or tuff. Some tuffaceous beds are massive with little or no jointing, and the boulders which are derived from such beds are up to 10 m in diameter.

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Chim Formation (name varied)

Definition

Specimens collected by Noakes (1939) in the Chim (now Chimbu) River, were examined by Edwards and Glaessner (1953) who divided the Upper Cretaceous rocks into two units - the Maram Shales and the Chimbu Tuffs. Rickwood (1955) used the name "Chim Group" for a sequence of "shales with occasional cone-in-cone structure, greywackes and tuffaceous mudstones" of Upper Cretaceous age exposed in the Chimbu area. No subdivision of the "Chim Group" was attempted by Rickwood, and no separate formations within the Upper Cretaceous could be mapped in 1968, so the unit is here renamed the Chim Formation.

Distribution and thickness

The Chim Formation consists of grey to dark grey mudstones and siltstones, with minor interbedded lithic or tuffaceous (Edwards & Glaessner, 1953) siltstones and sandstones. It crops out around a large part of the outer flanks of the Kubor Anticline, from the Bismarck Fault zone near Kerowagi, southeast to Mount Michael, and westwards from there to Mount Ialibu and into the Nebilyer Valley.

Relief on the Chim Formation is moderate to gentle, and dip slopes are not commonly preserved. Streams cutting the formation generally have broad V-shaped valleys, with very few gorges. Outcrop is restricted to the streams, with only flaky shale fragments and scarce sandstone cobbles on the ridges.

Noakes (1939) measured a section along the Chimbu River, and estimated the thickness of the Upper Cretaceous rocks to be 3,200 metres. A thickness of about 2,400 metres was measured directly from Plate 10, just east of the Chimbu River where dips are consistently about 30° NE. Elsewhere the thickness of the Chim Formation varies considerably. It is probably thickest to the south of the Kubor Range, but folding and faulting prevent accurate estimation of thickness in this area. An average thickness of the formation is probably about 3,000 metres.

Stratigraphic relationships and age

The Chim Formation is lowermost Upper Cretaceous and conformably overlies Lower Cretaceous Kondaku Tuff. Along the northeast and east flanks of the Kubor Anticline it is overlain unconformably by Eocene to Oligocene Chimbu Limestone. There was a large time interval between deposition of these two units, but because the contact is not exposed, it is not clear whether the angular relationship is due solely to erosion, or has been caused partly or wholly by thrusting of Chimbu Limestone southward over Chim Formation. South of the Kubor Anticline, Miocene Darai Limestone overlies Chim Formation conformably in places, and with a high-angle unconformity in other places. Jenkins et al. (1969) believe that the Chim Formation has been involved in diapiric folding which has caused the development of flat-bottomed, steep-walled synclines in the overlying Darai Limestone. Sliding of Darai Limestone on a décollement plane at its base may have truncated steep-limbed diapiric anticlines in the Chim Formation and juxtaposed flat-lying limestone and near vertical mudstone.

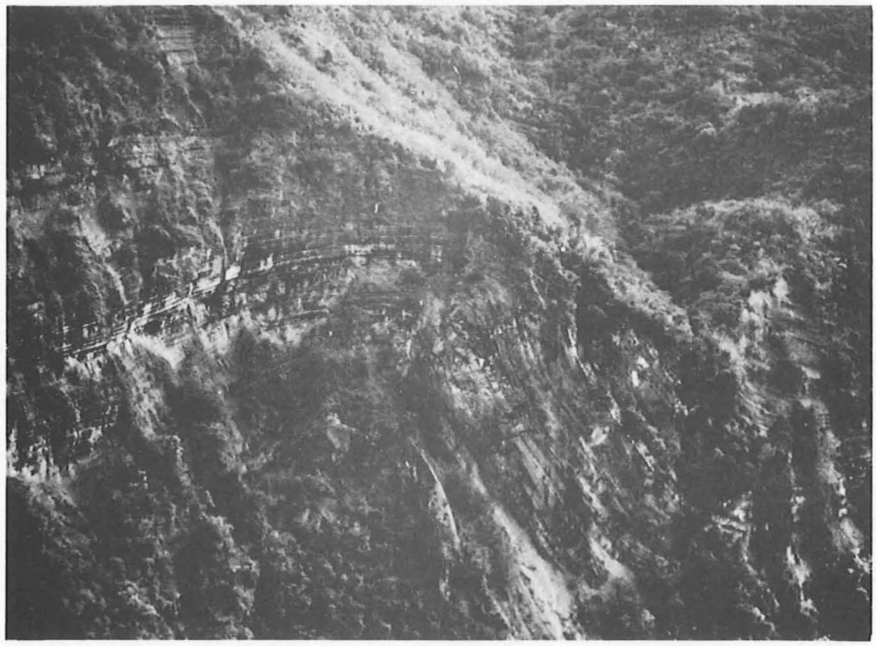


Fig. 13 Small monoclinal fold in Kondaku Tuffs exposed in the southern side of the Wahgi Gorge 20 km. west of Lufa. Neg. GA1236

Fig. 14 Interbedded sandstone, siltstone and limestone of the Upper Cretaceous Chim Formation in the Tua River 30 km WSW of Lufa. Thickest bed approx. 15 cm. Neg.GA1239.

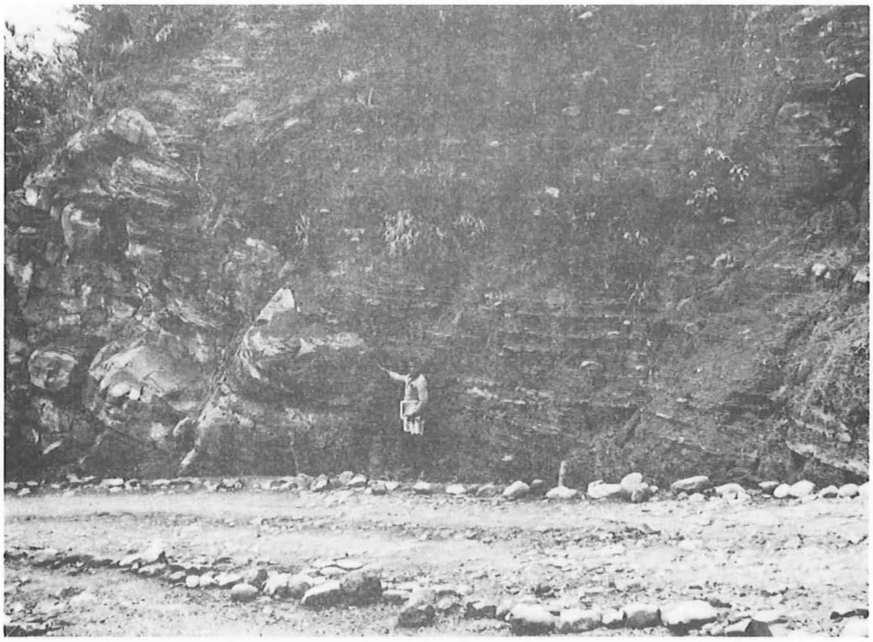


Fig. 15 Fault within Kondaku Tuffs juxtaposing coarse feldspathic sandstone containing plant fragments (left) and thinly bedded shale-siltstone containing ovoid calcareous concretions. Kup-Mingende road at Wahgi River Crossing. Neg.M.813.

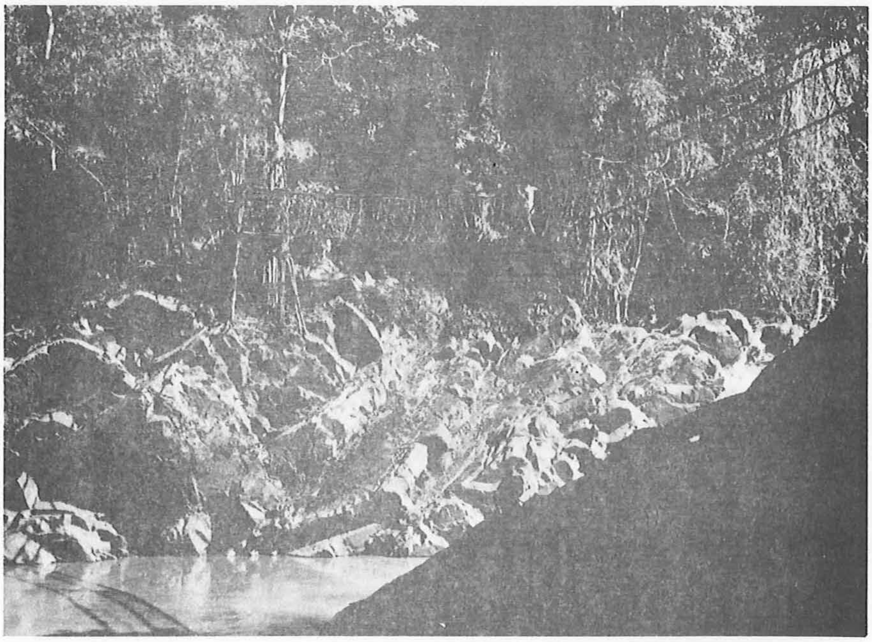


Fig. 16 Vine bridge across the Tua River about 1 km downstream from Wahgi-Asaro junction. Outcrop is composed of massive, bedded sandstone of the Upper Cretaceous Chim Formation. Neg. M.813

In the Mount Michael area, middle Miocene Movi Beds unconformably overlie the Chim Formation. East of Mount Suaru, the formation is unconformably overlain by upper Palaeocene Pima Sandstone. In the Nebilyer Valley, Chim Formation is overlain by calcareous Palaeocene mudstone and Eocene to Oligocene Nebilyer Limestone.

At Mingende, specimens of ammonites were collected by Noakes (1939), and these were found to be Cenomanian (Glaessner, 1945). The fauna includes:

Euomphaloceras hoeltkeri (Erni)

Puzosia sp.

Turrilites cf. scheuchzerianus Bosc.

Inoceramus sp.

a few foraminifera, including

Textularia cf. washitensis Carsey

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 natives (Stanley, 1950) were Mantelliceras sp. Turrilites cf. acutus Passy.

Only three specimens of Chim Formation collected in 1968 contained diagnostic microfauna; specimens 21NG0648 and 0651 from the Tua River, south of Mount Suaru contained the following:

0648 - Praeglobotruncana stephani (incl. turbinata forms)
Hedbergella spp.

0651 - Globotruncana spp. (incl. G. lapparenti group)
Praeglobotruncana sp. cf. P. stephani
? Hedbergella sp.
Heterohelix sp.
Anomalinoides sp. cf. A. undulatus Belford
Textularia sp.
Hyperammina sp. (abundant)

The fauna from 0648 is upper Cenomanian to lower Turonian, (Binnekamp & Belford, 1970).

No fauna younger than Turonian has been found in the Chim Formation. The age range of the Formation is therefore Cenomanian to lower(?) Turonian, that is, early Upper Cretaceous.

Structure and lithology

To the northeast of the Kubor Anticline, the Chim Formation dips regularly to the northeast. There are numerous small folds in the formation to the east and southeast of the Kubor Range, and strong folding and faulting to the south. Faulting has caused some deformation in the area 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 intraformational slumping. Examples of this type of deformation are exposed in many places, notably in the area west of Kerowagi. Deformation ranges from gentle though irregular intraformational folds to intensely and complexly contorted beds, and has occurred on all scales up to several metres in amplitude.

Bedding in the Chim Formation ranges from very massive, particularly in the siltstone and mudstones, to thinly and commonly rhythmically interbedded (2-10 mm beds) siltstones and/or mudstones, and laminated siltstones or sandstones (Fig. 14). Small-scale cross-bedding and ripple marks in some of the laminated sandstones indicate shallow-water deposition. The vague dark streaks and worm burrows noted in the Kondaku Tuff are also common in the Upper Cretaceous beds.

The dominant lithology in the Chim Formation is grey, dark grey or almost black mudstone to siltstone, commonly micaceous, and containing in places grey fine-grained ovoid calcareous nodules ranging in size from a few centimetres to over a metre across. Many of these nodules contain microfauna and macrofossils, including ammonites, gastropods, bivalves and belemnites. The mudstones and siltstones consist of angular to subrounded fine-grained volcanic rock fragments, quartz (up to 30%), plagioclase (usually oligoclase or andesine), and minor muscovite and/or biotite, calcite and heavy minerals. The siltstones are well sorted and contain only a small amount of clay matrix, but the shales and mudstones are made up predominantly of clay minerals with minor quartz and micas. Heavy minerals include opaques (magnetite and/or ilmenite), zircon, rare tourmaline, and epidote. Some specimens contain irregular patches of coarser or finer-grained material, suggesting intraformational erosion, possibly caused by slumping.

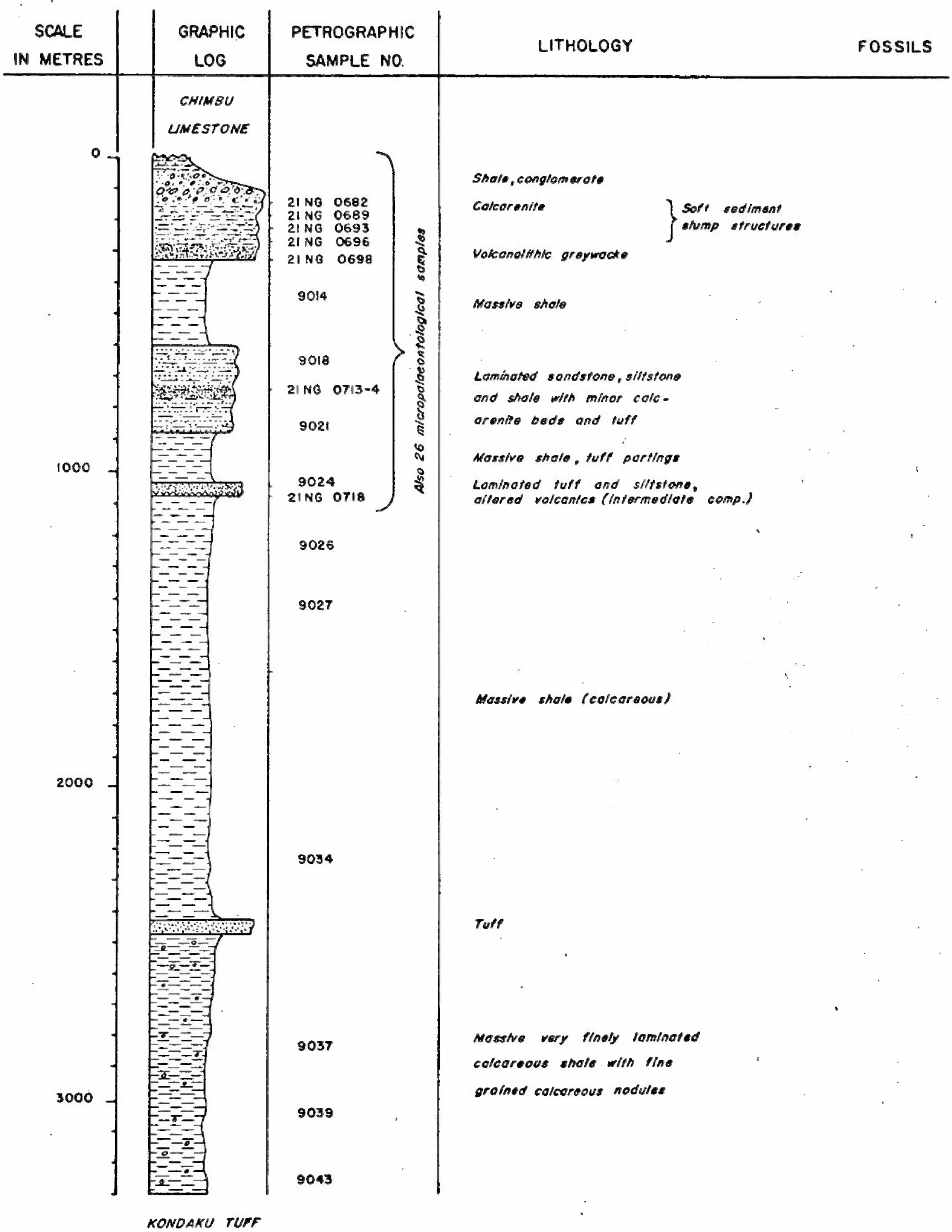
Very fine to medium-grained sandstone occurs as thin, widely to closely-spaced beds, and thick, massive beds (Fig. 16) within the dark mudstones and siltstones. The sandstones are pale greenish-grey to dark grey or greenish-grey, and consist of quartz, volcanic rock fragments, plagioclase, and micas (muscovite and biotite), glauconite (small rounded aggregates) and heavy minerals. Heavy minerals include zircon and ilmenite (commonly altered to leucoxene). Some specimens contain a high proportion of calcite cement and grade into sandy limestone; others consist of quartz, rock fragments and feldspar. Other components are hydrated iron oxides (intergranular stringers), small patches of calcite, and secondary chlorite. The arenites are well to very well sorted and the grains are subangular to rounded, usually subangular or subrounded.

Edwards and Glaessner (1953) noted the presence of tuffaceous beds in the upper part of the sequence. These and massive beds of agglomerate up to 10-15 m thick were mapped in a measured section in 1970 (Fig. 16a).

Interbedded with the siltstones and shales are numerous thin beds (Fig. 14) and fist-sized nodules of pale grey, fine-grained limestone, which generally have an iron-stained weathered surface. Cone-in-cone structure is commonly developed in the darker-coloured limestone beds and lenses.

Fig. 16 a.

CHIM FORMATION - CHIMBU RIVER SECTION



9014 - 9043 Noakes samples

21 NG 0682-718 - this survey

B55/A/16

Provenance and depositional environment

Edwards and Glaessner (1953) noted the lack of obvious 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 Wahgi sediments were derived from an andesitic volcanic source to the north, and deposited in shallow geosynclinal waters.

Small-scale cross-bedding, ripple marks and fine laminations, and the presence of well sorted sandy beds all point to shallow water, near shore deposition. No detrital material that could be said with confidence to have been derived from the core of the Kubor Anticline has been discovered in the Chim Formation. These observations support the conclusions of Edwards and Glaessner (1953) (see discussion of Kondaku Tuff).

TERTIARY

Ta Stage (U. Palaeocene-Eocene)

Pima Sandstone (new name)

Pima Sandstone is the name given to a sequence of fossiliferous sandstone with interbedded siltstone and mudstone which is exposed over a large area east of Mount Suaru, and extends across the Tua River to 145°E. The name Pima Sandstone is derived from the Pima River (145°49'E, 6°23'S), where the unit is well exposed.

Thickness of the unit probably exceeds 2,000 m in the type area, and may be as much as 3,000 m elsewhere. The base of the unit is a massive sandstone bed, at least 300 m thick, which unconformably overlies the mudstones and siltstones of the Chim Formation. This, and other prominent sandstone beds higher in the sequence thin to the west, and are absent west of Mount Suaru where mudstones of equivalent age are present. The Pleistocene Suaru Volcanics cover the western end of the Pima Sandstone.

Prominent strike ridges, dipslopes and bluffs of massive sandstone characterize the topography on the Pima Sandstone, especially south of the Tua River. The basal sandstone forms an almost continuous bluff and dipslope which can easily be traced on the airphotographs, and which bounds the Pima Syncline. Deep gorges are cut into the sandstone by the Pima River and other streams crossing the strike.

The sandstones are fine to coarse-grained, pale grey, green-grey or dark grey feldspatholithic types, usually thick-bedded (beds up to 3 m thick) with common, lenticular fossiliferous beds up to 1 m in thickness. In Oliabai (or Olu) Creek, southeast of Mount Suaru, tuffaceous beds and rare conglomerate were recorded. Fine laminations, ripple marks and small-scale cross-bedding are well developed in some sandy beds. Dark grey to black mudstone and siltstone, laminated in part, and thinly interbedded with fine sandstone, are intercalated with the massive sandstone beds. They form some thick beds (up to over 200 m) which appear to be rich in carbonaceous matter, rock fragments and clay minerals (but essentially free of sandstone). Ferruginous nodules and clasts of sandstone are present in isolated occurrences.

TABLE 2

Standard Ages		East Indian letter Stages	Planktonic Foram. Zones.	APC and BP Papuan Stages.
Miocene: upper	Tg		N15	
Miocene: middle	Tf	upper Tf (f3)	N14 N13	Ivorian
	Tf	lower Tf (f1-2)	N12 N11 N10	Taurian
	Tf	lower Tf (f1-2)	N9	
Miocene: lower	Te	upper Te (e5)	N8 N7 N6 N5 N4	Late Kereruan
Oligocene	Te	Lower Te (e1-4)	N3 N2 N1	Kereruan
Oligocene	Td Tc			Kereruan
Eocene: Upper	Tb			Upper Eocene
Eocene: Middle	Ta			Middle Eocene

Correlation of the East Indian letter stages, planktonic foraminiferal zones and standard ages (after Binnekamp & Belford 1970) and Papuan Stages used by APC & BP Petrol. Devel. Aust. (after Jenkins et al 1969).

The Pima Sandstone has been folded into a broad synclinorium, complicated by many smaller folds, and cut by a few small faults. The overall trend is east-northeast, swinging to east-west near Mount Suaru. Except where the beds are disturbed by faulting, dips are generally less than 50°, becoming almost subhorizontal just east of Mount Suaru.

Skwarko (1969) has examined specimens collected from the sandstone in Oliabai Creek and has identified Ostracidae, possibly related to Ostrea and Exogya, Rotularia sp. (closely resembling R. spirulaea (Lamarck)), and fragments of various Pectruodae and Gastropoda. 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 this fauna is considered by Skwarko to be Upper Cretaceous to Eocene, with a greater likelihood of being Eocene.

A specimen of sheared mudstone (21NG0618) from a tributary of the Kaugel River, east of Mount Ialibu contained:

Subbotina triloculinoides (Plummer)

Globorotalia pseudomenardii Bolli

G. chapmania Darr

G. aequa aequa Cushman & Renz

a group of Globigerina mckannai White

This fauna belongs to the Upper Paloeocene G. pseudomenardii zone (Binnekamp & Belford, 1970), and therefore is correlated with the Pima Sandstone. Similarly, calcareous mudstones beneath the Nebilyer Limestone in the Nebilyer Valley are correlated with the Pima Sandstone. Because of insufficient information, neither of these mudstones has been separated from the Chim Formation.

Shelly beds, ripple marks, and interbedding of sandstone and finer sediments all point to shallow water deposition. The most obvious source of the detrital material is from the older rocks to the north in the Kubor Range. There is a close resemblance in the field between the Pima sandstones and the tuffaceous sandstones of the Lower Cretaceous Kondaku Tuff. Probably the Pima Sandstone contains at least some reworked material from the Kondaku Tuff.

Ta3-Tc stage (Eocene-Oligocene)

Chimbu Limestone

Nomenclature

Rickwood (1955) applied the name Chimbu Limestone to a prominent strike ridge of Eocene/Oligocene limestone that extends 73 km southeastwards 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 upper Te limestone rest on Oligocene limestone. We propose to confine use of the name Chimbu Limestone to Eocene/Oligocene limestone, and to include the lenses of upper Te limestone in the Movi Beds (see page 43).

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Distribution and thickness

The Chimbu Limestone forms the basal unit of the Tertiary sequence in the southwestern limb of the Yaveufa Syncline and 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 northeastern limb of the Yaveufa Syncline. Approximately 300 m of calcarenite and limestone has been measured in the Chimbu River gorge. This appears to be the average thickness of the formation, although in places it is much thinner, and at Mount Elimbari it may exceed 1000 m.

Lithology

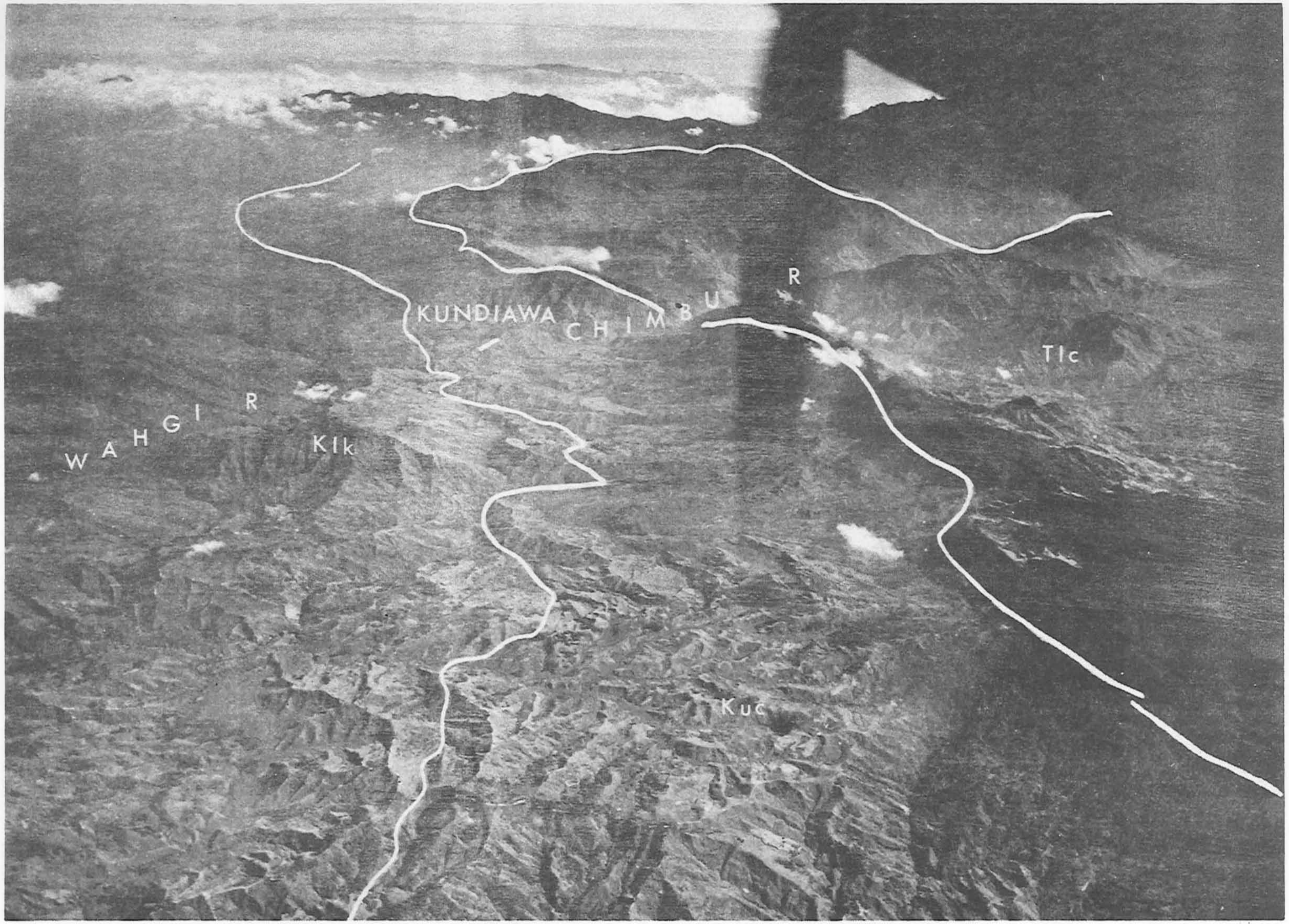
The Chimbu Limestone consists entirely of massive limestone and calcarenite. The lowermost 75 m in the type section are composed of dark grey coarse-grained calcarenite, and finer-grained brownish grey to buff-coloured limestone containing numerous Alveolina. Thence 7.5 m of brown to buff coloured Lacazinella limestone overlain by 60-135 m of very fine grained grey and buff coloured algal and Heterostegina limestone. These are in turn overlain by 90 m of pure white limestone composed almost entirely of Numulites. The limestone contains numerous large solution cavities, most of which are at least partially filled with recemented limestone rubble. Many major and minor faults cut the limestone especially in the Bismarck Fault Zone and small slickensided faces are common. At many places in the buff coloured Eocene limestone (notably near Chuave) there is an abundance of well preserved though difficult to collect macrofossil material. This includes various open and closed coil gastropods, belemnites, pelecypods and echinoids. There is an unsubstantiated report of a complete, large fish having been collected from one of the quarries near Chuave.

The limestone was formed 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 Upper Jurassic Maril Shale. In the Goroka Valley near Asaro village the limestone rests nonconformably on granite of unknown age, and near Geppavi Hill, 15 km southeast of Goroka, it overlies Goroka Formation metamorphics of possible Palaeozoic or Mesozoic age (McMillan & Malone 1960). Lower Miocene sediments (Movi Beds) overlie the limestone with slight disconformity, and near Nambaiyufa they overlap the Chimbu Limestone cuesta.

The limestone contains abundant foraminifera which date it as middle Eocene to lower Oligocene (Ta3 to Tc) (Bain & Binnekamp, in prep). It is thus 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). A rich macrofauna has been sampled, and a micropalaeontological study has been completed (Bain & Binnekamp, in prep).



<u>Fig. 17</u> Lower Wahgi Valley with Bismarck Mountains on the right. Tertiary Chimbu Limestone (Tlc) overlying Upper and Lower Cretaceous shale and sandstone (Kuc & Klk). 12-3 188X Bis.Ra. to Kibagh Vic Chimbu 22,300 feet, 6", 1943.

Nebilyer Limestone

The limestone unit which forms the prominent scarp on the western side of the Nebilyer Valley was named Nebilyer Limestone by Rickwood (1955). He described the unit as "hard, grey, frequently argillaceous limestone of Eocene to Oligocene age." Its maximum thickness was estimated at 300 m.

Photogeological interpretation shows that the limestone is exposed for 30 km southwards from the southern slopes of Mount Hagen volcano to the Kaugel River; the outcrop area is nowhere more than a kilometre in width. The northern and southern extremities of the limestone are buried by Quaternary volcanics. Recent field work (Jenkins et al., 1969) has shown that the limestone due west of Togoba is only 106 m thick. This figure appears to be representative of the thickness of the unit along most of its north-south extent. The unit thins appreciably in the south and appears to lens out completely near the Kaugel River.

The Nebilyer Limestone consists entirely of limestone and calcarenite with some very minor argillaceous and silty interbeds. In the section described by Jenkins et al., (1969), the lowermost 21 m consist of dark grey to grey-brown calcarenite with thin silty and argillaceous interbeds, overlain by 45 m of dark grey-brown micrite. The upper part of the micrite is coarser-grained, less argillaceous and lighter coloured than the lower part. The change is gradational. The micrite is homogeneous in beds about 2-5 cm thick except for the lowermost 10 m where 15-45 cm thick beds are slightly pyritic and calcite veined. Massively bedded medium-grained grey and grey-brown calcarenite forms the uppermost 40 m of the unit in this section.

The limestone contains rare Globigerina, Truncorotaloides and keeled Globorotalia sp. suggesting an Eocene age (S.F. Schuyleman in Jenkins et al., 1969). Common small Rotaliids, agglutinating forams, rare plankton, algae, and bioclastic debris are also present but no other diagnostic fossils have been seen.

The unit conformably overlies calcareous siltstone believed to be of Upper Palaeocene age. The contact is gradational. Conformably overlying the limestone is a 6 m thick bed of Miocene greywacke, which is in turn overlain by over 550 m of Miocene mudstone and greywacke.

Lower Te - upper Tf stage (upper Oligocene - middle Miocene)

Darai Limestone

Buchan & Robinson (1969) and Jenkins et al. (1969) described thick Te-Tf shelf limestone deposits in the Mendi-Kagua area which they called Darai Limestone. The formation covers most of the southern fall of the central range of Papua and New Guinea, west of Mts Karimui and Favenc. We include in this formation the outliers of subhorizontal cliff-forming lower Te-Tf limestone south and southwest of Mt Suaru.

In the map area, Darai Limestone forms small, subhorizontal areas of mature karst topography bounded by cliffs and sharp ridges. More extensive strike ridges with superimposed karst or pinnacle topography are developed south and west of the map area. Because of the massive nature of the limestone and the wide spacing of joints, erosion of the cliffs has produced large (5-20 m), roughly cubic blocks below the cliffs and in stream beds.

The formation is only about 100 m thick within the map area, but thickens to the south and west where estimates of average thickness range up to 1,200 m. In the vicinity of the Purari River, 10-15 km south of the map area, it is 500-1000 m thick.

The Darai Limestone consists of thick-bedded to massive, light-coloured biosparite, bio-micrite, and calcareous arenite with minor biosparudite* and breccia. The formation was not mapped in sufficient detail to determine the relative proportions of the constituent rock types except in the most general terms.

Probably the most common rock types within the map area are yellow, brown, and buff to pale grey calcareous arenites and sparites, both to some extent bioclastic. These lithologies are most common in the lower part of the formation where they are interbedded with very minor amounts of calcareous siltstone and sparudite. They appear to be relatively uncommon to the south and west of the map area. The upper part of the formation is composed mostly of micrite and sparite.

Cross-bedded, coarse-grained calcareous arenite which forms low cliffs on the south side of the Tua River west of Karimui consists of angular quartz and feldspar fragments (up to 60%), fragmental bioclastic material, a few percent of intact foraminiferal tests, and an iron-stained calcareous cement. This rock type grades laterally and vertically into biosparite containing up to 20% fine angular to rounded siltstone clasts and about 5% cement.

Micrite (commonly bioclastic) may be white, cream to pale brown, or pale grey, and is composed of up to 90% organic detritus (mostly benthonic and planktonic foraminifera and algae). Thin beds and small patches of biosparite composed almost entirely of foraminiferal tests and comminuted shell material, are commonly present within the massive micrite.

Dark grey-brown intrasparite is commonly composed largely of algal, foraminiferal, and pellety micrite fragments set in a sparry cement. Limestone breccia, some of which is intraformational, and conglomerate containing predominantly limestone detritus, were observed as stream boulders; however, both of these rock types appear to be relatively minor.

Within the map area, the sub-horizontal Darai Limestone rests on highly deformed, near vertical Upper Cenomanian-Lower Turonian siltstone, and is overlain by Pleistocene Volcanics from Mts Karimui and Ialibu. It contains foraminifera which indicate that the formation within the map area is of lower Te to lower Tf age (Binnekamp & Belford 1970). To the west of the map area, Jenkins et al. (1969) noted that the Darai Limestone "overlies Upper Eocene to Oligocene limestone along the north eastern 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." They noted that in the same area the formation is of lower Te to upper Tf age, and is conformably overlain by the Upper Miocene to Pliocene Orubadi Mudstone. Similar stratigraphic relationships exist in the Pio-Purari area to the South of Mt Karimui (Rickwood & Kent, 1956).

* The terminology is that of Folk (1965)

Fig. 18 Hogback of Eocene-Oligocene Chimbu Limestone trending southeastwards. Lower to middle Miocene sediments crop out to the left of the limestone, Cretaceous sediments to the right. The highest point on the limestone is Mount Elimbari. The peak in the left background is Mount Michael. (View from pass at 3000 metres ASL. on track from Chuave to Kundiawa behind the limestone). Neg.GA2384.

Fig. 19 Mount Elimbari viewed from the northwest near Chuave. Neg. GA2392.

Fig.20 Hogback of the Chimbu Limestone (dark ridge, right middle distance) overlying Mesozoic sediments. Peak on the right skyline is Mount Wilhelm (4,500 metres). View is to the north-west from the western side of Mount Michael. Neg. GA2379.

Fig.21 Deeply dissected country in the Wahgi Gorge. The Kundiawa-Gumine road (left foreground) is cut into Kubor Granodiorite. Neg. GA2386

By far the greater part of the formation is composed of bioclastic debris and chemically formed carbonate matrix or cement, clearly of local origin. However the lowermost beds and the outcrops nearest the Kubor Range contain material derived from outside the zone of deposition. This clastic material consists of quartz, feldspar,and siltstone which most probably resulted from erosion of rocks exposed on the southern side of the Kubor Range.

Medium scale crossbedding in the arenites, and the extensiveness of the bioclastic carbonate deposits indicate that the formation was deposited on a shallow marine shelf. It is the shelf facies equivalent of the basinal Aure Group.

Aure Group (undifferentiated)

Conformably overlying the Nebilyer Limestone, southwest of Mount Hagen town, is a sequence of thinly bedded calcareous mudstone, greywacke and minor siltstone and limestone. Rickwood (1955, p. 77) correlated these rocks with the Miocene sequence in the Lai Syncline to the northwest and named them "Gai Group". The Lai Syncline sequence has since been mapped by Dekker and Faulks (1964) and by Dow et al. (1968) as upper Te (Pundugum Formation) and lower Tf (Burgers Formation). Dow et al. also tentatively mapped the rocks in the northwestern end of the Kaugel Syncline (Fig. 50) as Pundugum Formation. A.L. Findlay (pers. comm., 1969) recently mapped the rocks of the Kaugel Syncline as Aure Group. This name, derived from the Aure River (145°30'E, 6°40'S), is adopted in this report.

Rocks of the Kaugel Syncline are well exposed along the road from Mount Hagen to Tambul, beyond the western boundary of Plate 1, where they underlie a topography of moderate to strong relief. Apart from road cuttings, outcrops are limited to stream channels and eroded foot tracks.

Due west of Mount Hagen town, dips in the Miocene sequence are gentle to flat, with a monoclinal or asymmetrical anticlinal flexure, the axis of which trends north-northwest along the western side of the Gogimp Valley. To the south, the dips steepen around the northwest-southeast trending axis of the Kaugel Syncline. Lithologies include thin-bedded to laminated dark greenish-grey mudstones and siltstones, medium to coarse-grained, green to almost black volcanic-derived lithic sandstones, inter-laminated mudstones, siltstones and sandstone, and minor grey algal or laminated limestones. A typical sandstone specimen consists of fine-grained volcanic rock fragments, largely replaced by calcite, some detrital quartz and plagioclase, and rare grains of quartzite, muscovite and zircon in a matrix of very fine-grained calcite. Sixty-five percent of the rock is calcite, five percent of which is fragments of coarse limestone. The grains are subrounded to rounded, well sorted, and range in diameter from 0.2 to 1.0 mm (average 0.7 mm).

The provenance of these rocks is predominantly volcanic, possibly including both older and contemporaneous volcanic rocks; they have been deposited in a moderately deep-water environment, flanking a rising landmass in the area of the present Kubor Range.

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Upper Te to lower Tf stage (lower to middle Miocene)

Movi Beds (new name)

Nomenclature

Movi Beds is the name proposed for a 4000 m thick sequence 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 which is situated on the formation 10 km north of the Asaro River section.

Distribution and thickness

Within the map area, the Movi Beds are restricted to the Yaveufa Syncline and areas west and southwest of Mount Michael (i.e., the nose, and northeast and southeast flanks of the Kubor Anticline). Outside the map area, the formation extends eastward to the Okapa area and south into the Aure Trough.

Thickness varies from approximately 4000 m in the Asaro River section to less than 500 m in the Chimbu River area. Both areas lie within the Bismarck Fault Zone, so precise measurement of thickness is not possible. However, the estimate of thickness in the Asaro River is conserative and makes allowances for minor repetition in the incompetent shale and siltstone beds. Fossil and lithological evidence shows that there is no major repetition in the sequence. The thickness of Movi Beds in the Chimbu River area is less confidently estimated. It is possible but unlikely that a significant part of the sequence has been removed by erosion in that area.

Stratigraphic relationshipsand age

The Movi Beds unconformably overlie the Chimbu Limestone and are conformably overlain by the Asaro Formation in the Yaveufa Syncline. To the west and south of Mount Michael, the formation unconformably overlies Chim Formation and possibly Kondaku Tuff, and is overlain (near Nomane Mission) by two small areas of Recent? olivine basalt. The nature of the basal unconformity is not fully known, for although it has been crossed in four places, no exposure was seen; unconformity has been deduced from structural and palaeontological evidence and from photogeological interpretation. In the vicinity of Nambaiyufa Mission (12 km NW of Lufa), upper Te to Tf limestone of the Movi Beds paraconformably overlies the Tc Chimbu Limestone. Approximately 3.5 km west of the Wahgi-Asaro River junction 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 Daulo Volcanic Member, and by a large Upper Miocene hypabyssal diorite stock (Michael Diorite) to the south of the Yaveufa Syncline.

Within the map area, the formation has been dated as upper Te to Tf stage on the basis of an abundant fauna of larger and smaller foraminifera (Binnekamp & Belford, 1970). The Asaro River section was sampled in great detail during the 1970 work, but the specimens have not yet been examined.

Poorly preserved echinoids collected from the Asaro River have been submitted to Professor G.M. Phillip for identification; other macrofossils (e.g. gastropods, lamellibranchs) have also been collected but not identified.

Lithology

The Movi Beds include a wide variety of marine sedimentary rock types, and varies considerably in appearance and general composition from one locality to another. For example, the sequence within the map area is largely calcareous siltstone and conglomerate with some tuffaceous beds and limestone lenses. To the southeast, outside the map area, the sequence is that of a typical flysch: a large thickness of matrix-rich volcanolithic sandstone and siltstone (greywackes) with intraformational slump breccias. The following discussion of rock types within the Movi Beds refers only to that part of the formation that lies within the map area, and especially to the Asaro River section (Fig. 22).

Rock types vary from calcareous shale and siltstone, to calcareous sandstone (volcanolithic and tuffaceous), and round pebble polymict 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 of the sequence. The latter are probably the intrusive equivalents of the volcanic rocks of the Daulo Volcanic Member.

The formation is well bedded on scales ranging from microlamination (1-2 mm) in siltstone and shale, to sandstone, limestone, and conglomerate beds 3-4 m thick, and fine and coarse-grained sediments in 100-1000 m thick units (See Fig. 22). Bedding in the incompetent shale units has been contorted by soft-sediment deformation (Fig. 25) and post-Miocene faulting. However the competent sandstone, limestone and conglomerate units are relatively undeformed (Fig. 22a).

The thin sequence exposed in the Chimbu River Valley consists largely of light grey calcareous siltstone with minor greenish sandstone and conglomerate beds. Some beds of siltstone are micaceous; others tend towards marl. No section was measured, as the sequence is complexly folded and faulted and poorly exposed.

In the Mai River valley, the Movi Beds are well exposed in small stream beds and road cuttings. Thickness is probably 2-3000 m, rather than 1500 m as estimated by McMillan and 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. These beds are overlain by interbedded dark green-grey shale and siltstone, sandstone, and polymict pebble conglomerate. The conglomerate is dark green and contains rounded pebbles of chert, limestone, sandstone and various volcanic rock types. Some of the sandstone beds are highly feldspathic and appear tuffaceous. The upper part of the sequence, seen in the area between Chuave and Mt Kerigomna, consists of massive light grey siltstone (which contains sparse round pebbles of chert, limestone and volcanics), small limestone lenses, well indurated polymict conglomerate, and massive, highly indurated fine-grained light grey sandstone. McMillan and Malone (p. 32) describe the uppermost 1500 m in the Watabung area as a sequence of grey shale and mudstone, calcareous in part, containing grey limestone lenses (up to 60 m thick), and overlain by bedded greywacke which contains abundant charred plant material. The topmost 90 m contain massive, discontinuous beds of polymict pebble conglomerate up to 12 m thick.

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

A complete section of Movi Beds is exposed in the banks of the Asaro River about 7 km north of Lufa. Thickness is 4100 m. This represents the maximum development of the unit within the map area and is the only complete measured section. Thicknesses in the following description are approximate.

Asaro River section (Fig. 22):

The lowermost 250 m of the sequence consist of interbedded grey siltstone and green tuffaceous sandstone. Bedding is well defined in the sandy units (beds 2-10 cm), but not in the silty units, although laminations (1-10 mm) are present in both. Ripple marks and carbonized plant remains are common in the sandstone, and irregularly shaped beds of intraformational shale and sandstone breccia (10 cm - 4 m thick) occur in the upper part of this unit. The next 500 m consist of massive laminated grey to grey-brown siltstone/shale containing numerous thin, contorted and slickensided calcite veins; there is probably some repetition within this unit. The siltstone-shale sequence is overlain by 520 m of coarser-grained rocks: mostly sandstone, conglomerate, and limestone. In detail this consists of:

TOP

200 m	regularly bedded, medium to coarse-grained, green tuffaceous sandstone (2-60 cm) and thin calcarenite beds (1-3 cm)
40 m	Calarenite/coral breccia; grey-green siltstone/shale and thin interbeds of laminated tuffaceous sandstone, massive polymict pebble conglomerate with sandstone and coralline limestone lenses.
30 m	Regularly thin-bedded (2-4 cm) greenish sandstone and siltstone
100 m	Medium-bedded (18-20 cm) tuffaceous sandstone and siltstone
150 m	Thinly bedded blue green siltstone

Worm markings and burrows, iron stained carbonized wood, ripple marks, fine pebble lenses, thin but persistent limestone beds, and rounded, light-coloured concretions (possibly toroids, see Fig. 23 and Conybeare & Crook, p. 190) are present throughout this unit, and suggest a shallow water origin.

Overlying these units are 750 m of highly contorted, massive, light grey shale and siltstone with minor calcareous beds and rare lenses (3 x 1 m) of cream limestone rubble. As in the lower shale unit, repetition due to faulting is likely. The overlying 1000 m of sediment is predominantly

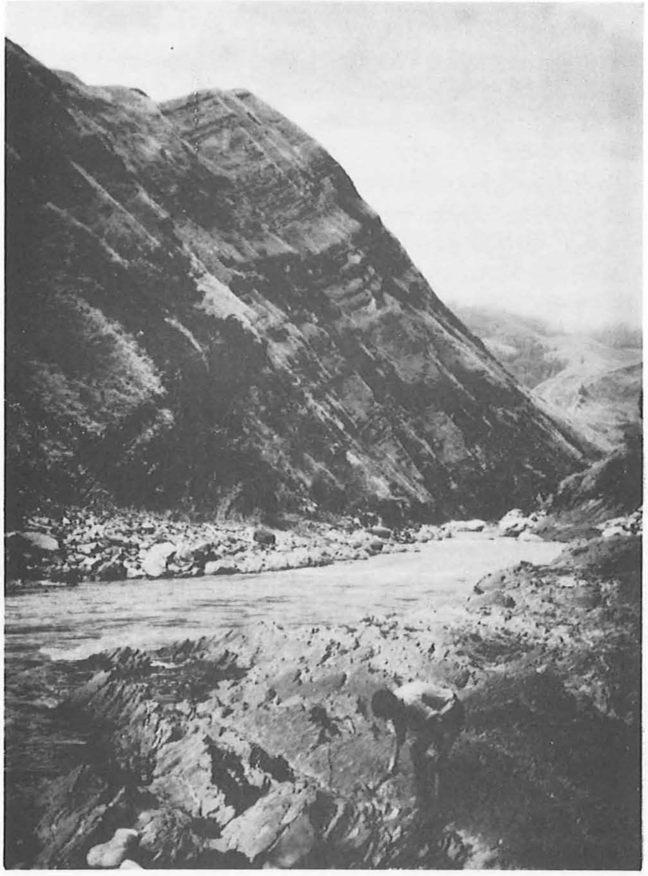


Fig. 22 Interbedded sandstone and siltstone of the Lower Miocene Movi Beds in the Asaro River 6 km NW of Lufa. Neg. GA1264

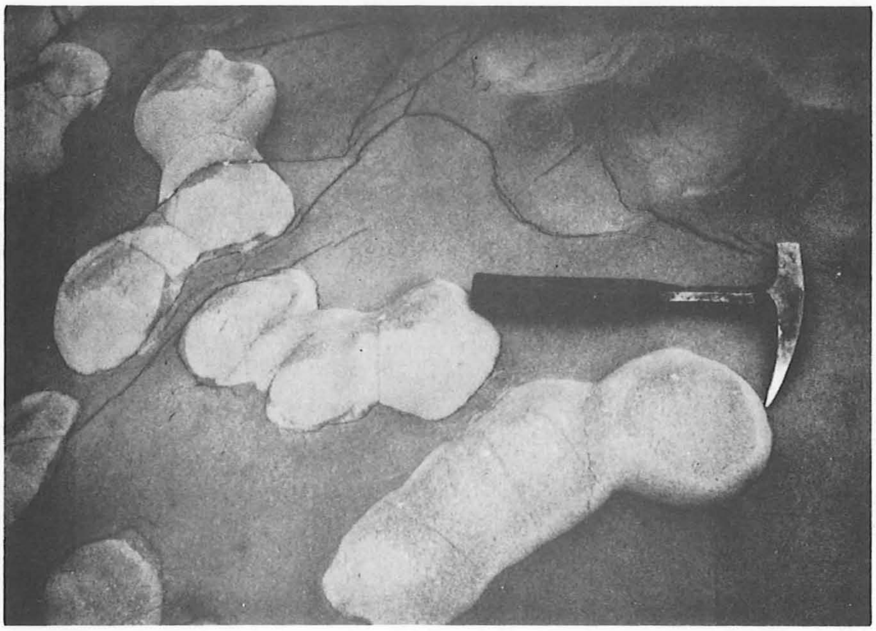
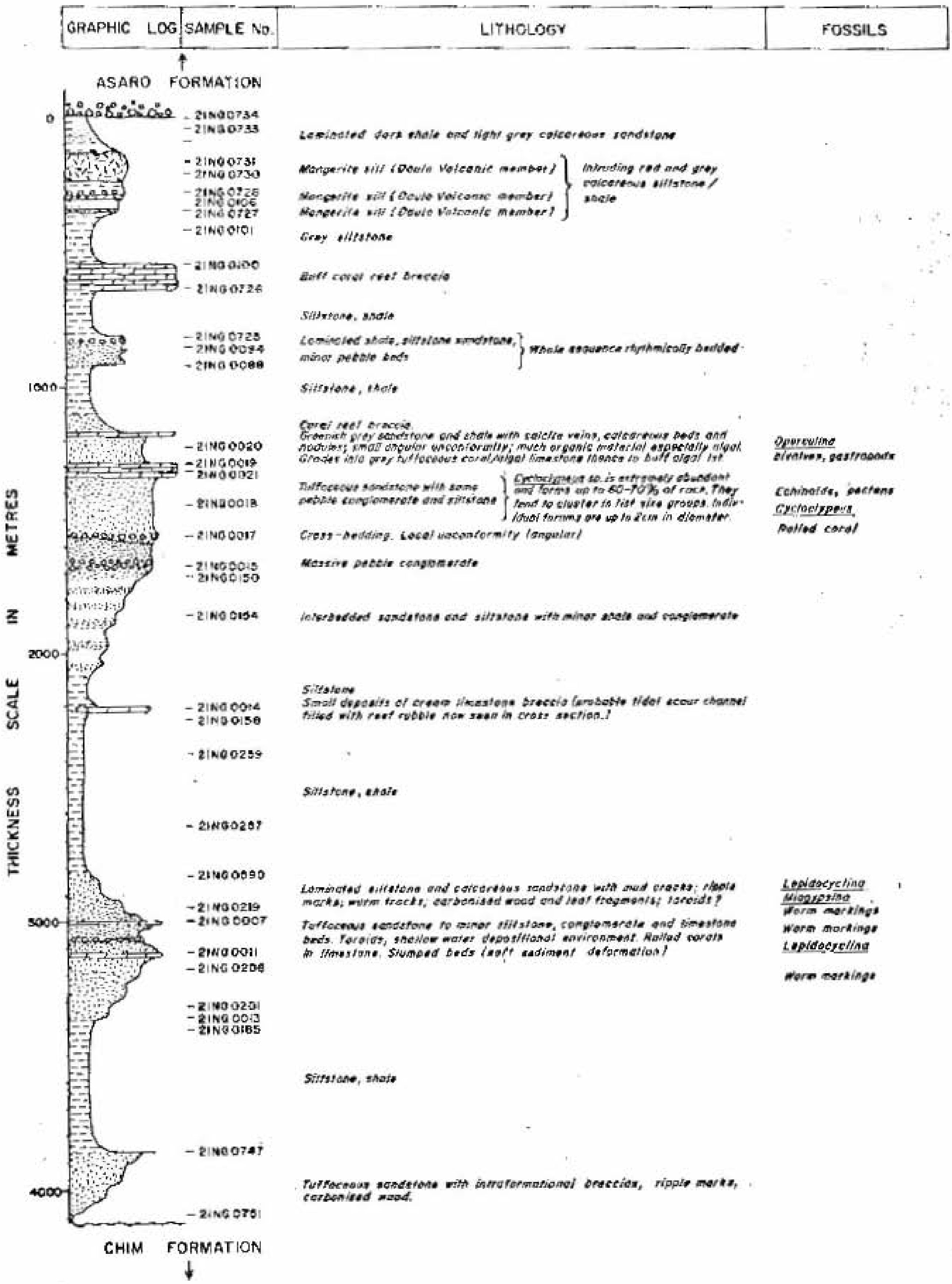


Fig.23 Toroids? developed on bedding plane in tuffaceous sandstone of the Movi Beds in the Asaro River about 6 km NW of Lufa. Locality 21NG0006 Neg.GA1267

Fig. 22a.

MOVI BEDS — ASARO RIVER SECTION



M1

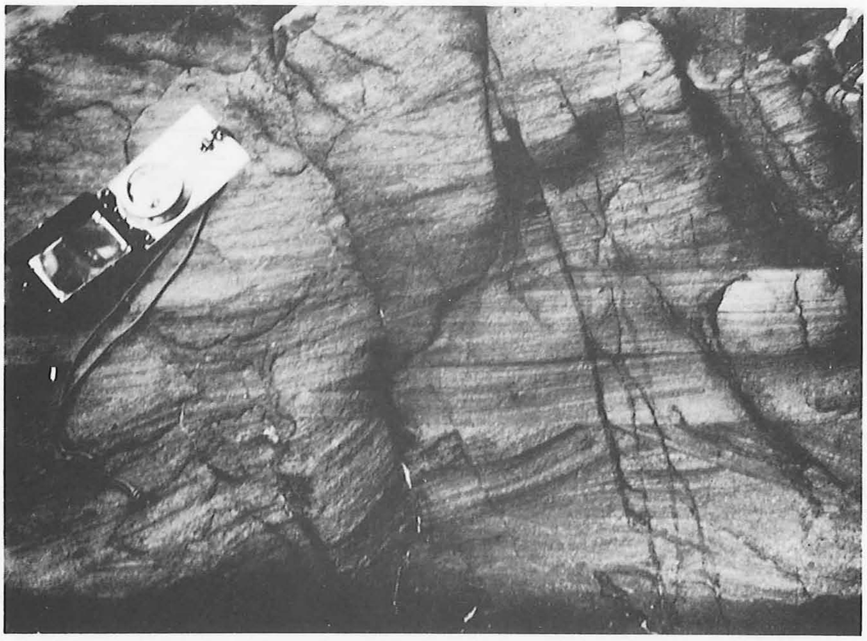


Fig. 24 Cross bedding in tuffaceous Lower Miocene sandstone of the Movi Beds. Medium scale cosets (10cm-20cm) associated with pebble beds, toroids, ripple marks, scour channels, small slumps and minor unconformities indicate 2 shallow water marine or lacustrine sequences. Scale: Compas is 18 cm long. Neg. GA1240

Fig. 25 Slumped beds of shale-siltstone of the Lower Miocene Movi Beds, exposed in the Asaro River 6km NW of Lufa. Locality 21NG0011. Neg. GA1222

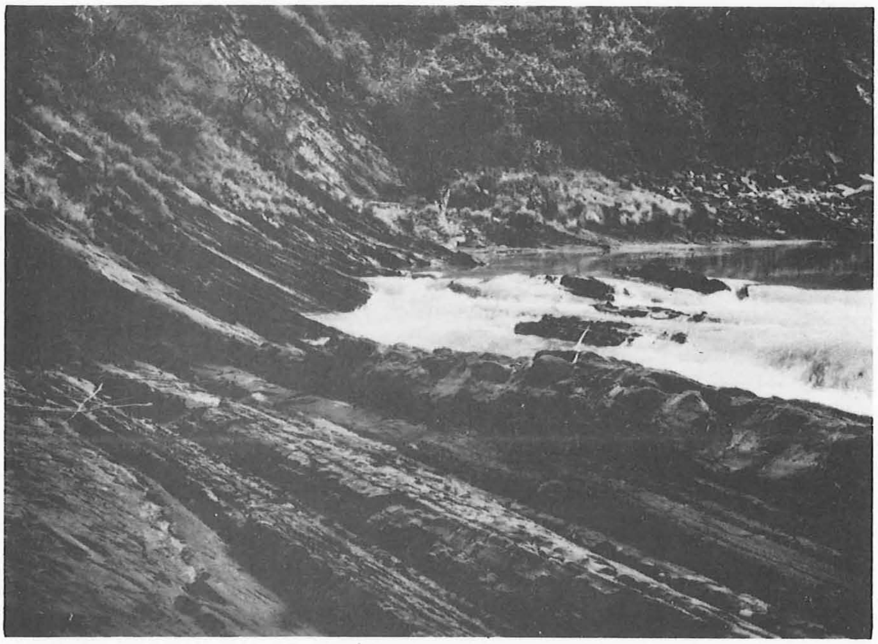


Fig.26 Interbedded sandstone and siltstone of the Lower Miocene Movi Beds in the Asaro River 6 km. NW of Lufa. Thickest bed approx. 30 cm. Neg. GA1269

coarse-grained and grades upwards from interbedded shale and sandstone (2-5 m beds) in the lower 300-400 m to massive sandstone, polymict conglomerate, and limestone in the middle and upper parts of the unit.

Green tuffaceous sandstone, massive, or in 1 to 2 m thick beds, is by far the most common rock type is this unit. Polymict round-pebble conglomerate containing pebbles of green and red chert, volcanics, quartz, limestone, siltstone, sandstone and gabbro forms beds and lenses 5 cm to 5 m thick in the sandstone. The uppermost 200 m of the unit is more thinly bedded and contains grey-green shale and siltstone, and two thick (10-20 m) limestone beds. The lower limestone is a buff algal limestone which grades upwards and downwards into calcareous tuffaceous sandstone; the upper limestone is a buff coral reef breccia.

Cross bedding, minor angular unconformities, pebble beds, calcite veins and calcareous beds and nodules are notable features. Immediately below the lower limestone bed there is a distinctive sandstone unit about 1-200 m thick in which *Cycloclypeus* sp. forms up to 60% of the rock. These foraminifera occur scattered throughout the sandstone, but mostly in fist-sized clusters. Individual specimens are up to 2 cm in diameter. Numerous echinoids and *Pecten*-like shells are also present in this horizon. *Operculina* sp., together with small gastropods and bivalves, are common in the beds between the two limestone units.

The uppermost 1100 m of the sequence consists of shales and siltstones with minor sandstone and pebble beds, and 100 m of buff coral reef breccia (550 m below the top). Three porphyritic hornblende mangerite sills (one 100 m thick) have intruded the upper 400 m of the section, and numerous faults have probably caused repetition in the highly disturbed shale beds. About 20 km south-southeast of the Asaro River section, the Movi Beds contain a 100-300 m thick calcareous unit which forms prominent cliffs on the southern slopes of Mount Michael. This unit consists of buff and pale grey clastic and reef limestone, calcarenite, lithic limestone breccia, and grit, and then beds of mudstone and shale. It is strongly folded and faulted, possibly partly as a result of forceful intrusion of the adjacent Michael Diorite.

Provenance

The siltstone, sandstone, and conglomerate were derived predominantly from andesitic rocks, although grains and small pebbles of chert, limestone, and plutonic and metamorphic rocks are commonly present. Chloritized fragments of lavas and pyroclastic rocks, partly sericitized and abraded feldspar grains, and iron-stained, altered ferromagnesian grains, were probably derived from the late Mesozoic formations exposed on the Miocene Kubor landmass. Reworked Chimbu Limestone is the probable source of most of the calcareous detrital material. However, a large proportion of the clastic material consists of fresh plagioclase and ferromagnesian crystals and fresh to partly altered volcanic rock fragments which are identical in appearance to the many lava types present in the overlying Daulo Volcanic Member. This last observation suggests that the Daulo Volcanic Member may interfinger with the Movi Beds in the unexposed axial parts of the Yaveufa Syncline. The age ranges of the Movi Beds and Asaro Formation are consistent with this hypothesis, although no lavas have been found within the Movi Beds.

M4

The large amount of fresh crystalline material of volcanic origin intimately mixed with material derived from the Kubor-Bismarck landmass (Fig. 26a) in these sediments suggests that the volcanic detritus was originally deposited on this landmass as tuff and lava. Further, the freshness of this volcanic material indicates that this landmass was rapidly eroded: the abundance of wood fragments in the sediments 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 sediments in the southern part of the Aure Trough.

The scarcity of granitic detritus in sediments close (0.20 km) to the Bismarck Intrusive Complex indicates that the Complex was not exposed during the deposition of the Movi Beds. Known pre-Tertiary plutonic bodies (Kubor Granodiorite, Mt Victor Granodiorite, and several small, unnamed intrusives in the Goroka and Bena Bena Formations) are either greater than 40 km distant from the Miocene sedimentary basin or less than 5 sq km in surface area, and have not contributed much sediment.

Depositional environment

The thickness of sediments (4,000 m), the abundance of wood fragments, and the presence of coral reefs and shallow water sedimentary structures indicate deposition close to a landmass in a shallow subsiding basin. The basin was the northwestern-most extension of the Aure Trough, and shallowed considerably towards the northwest. This is indicated by thinning of the sequence from 4,000 m in the Asaro River section to less than 500 m in the Chimbu Valley. In the Chimbu area, there is a greater proportion of limestone,and the siltstone is more calcareous than in the Asaro River area. Lateral thinning and facies changes indicate that the basin was only slightly more extensive than the present-day outcrop area (Fig. 26a). The Yaveufa syncline sequence was deposited in a narrow marine inlet (Yaveufa Inlet) some 25 km by 50 km in area, surrounded by deeply dissected mountains. Water depths were variable with a consistent overall increase in depth towards the open sea (Aure Trough). Thus sediments in the southeastern-most part of the map (Aure Trough) are less calcareous than those in the Yaveufa Syncline and have deep water turbidite characteristics.

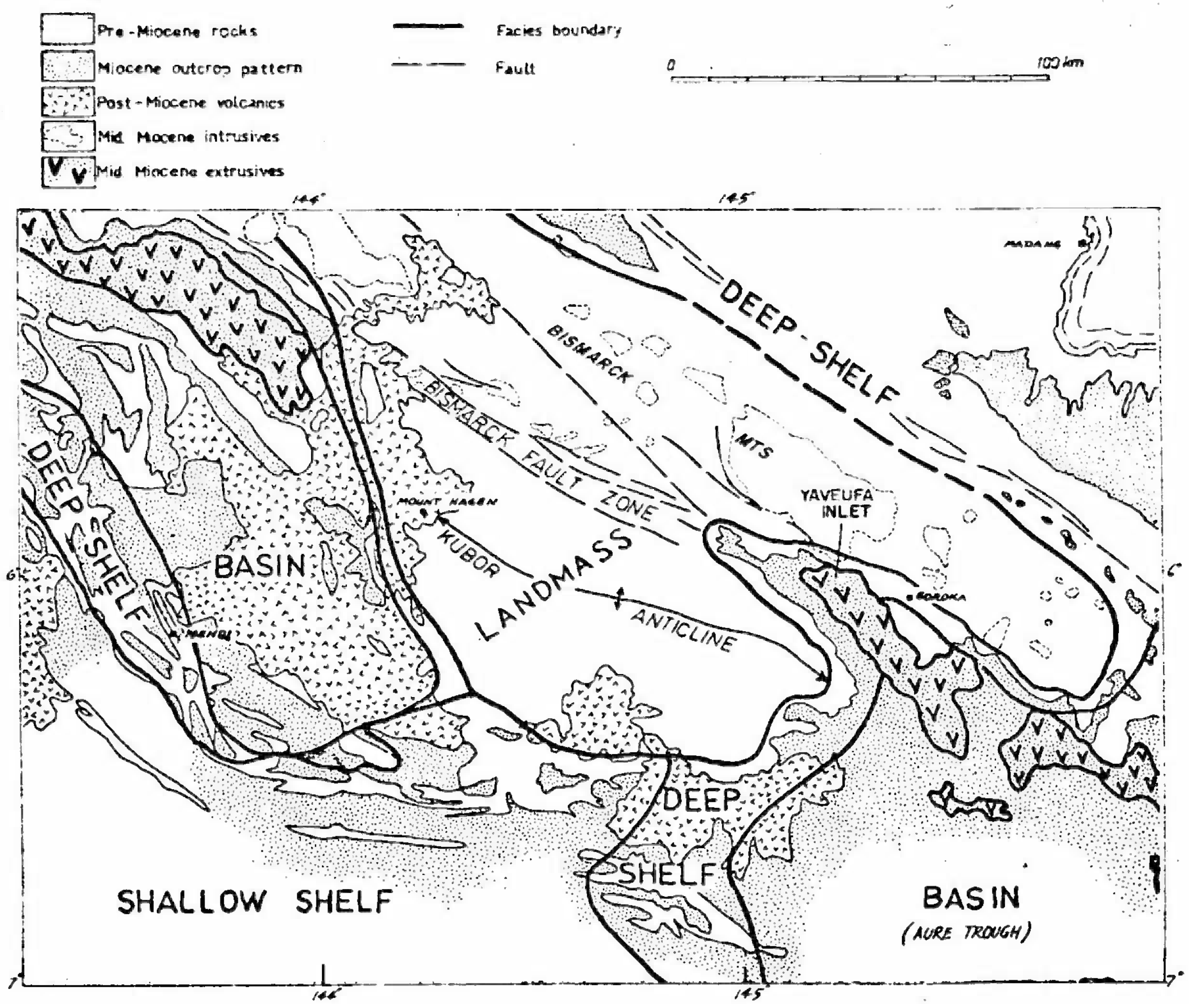
Figure 26(a) is a simple reconstruction of the Miocene palaeogeography of the map area and adjacent regions, based on the work of Jenkins et al. (1970) and incorporates their information for the Mendi area. The facies boundaries shown correspond approximately with the boundaries of the various Miocene formations. For example the "shallow shelf" area contains only Darai Limestone; the "deep shelf" areas contain Nembi Group (Jenkins et al., 1969) in the Mendi area, Puri Limestone (Rickwood & Kent, 1955) in the area between the Darai Limestone and Aure Trough, and Movi Beds in the Goroka area. The "basin" areas contain rocks of the Movi Beds and Asaro Formation (in the Aure Trough); the Burgers Formation (Dow et al., 1968) in the western basin, and Aure Group (undifferentiated) in both basins. The "Landmass" consists of Palaeozoic and Mesozoic formations and sub-surface Miocene intrusives.

The basin west of Mt Hagen and the Aure Trough, were connected only by very shallow seas south of the Kubor Anticline. The Kubor Anticline was a land area and did not receive any Miocene sediments.

MS

Fig. 26a

MIOCENE PALAEOGEOGRAPHY



855/A/18

Lower Tf Stage (Middle Miocene)

Asaro Formation (name varied)

Nomenclature

The lower Tf Asaro Conglomerate (volcanolithic conglomerate and greywacke) of McMillan and Malone (1960, p. 34) interfingers with and grades into contemporaneous basic volcanics which they called "Daulo Volcanics." It is not possible to map these units separately, and thus the volcanolithic sediments and volcanics are here renamed the Asaro Formation and the Daulo Volcanic Member respectively. This follows the pattern of nomenclature adopted for correlative rocks which are exposed 270 km to the west in the Burgers Mountains (i.e. Burgers Formation and Tarua Volcanic Member) and proposed for other lower Tf volcanolithic sediments and intermixed volcanics in Papua and New Guinea. In this report, the Lamari Conglomerate mapped near Okapa and Kainantu by Dow and Plane (1965) is included in the Asaro Formation. The Daulo Volcanic Member is discussed separately.

Distribution and thickness

The Asaro Formation crops out in a 10 to 15 km wide belt along the western side of the Goroka Valley from Mount Kerigomna to the Okapa and Kainantu area 100 km to the southeast. Within the map area, the formation occurs wholly within the Yaveufa Syncline. About 8 km north of the Asaro River gorge the maximum thickness of the formation including the well-developed volcanic member has been estimated from the airphotographs as 4,800 m. However, the formation thins appreciably to the northwest and southeast, and appears to thicken in the trough of the syncline. The Yaveufa Syncline is thought to represent the original lower Tf depositional basin, only moderately deformed and eroded. From about 13 km north of Lufa to the vicinity of Mt Kerigomna, the Daulo Volcanic Member predominates almost to the exclusion of the Asaro Formation. Elsewhere, the Daulo Volcanic Member is 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

The topography developed on the Asaro Formation and Daulo Volcanic Member is characterized by high to moderate relief, steep slopes, and a fine dendritic drainage pattern which is partly bedding-controlled. This drainage is particularly well developed in the grassy areas along the eastern limb of the Yaveufa Syncline.

Lithology

The Asaro Formation is mainly marine and is made up almost entirely of detritus derived from basic volcanics of the Daulo Volcanic Member. It shows extreme lateral variation. The volcanolithic sediments consist of waterlaid tuff, polymict volcanic pebble, cobble, and boulder conglomerate, greywacke, and calcarenite which commonly contains volcanic detritus.

The formation is named from the Asaro River. The type area is west of Kami (145°25'E; 6°13'S), where the Asaro River has exposed a complete section. This section has not yet been measured but thickness has been estimated from airphotographs. It consists largely of coarse polymict volcanolithic conglomerate and agglomerate. Siltstone, tuff, greywacke and limestone lenses are relatively minor.

Traverses across the Yaveufa Syncline, about 13 km north of the Asaro River gorge (also Stanley, 1950), reveal great lateral variation in the succession, the Daulo Volcanic Member being common in the upper parts of the sequence. About 1,000 m of massive chocolate and red-coloured tuffs and porphyritic basic lavas are overlain by a lenticular coralline limestone body which is about 80 m thick and contains Miogypsina sp. This is in turn overlain by another 1,000 m (approx.) of conglomerate, tuff and fine agglomerate which contains a few thin beds of siltstone and pink and chocolate-coloured gritty limestones containing Miogypsina sp. A further 2,000 m (approx.) of agglomerate, tuff and lava make up the remainder of the sequence.

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

In the Kainantu-Okapa area the formation has been described by Dow and 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 unabraded 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 lenses of reef limestone indicates shallow water deposition.

Petrography

Suites of samples were collected from two outcrops of volcanolithic conglomerate, one from 7.5 km north of Movi Mission, the other from 12.1 km east-south-east of Movi Mission. The first outcrop (21NG2504) consists of angular to subrounded cobbles and boulders of augite "andesite" (see Daulo Volcanic Member petrography) in a matrix of ferruginized augite latite tuff which contains 5 percent sanidine. The second (25NG2533) is a coarse polymict conglomerate with a varied assemblage of rounded boulders and cobbles in a pebbly sandstone matrix composed of fragments of fine-grained volcanic rock, and augite and plagioclase crystals. The clasts include:

Olivine-augite "andesite" (3 samples)
altered andesitic welded ash flow tuff (3 samples)
hornblende-augite "andesite"
biotite-augite "andesite"/latite
altered olivine-augite "andesite"
olivine-augite-albite analcitite (metamorphosed?)
fine-grained white limestone

M8

Age and Stratigraphic relationships

North of Lufa the Asaro Formation conformably overlies upper Te to lower Tf Movi Beds which are exposed to the north and southwest of the unit, but are absent or concealed in the Goroka Valley. Where volcanic rocks are present, the base of the formation is put at the first major lava or agglomerate bed. Where the volcanics are absent, the boundary between the Movi Beds and Asaro Formation is gradational over several hundred metres, and it is put arbitarily at the first major volcanolithic conglomerate. In the Okapa area, the Asaro Formation unconformably overlies lower Te Omaura Greywacke (Dow & Plane 1965); it overlaps progressively older beds near Asempa and Sonofi villages, and four miles (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 foraminifera (Stanley et al., 1950, McMillan & Malone, 1960). Recent isotopic age determinations (Page and McDougall, 1970a) confirm the lower Tf age of the Daulo Volcanic Member. Only Quaternary alluvial deposits overlie these beds.

The Asaro Formation is thus a correlative of the Burgers Formation, Karawari Conglomerate, and Wogamush Beds to the northwest (Dow et al., 1968) and the Kapau Sub-Group (Smit, in prep.) and Talama Volcanics (Macnab, 1970) to the southeast. All of these formations formed part of a narrow Miocene volcanic arc that extends from the Vogelkop in West Irian to within a few tens of kilometres of Port Moresby (Dow and Bain, 1970).

Daulo Volcanic Member (name varied)

Distribution and thickness

Volcanic rocks of the types first mapped near Daulo (6°02'S, 145°14'E) by McMillan and Malone (1960) extend from 7 km west of Mount Kerigomna (i.e. 6°S, 145°05'E) southeast to within a few kilometres of the Asaro River, northeast of Lufa. Outcrop width ranges up to a maximum of 15.3 km, northeast of Movi Mission, and the maximum thickness is approximately 4,800 m in the same area. At their northern extremity, the volcanic rocks grade into volcanolithic and lithic sandstones, siltstones, and mudstones, and limestones. At the southern margin, the gradation is into volcanolithic conglomerates and associated sandstones, tuffs, siltstones and shales.

Lithology

The Daulo Volcanic Member is predominantly coarse red, purple, or multicoloured polymict agglomerate. Interbedded with this are lesser amounts of reddish or dark grey to black porphyritic basic lavas, and welded ash flow tuffs. Zeolites are common, particularly in the agglomerates, filling vesicles and other cavities and forming veins. The agglomerates consist of angular to subrounded fragments of porphyritic, commonly zeolitic and/or amygdaloidal basic lavas in a zeolite-bearing gritty crystal-lithic tuff matrix.

Petrography

The petrography of a number of samples of lava, volcanic rudite from the Asaro Formation, agglomerate, welded ash flow tuff and tuff is summarized in Table 3. 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"
augite - olivine basalt or shoshonite
(hornblende) augite olivine basalt
absarokite
augite - olivine analcitite
(biotite) augite - olivine - analcite "basanite"
augite - olivine - analcite basanite
(olivine-)augite-analcite mugearite or latite
augite - analcite latite
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 (commonly partially or completely altered) in the combinations listed above. These are set in a fine-grained groundmass of plagioclase, augite and opaque iron oxides, chiefly magnetite. Interstitial to and mantling the groundmass plagioclase are small amounts (up to 5%) of potash feldspar (sanidine where specifically identified). The "andesites" containing olivine have less hornblende and more potash feldspar than those without olivine.

The basalts consist of phenocrysts of labradorite, pale green augite, partly to completely altered olivine, and in one case, a little hornblende pseudomorphed by magnetite, in a groundmass of labradorite, augite, magnetite (up to 10 percent) and in one specimen, secondary green biotite. Specimen 21NG1075 B (Fig. 27) is a rock type which is not common in the Daulo Volcanic Member. It consists of large augite and olivine phenocrysts in a groundmass of plagioclase, biotite, augite, ilmenite and interstitial alkali feldspar; in accordance with the nomenclature of Joplin (1968) this rock is an absarokite.

Two specimens of augite-olivine analcitite were collected from widely separated areas in the Daulo volcanics. These rocks consist of euhedral phenocrysts and smaller crystals of analcite (X-ray diffraction and electron microprobe determinations), very pale brown augite, and partly to completely altered olivine (see Figs. 28, 27 and 30). The more altered specimen, in which the analcite is very turbid and shows ghost cross-hatched multiple twinning (Fig. 28), contains a small amount of sandine. Minor phases include magnetite, ilmenite and apatite. The (biotite-)augite - olivine - analcite and augite - olivine - analcite basanites are similar to the analcitites, but contain less analcite, up to 65 percent andesine, and up to 20 percent sanidine, with the above combinations of augite, olivine and (minor) biotite phenocrysts, and magnetite.

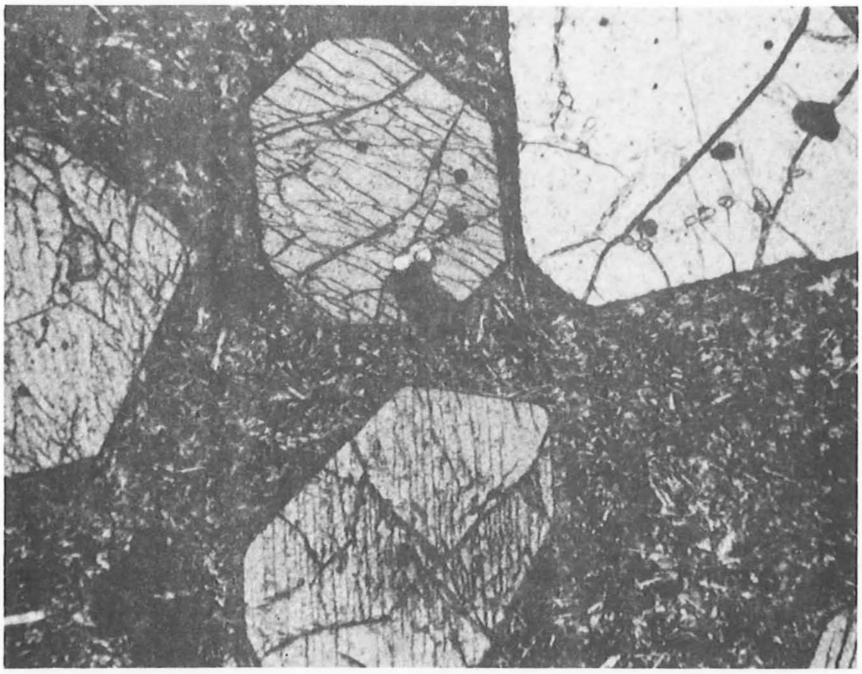


Fig.27 Absarokite (21NG 1075B) from the Daulo Volcanic Member. Large euhedral phenocrysts of augite and olivine, and microphenocrysts of titaniferous magnetite or ilmenite, in a groundmass of labradorite, augite, biotite, sanidine ilmenite and apatite. 45X, plane polarized light.
Neg. M/1021.

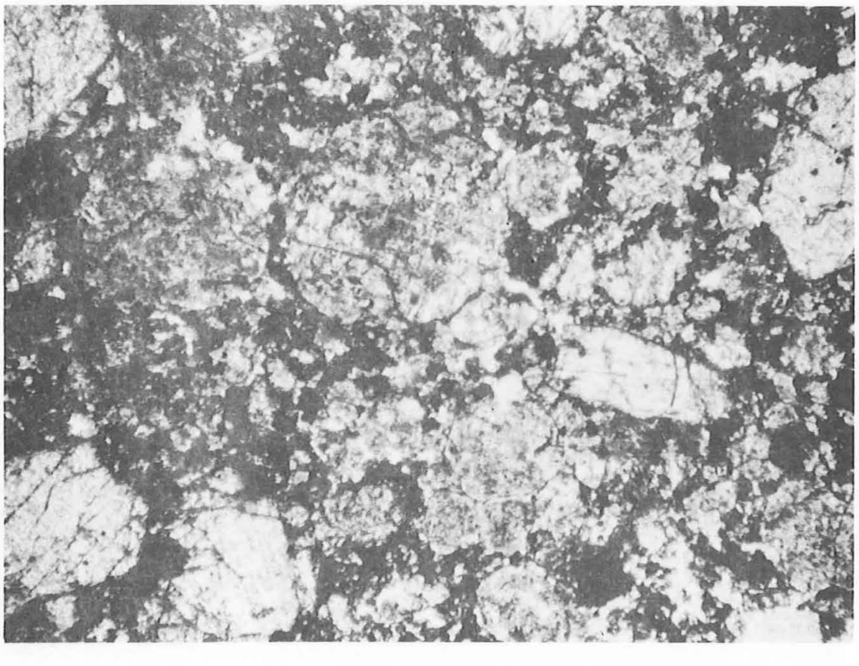


Fig.28 Olivine-augite analcitite (21NG2505), Daulo Volcanic Member. Shows phenocrysts of augite, and analcite with ghost cross-hatched lamellar twinning (near centre). Groundmass is augite, analcite, magnetite and orthoclase. Olivine not shown. 45X, plane polarized light.
Neg. M/1021.

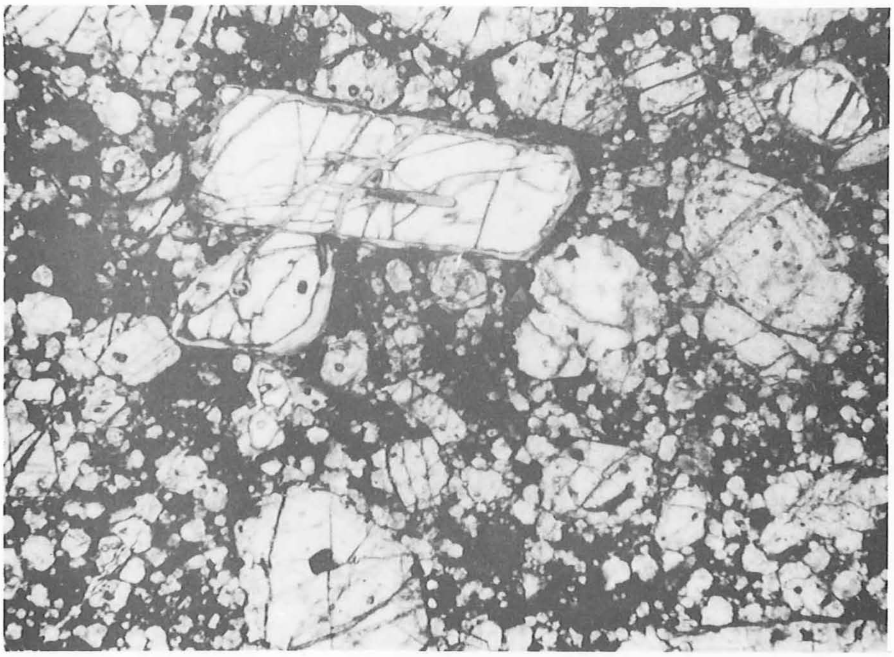


Fig.29 Olivine-augite analcitite (21NG 2037) from the Daulo Volcanic Member. Phenocrysts of zoned augite, partly altered olivine (two adjacent crystals, upper left) and analcite in a groundmass of analcite, augite, magnetite/ilmenite, apatite and altered glass. X45, plane polarized light. Neg. M/1021.

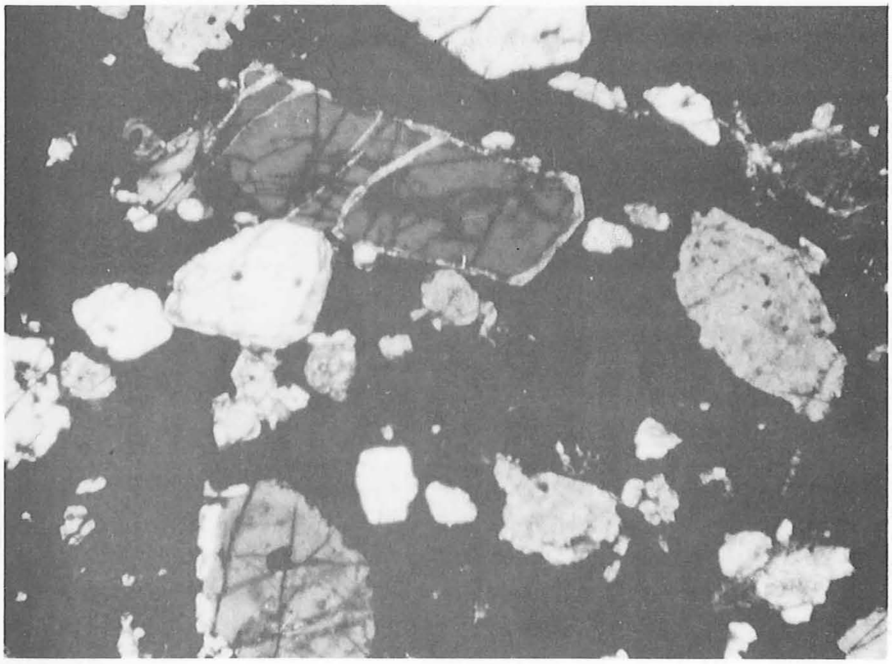


Fig.30 As for Fig.29. Crossed polarizers reveals amount of isotropic analcite present, and twinning in augite (top) Neg. M/1021.

Table 3 - Estimated modes of samples of the Daulo Volcanic Member

Specimen No.	Name.	Plagi-oclase %	Pheno-crysts	Quartz %	Alkali Feldspar %	Nepheline %	Augite %	Basaltic Hornblende	Olivine %	Biotite %	Magnetite &/or il-menite	Zeolites/analcite	Others
21NG 0630	High potash augite-olivine basalt (shoshonite)	70	Yes An 63	-	2-3	-	15	-	5	-	5 (mt)	-	Secondary muscovite or phlogopite, and serp-entine, in olivine
21NG 1075A	Hornblende-augite "ande-site"	80	Small	1+	1-2	-	2	3	-	-	3-4	-	Chlorite - 5% Prehnite-trace
21NG 1075B	Absarokite	40	Nil	-	5(?)	-	30	-	5g*	10g.o.+	7-8(ilm)	-	
21NG 1075C	Altered hornblende "ande-site"	50-60	Abundant	1-2	2-3	-	5-10 g.o	7	-	-	4	-	Calcite 2-3% Prehnite 1% Green secondary min-erals 20%
21NG 1077	Hornblende augite "ande-site"	70	altered	1-2	5	-	10	-	-	-	3-4	Laumontite(?) 1-2%	Calcite 1% Apatite (trace)
21NG 2031	Incipiently metamorphosed augite "andesite"	57	No	-	-	-	35	-	-	-	2	Wairakite(?) 2%	Chlorite 3%, epidote 2%, sphene-trace.
21NG 2034	(Biotite-) augite-olivine -analcite "basanite"	65	Rare (ande-sine)	-	1-2	-	20	-	5-7	1	1-2	Analcite 5-7% (primary)	Apatite (trace)
21NG 2035	(Alkali)augite-olivine-analcite trachyte				Sanidine 60+		15		tr(orig 5%	2-3	2-3(mt)	Primary analcite 10%	Chlorite 1-2%. Biotite (tr)- after olivine
21NG 2036	(Olivine-) augite-analcite trachyte or latite	5-10		-	Sanidine 25-30	-	35	-	Orig. 3-4	-	5 (mt)	Primary analcite 15%	Apatite 1-2%. Chlorite, muscovite opaques after olivine
21NG 2037	Augite-olivine analcitite	-		-	-	-	25	-	7	-	2(mt-ilm)	Primary analcite 25%	Apatite (trace). Inter-stitial chloritized glass, with opaques, micas.
21NG 2041	Augite-olivine-analcite basanite	Feldspar 40%(plagioclase & sanidine)				-	25	-	5(bowlingi-tized)	trace	3 (mt)	Primary analcite 15%. Indet.zeo-lite (tr)	Chlorite 10%; muscovite (tr); calcite 1%; apatite (tr).
21NG 2044	Augite-analcite latite	54	Yes	-	20(?)	-	10	-	-	-	8 (mt)	Analcite (primary) 1%; analcite (sec-ondary) 1%	Apatite 1%; chlorite 5%.
21NG 2053	(Olivine) augite analcite mugearite or latite	40-45	Micro	-	15-20 (sanidine)	-	10	-	(5) (repl)	-	7 (mt)	Primary analcite (altered) 15%	Hydrated Fe oxides 3%. Alt. products of olivine 5%.
21NG 2500A	Hornblende augite "andesite"	60-75	Nil	2-3	5 sanidine pheno.	-	10	5	-	-	5 (mt)	5-10% Laumontite	Chlorite-secondary Apatite (trace)
21NG 2502A	Basic augite latite	60	altered	-	5-10 sani-dine(?)	-	20	-	-	-	1-2(mt)	-	Calcite 1-2% Chlorite 2-3% Epidote 3-5%
21NG 2504A	Augite andesite	30-35	An 40 abundant	-	-	-	10-15	-	-	-	2-3(mt)	rare	Groundmass 50%-plag. and altered glass: chl.
21NG 2504B	Augite andesite	65	" "	-	-	-	20	-	-	-	2-3(mt)	-	Bright green chlorite 1-25%; calcite 5%
21NG 2504C	Augite andesite	Similar to 2504B - a more altered groundmass; cavities filled by chlorite and actinolite(?)											
21NG 2504D	Ferruginized augite latite tuff(?). Matrix of volcanic rudite	45	An 47	-	5 sanidine(?)	1	15	-	-	-	-	1-2% fibrous	Ferruginized groundmass 30%
21NG 2505	Olivine-augite analcitite	-	-	-	2-3(Or)	-	30	-	5 (alt.)	-	5-7(mt)	25-30% analcite 2% natrolite?	Apatite (trace)
21NG 2506	Augite-analcite basanite(?) In agglomerate	40(-)	altered	-	-	-	25	-	-	-	7-8(mt)	30-35% analcite	Calcite 1%

Table 3 - Estimated modes of samples of the Daulo Volcanic Member (contd)

Specimen No.	Name	Plagi-oclase %	Pheno-crysts	Quartz %	Alkali Feldspar %	Nepheline %	Augite %	Basaltic Hornblende	Olivine %	Biotite %	Magnetite &/or il-menite	Zeolites/analcite *	Others *
21NG 2507	Ferruginized welded ash flow tuff												
21NG 2508A	Biotite-augite-andesite	50	altered	-	-	-	25	-		5(green)	10 (mt)	-	Secondary "iddingsite" and "bowlingite"
21NG 2508B	Altered, zeolitized olivine-augite basalt	10	v. "	-	-	-	15	-	2-3	-	-	60% natrolite	Ferruginized groundmass 15%
21NG 2509	(Olivine) augite basalt	55	An70 30%	-	-	-	20	-	pseudomorphed by biotite	10 (green)	10+(mt)		"Bowlingite" 5%
21NG 2524	(Olivine) augite basalt	35+	micro	-	-	-	40 (-)	-	5(altered)	-	5(mt?)	-	Devitrified glass 15% Biotite-bowlingite-iddingsite after olivine
21NG 2524A	(Hornblende-) augite-olivine basalt(alkaline)	70	No An 50	-	1	-	10	1, orig. 3%	2-15	-	2 (mt)	heulandite(?)-trace	Secondary iddingsite in olivine
21NG 2529	Andesitic crystal tuff	75	An 47	-	-	-	10	-	-	-	5-7(mt?)	-	Rock fragments 5% Matrix 50%
21NG 2531	Hornblende-augite "andesite"	80(-)	altered	-	trace	3(?)	10	3-5	-	-	5-7(mt)	-	Analcite 1%
21NG 2533A	Hornblende-augite-olivine "andesite"	75	No	-	2-3	-	10-12	1, orig. 7	(2)replaced	-	3-4(mt)	analcite indet. zeolite trace	Iddingsite, bowlingite; mica after olivine. Trace de-vitrified glass.
21NG 2533B(1)	øAltered andesitic welded ash flow tuff	15-20		-	-	-	-	2-3	-	-	-	-	Altered glassy matrix 69%, rock fragments 10%
21NG 2533B(2)	øAltered andesitic welded ash flow tuff	Similar to 2533B(1); rock fragments include hornblende tonalite; contains natrolite (?) contains more hornblende than 2533B(1)											
21NG 2533D	øBiotite-augite "andesite" latite	80	present	--	-	-	10-12	-	-	5	5 (mt)	-	
21NG 2533E	ø(Olivine) augite "ande-site"	75	An 48	-	trace	-	20	-	altered	-	3 (mt)	-	Iddingsite (after olivine 2%, apatite (trace)
21NG 2533F	øOlivine-augite "andesite"	70	present	-	-	-	15	-	5 (largely altered)	-	5 (mt)	-	Altered glass 2-3%. Chlorite, epidote, etc.
21NG 2533G	øOlivine-augite "andesite"	75		-	trace	-	10	-	8 g	-	7 (mt)	-	Apatite (trace)
21NG 2533H	øLimestone	0.15 to 0.20 mm calcite crystals with rare grains of quartz, plagioclase, and fine-grained volcanic rock fragments											
21NG 2533I	øAltered andesitic(?) welded tuff	15						5			2		Volcanic rock fragments 5%; glassy matrix 73%
21NG 2533J	øHornblende-augite "ande-site"	70	present	-	-	-	15	1-2	-	-	10(mt)		Red-brown Fe oxides 2-3%
21NG 2533L	øAltered olivine-augite "andesite"	65	present	-	-	-	20	after olivine	5 (pseudo-morphed)	after olivine	5-7(mt & ilm)	2-4% wairakite	Calcite (trace); apatite (trace); Fe oxides
21NG 2533M	ø(Olivine) augite-albite analcitite(metamorphosed)	30 Albite		-	-	-	15	-	2	-	5-7(mt)	1% analcite	Apatite 1%
21NG 2533N	ø(Hornblende)-augite "andesite"	85	present	-	-	-	5	1	-	-	5+ (mt)	trace (fibrous)	Chlorite 2%

*Present in the groundmass. +Present in groundmass only. øPebble, cobble or boulder in volcanic rudite.

Specimen 21NG2053 is an (olivine) augite - analcite mugearite or latite, consisting of phenocrysts of augite, altered primary analcite and olivine, and microphenocrysts of plagioclase and magnetite, in a groundmass containing sanidine (15-20 percent of the rock), plagioclase, analcite, augite and magnetite. Specimen 21NG2044, an augite-analcite latite is similar, but lacks olivine, and contains about 20 percent sanidine. The augite-olivine-analcite trachytes, 21NG2035 and 2036, consist of phenocrysts of augite, olivine and analcite in a groundmass of sanidine (60 percent in 2035, 25-30 percent in 2036), plagioclase (5-10 percent in 2036 only), analcite, magnetite and secondary minerals.

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

Specimens of welded ash flow tuffs from the Daulo Volcanic Member consist of fine-grained and altered glassy volcanic rock fragments 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.

Specimen 21NG2529 is an andesine-rich crystal tuff, also containing augite, fragments of fine-grained volcanic rock and a large clast of hornblende microdiorite, in a very fine-grained dusty matrix.

The samples listed in Table 3 are characterized by the absence of orthopyroxene, the rarity of quartz and the common occurrence of analcite and potash-rich phases such as potash feldspar and biotite. These features indicate an undersaturated, alkali-rich chemistry; those types containing abundant primary analcite are undersaturated and highly sodic, while those containing alkali feldspar and biotite are probably high potash (or shoshonitic) types. Several samples, classified as "andesite" in Table 1, are not true andesites, because they lack orthopyroxene and some contain small amounts of alkali feldspar in the groundmass. These and two of the basalts are high potash, near-saturated or saturated varieties, intermediate in character between true calc-alkaline hornblende andesites and their shoshonitic or normal alkaline equivalents.

The following are analyses of samples of Daulo Volcanic Member from Page (1971):

Sample No.	Rock type	K_2O%	Locality
21NG 2033 (GA 5639)	brecciated lava	6.88	Daulo Pass
" 2034 (GA 5640)	analcite basanite	7.37	Daulo Pass
" 2035 (GA 5641)	" "	4.52	Daulo Pass
" 2036 (GA 5642)	" basalt	2.95	Daulo Pass
" 2037 (GA 5643)	" "	1.37	Daulo Pass
" 2044 (GA 5645)	" trachyte	3.95	3.2 km SW of Kenangi
" 0630 (GA 5870)	pyroxene andesite	2.38	9 km S of Oliguti
" 2533A(GA 5872)	andesite	2.26	13 km NW of Oliguti

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The first three are unusually high in potash, and are comparable in this respect to the leucite-rich lavas of Uganda (Holmes & Harwood, 1937). All except 21NG 2037 are high in potash relative to their inferred silica content. Much of the analcite which appears to be a primary phase in these rocks bears striking morphological similarities to leucite, and has possibly formed as pseudomorphs after leucite. Much of the freed potash may have formed interstitial potash feldspar. If this is so, it may account for the high potash contents of the analcite-bearing lavas; when erupted, they may have been similar to the Ugandan leucitites and leucite basanites. The high potash(?) andesites (0630 and 2533A) are similar to some of the Pleistocene Highlands volcanoes lavas.

Age

Page and McDougall (1970a) have dated specimens of the Daulo Volcanic Member at 8.3 to 15.0 million years, by the K/Ar method. Only the ages between 12.5 and 15.0 million years were considered reliable. The volcanic rocks interfinger with sedimentary rocks bearing a lower Tf microfauna (D.J. Belford pers. comm., 1969). Thus the Daulo Volcanic Member is restricted in age to the lower middle Miocene.

Origin

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

Underlying the Miocene rocks is a thick sequence of Mesozoic sediments overlying a basement which probably includes Palaeozoic metamorphic rocks and late Palaeozoic to early Mesozoic intrusive rocks. Joplin (1968) has pointed out that rocks of alkaline and shoshonitic chemistry are typically developed in relatively stable continental areas which have commonly undergone either upwarping and block faulting (alkaline magmas) or recent stabilization (shoshonites). Calc-alkaline lavas are usually generated in active island arc environments, such as Japan and the Kurile arc. The Daulo volcanics have been extruded in an area with some characteristics of both island arc and continental tectonics, and this may be the reason for the indistinct and mixed affinities of the volcanic rocks.

QUATERNARY

Pleistocene

The Highlands Volcanoes

General description

Mounts Hagen, Giluwe, Ialibu, Suaru (Figs 31, 35) and Karimui (Fig. 34), and Crater Mountain are large Quaternary stratovolcanoes which have developed on the outer western, southwestern and southern flanks of the Kubor Anticline (Fig. 32). The volcanoes are believed to be Pleistocene

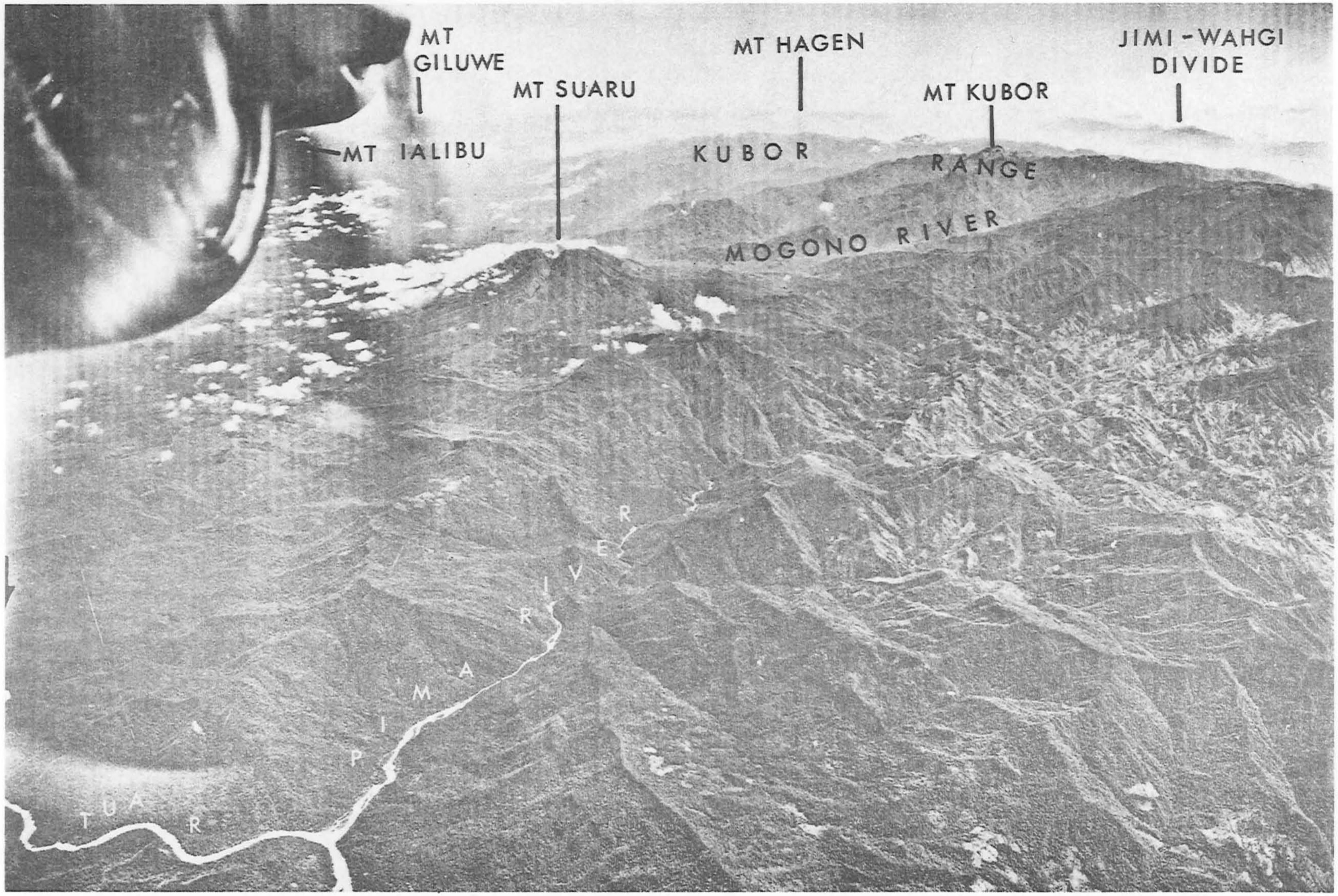

Fig.31 Southern flank of the Kubor Range, viewed to the North West.
33LT-5RGL M718 338RS 1948,6" 26,000 ft CPE 7614.

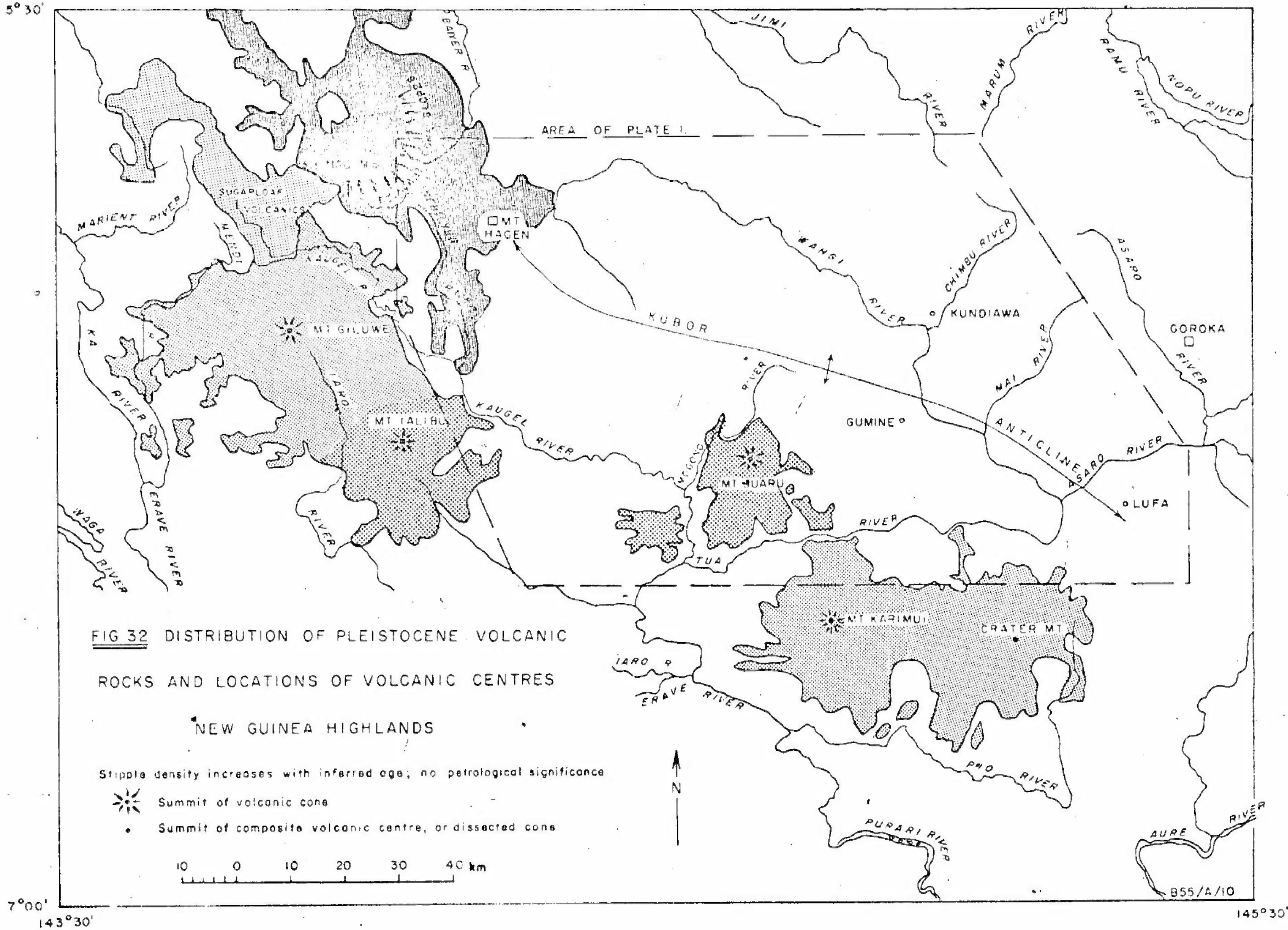

FIG 32 DISTRIBUTION OF PLEISTOCENE VOLCANIC ROCKS AND LOCATIONS OF VOLCANIC CENTRES NEW GUINEA HIGHLANDS

in age, and some have been affected by late Pleistocene glaciation (Perry, 1965; Blake and Löffler, 1971). The dimensions of the volcanic cones may be summarized as follows:

Name	Summit height above sea level (metres)	Cone diameter (km)
Mount Hagen	3,762	25+
Mount Giluwe	4,160	20
Mount Ialibu	3,465	16
Mount Suaru	2,665	12
Mount Karimui	2,570	14
Crater Mountain	3,200	no single major cone

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

Mount Hagen appears to be the oldest of the volcanoes on the grounds of its state of preservation. Its northern and western slopes have been almost completely removed, leaving a large area of deep, steep-sided valleys. The elliptical outline of the volcano is still apparent in the less deeply eroded southern and eastern slopes; this shape suggests that the volcano is composite. Remnants of cirques and moraines on the jagged, rocky crest of Mount Hagen are the result of late Pleistocene glaciation (Perry, 1965; Blake & Löffler, 1971). A 200m high satellite cone has developed on the southeastern flank of the volcano, and several small cones are scattered over the apron to the east. Mount Hagen has the most extensive apron of the six volcanoes visited. Deposits, probably of lahar and nuée ardente origin, have been found in the Yuat River up to 130 km from Mount Hagen volcano (Dow et al., 1968). Lava and fragmental deposits extend 40 km south to the Kaugel River, 25 km east into the Wahgi Valley, and 50 km west to Wabag. The apron of Mount Hagen consists of layered tuff, rubble beds, lava flows, conglomerate, and lahar and nuee ardente deposits (commonly extremely poorly sorted, with blocks up to a metre or more across set in a sand to silt-size feldspathic matrix. Vesicular lava was found south of Kuta, 30 km southeast of the summit of Mount Hagen. Stratification and small-scale unconformities are present in tuff and ash exposed in cuttings along the Mount Hagen-Wabag road.

Mount Giluwe is probably the youngest of the six volcanoes, and it is the best preserved. The Kara Plug, southwest of Mount Ialibu, has been dated at 1.11±0.4 m.y. (late Pleistocene), and is believed to be linked with the Giluwe Volcanics (Buchan & Robinson, 1969). Much of the area of the volcano has suffered little erosion prior to or since the late Pleistocene glaciation (Blake & Löffler, 1971), although some streams are deeply incised into its upper slopes. Moraines, cirques, tarns, polished pavements and ragged exposures of plugs and dykes are evidence of a past glaciation of the mountain. Blake and Löffler also recorded the presence of intraglacial lava deduced to be about 25,000 years old. Giluwe has several small satellite vents and domes which are not shown on Plate 1. On the flanks of the volcano, about 16 km southeast of the summit, there are six small craters on and near an east-west trending, en echelon normal fault system (Plate 8). D.H. Blake (pers. comm., 1971) believes that these craters may be as young as 1000 years. There is a small, but prominent cone, with surrounding lava flows which extend 3 km to the east, 5 km northwest of Pabarabuk Mission (Fig. 33 and Plate 8). This cone may be linked with Mount Giluwe. Thin lava flows, lava domes, plugs and dykes were seen on the summit area of Mount Giluwe. The volcano is surrounded by an apron of vesicular lava, volcanic rubble, and ash (which commonly covers the other deposits).

Mount Ialibu, the least well known of the volcanoes, is highly dissected in the summit and northern flank areas, but the other slopes are well preserved. Perry (1965) judged Mount Ialibu to be Pleistocene; it is probably older than Mount Giluwe, but younger than Mount Hagen.

Mounts Suaru and Karimui (Figs 34, 35) are similar in size, appearance and state of preservation, and are both probably a little younger than Mount Ialibu. Each is cut by deep gorges: two large gorges have cut the cone of Mount Suaru almost in two, and Mount Karimui is eroded almost to base level on its southern side. Mount Suaru has two small satellite cones (Plate 15), one of which has a crater lake; a small cone composed of hornblende andesite 6 km east of the Pima River (Plate 15) may also be connected with Mount Suaru. Both Suaru and Karimui have produced mainly massive and vesicular lava, lesser agglomerate and rubble, and minor ash, tuff and lahar deposits.

Crater Mountain is the most complex of the volcanic centres in the area; it is made up of an extensive basement volcanic complex overlain by about twelve small, much younger cones, water-filled craters, and their associated lava flows. The basement complex, which may be as old as Pliocene, consists of thick piles of lava from at least three deeply-eroded eruptive centres, and covers an area of 700-800 sq km. Remnants of massive lava flows extend as ridge cappings north towards the Tua River and south almost to the Pio River (Fig. 32). A group of small, eroded centres at the western end of the complex is partly buried by lava from Mount Karimui. The almost uneroded younger centres and lava flows cover a large area of the older volcanics. Flows have extended down several stream valleys, one as far as the Tua River, another to the area of Agotu Mission (Plate 16), and have diverted a number of streams. These younger flows are covered by only small trees and are probably Recent.

Petrology

Sixty-seven samples from six volcanoes (Fig. 32) were examined. Details of the petrography are summarized in Table 4.

In hand specimen the rocks are generally light grey to black (colour depending to a great extent on grainsize and magnetite content as well as on ferromagnesian content) with phenocrysts (less than 1 mm to over 1 cm across) of white plagioclase, black pyroxene and/or hornblende and, commonly, green olivine. Few specimens are vesicular, and only a few display flow-alignment of microlites. Partly assimilated phyllite, amphibolite, diorite and quartzite xenoliths and quartz xenocrysts were found, in a few specimens.

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Fig.33 Small volcanic cone in the Nebilyer valley 22 km SSW of Mount Hagen township. Basaltic lava derived from this cone is interbedded with lava and agglomerate from Mount Hagen Volcano. Neg. GA2376

Fig. 34 N.E. slopes of Mount Karimui, deeply dissected Pleistocene volcano. Neg. GA2380

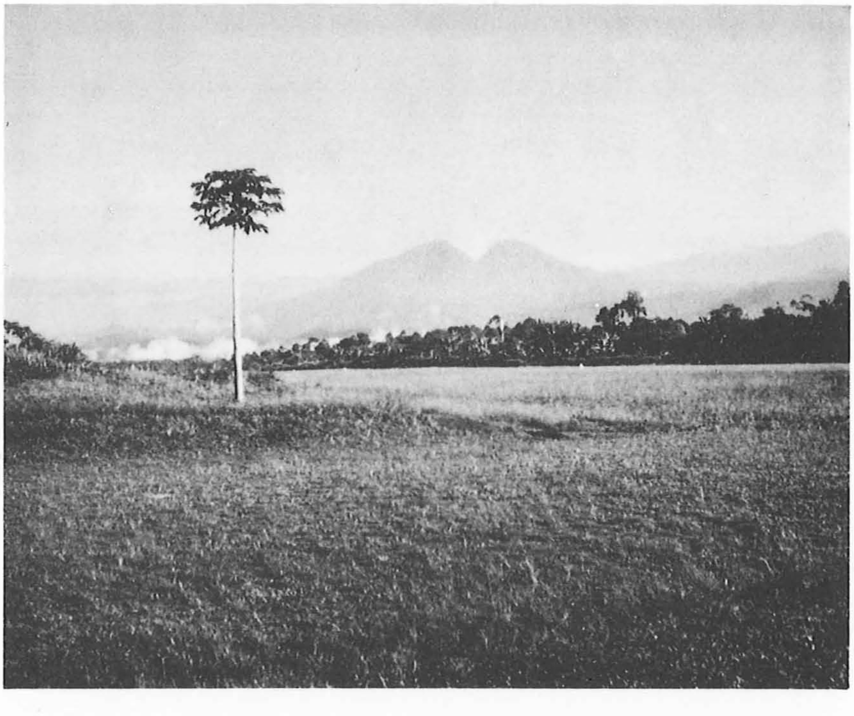

Fig. 35 Mount Suaru volcano viewed from Karimui airstrip. Note the deep V-shaped gorge bisecting the cone.
Neg. GA2921

Table 4 - Estimated Modes of Samples from the Highlands Volcanoes

Volcano; Sample No.	Rock Name	Plagioclase* %	Augite* %	Olivine* %	Hypersthene*+ %	Hornblende* %	Opaques$^{\phi}$ %	Alkali Feldspar %	Other
Mount Hagen									
11NG 0056A	Calc-alkali(?) hornblende-2-pyroxene basalt	60(An52-65)(P)	Augite and hypersthene 15% (P)	-	(P)(g)	10	10	-	Quartz (1%)
11NG 0056B	Calc-alkali(?) hornblende-2-pyroxene basalt	65(An52) (P)	10(P)	-	5-7(P)(g)	5	10-12	-	Apatite (trace)
11NG 0056D	Olivine basalt (high K,)	60(An64) (P)	25(P)	10(P)	-	-	5-7	2-3	Apatite (trace)
11NG 0059	Olivine basalt (high K;)	55(An52) (P)	20(P)	10(P)	-	-	5-8	5	Apatite (1%) Chloritized glass (trace)
20NG 0600	Olivine basalt (high K?)	40-45(An68-71)	20(P)	10(P)	-	-	2-3	trace	Altered glass (25-30%)
11NG 1113	Olivine basalt, (high K?)	70(An50-55)	15(P)	5-7(P)(g)	-	-	5	2-3	Apatite (1%) Altered glass(1-2%)
20NG 1199	Hornblende 2-pyroxene basalt(calc-alkaline?)	40(An55)	15(P)	-	15(P)(g)	5	5	trace	Apatite (trace) Analcite (1-2%) Xenoliths: siltstone (1%); quartz (2%)
20NG 1319	(Hornblende-)olivine-2-pyroxene basalt	55-60(An66)	15-20(P)	2-3(P)	10(g)	1-2	10	-	-
20NG 1320	Olivine basalt	60-65(An63)(P)	15-20(P)	5(P)(g)	10(P)(g)	-	3-5	-	-
Mount Giluwe									
13NG 0500	Olivine andesite or basalt	50(An32) (P)	30(P)	10(P)(g)	-	-	7	-	Apatite (trace)
13NG 0501	2-pyroxene andesite (calc-alkaline?)	75(An48) (P)	5	-	10(P)(g)	5 pseudomorphed by magnetite	8	-	-
13NG 0502	2-pyroxene andesite (calc-alkaline?)	60(And/labr.)	Augite and hypersthene 30%		-	-	5	-	-
13NG 0503	Olivine basalt (high K?)	75(An35-85)(P)	15(P)	5(P)	-	-	1-2	trace	Apatite (1%)
13NG 0504	Olivine basalt (high K?)	Same as 0503							
20NG 0601	Olivine basalt (high K?)	60(An68-70)(P)	15-20(P)	5(P)(g)	-	-	5	trace	
20NG 0603A	Olivine-hornblende basalt (high K?)	70(An62) (P)	15-20(P)	5(P)		1-2	2-3	trace	Apatite (trace) glass (trace)
20NG 0603B	Olivine basalt (high K?)	40(An72) (P)	30(P)	5(P)	-	-	5+	trace	Apatite (1-2%)
20NG 1006B	Hornblende-augite andesite(?)	Mineral percentages not estimated; 10% hornblende phenocrysts partly pseudomorphed by opaques.							
20NG 1006C	Hornblende-augite-andesite(?)	Similar to 1006B - hornblende more completely pseudomorphed.							
13NG 6007	Olivine basalt	73(An42-65)(P)	15(P)	5(P)	-	-	1-2	-	Apatite(trace)
Mount Ialibu									
21NG 0613	Olivine-andesine "basalt"	50(An47) (P)	20(P)	5-7(P)	-	-	5		Apatite (trace)
Mount Suaru									
21NG 1369B	Olivine basalt (high K?)	75(An63) (P)	10(P)	3(P)	-	-	7	trace	Apatite (trace)
21NG 1369C	Olivine-hornblende-2-pyroxene basalt	60-65(An50)(P)	20(P)	2(P)	1-2(P)	2-3	7	-	Calcite 2%, apatite (trace)
21NG 1369D	Olivine basalt	75(An55) (P)	15(P)	2(P)	-	-	5	-	Apatite (1%)
21NG 1369E	Olivine basalt (high K?)	70(An57-58)(P)	15(P)	5-8(P)	-	trace	5		Apatite (trace)
21NG 1369F	Olivine basalt	70(An55) (P)	20(P)	5(P)	-	-	3-4	-	Apatite (trace)
21NG 1369G	2-pyroxene andesite	70-75(An40)(P)	15(P)	-	5(P)(g)	-	3-5	-	Apatite (rare)
21NG 1369H	Olivine-hornblende-2-pyroxene basalt (calc-alkaline?)	60(an47-65)(P)	20(P)	5(P)	1-2(P)	5	7	-	
21NG 1370	Olivine basalt	60+	25(P)	5(P)	-	-	5+	?	
21NG 1383A	(Hornblende-) 2-pyroxene basalt	70-75(An54)(P)	10(P)	-	1-2(P)	1(relict)	5	?	Apatite (1%)
21NG 1383B		60-65(An63)(P)	5(P)	-	-	-	7	-	Apatite (trace)
21NG 1383C	Olivine basalt/ shoshonite	50(An63) (P)	20(P)	5(P)	-	-	5	up to 5	Glass (1%)
21NG 1435	Hornblende mugearite/ hawaiite	70(An42) (P)	-	-	-	15	1-2	10	Apatite (trace)

Table 4 - Estimated Modes of Samples from the Highlands Volcanoes (contd)

Volcano; Sample No.	Rock Name	Plagioclase* %	Augite* %	Olivine* %	Hypersthene*+ %	Hornblende* %	Opaques ø %	Alkali Feldspar %	Other
21NG 3039	Olivine basalt (high K?)	65(An68) (P)	25(P)	1-2(P)	-	-	5	trace	Calcite (2-3%) apatite (trace)
21NG 3040	Hornblende-augite basalt	80(An65) (P)	10(P)	-	-	5-7	2	-	Calcite (1%), apatite (trace) glass (trace)
21Ng 3040A		60-65(An31-56) (P)	25-30(P)	-	-	7	2-3	trace	Quartz (2-3%)
21NG 3040B	Basaltic andesite (high K?)	60-65(An42)(P)	25(P)	5	-	-	5+	trace	Calcite (trace) apatite (trace)
21NG 4040C	Olivine-augite andesite (high K?)	75(An38-41)(P)	15(P)	1-2(P)	-	1	5	trace	apatite (trace) chlorite (trace)
21NG 4045B	Olivine shoshonite/ hawaiite	60-65(An47-49) (P)		20(P)	5(P)	-	3-4	5	nepheline (1%) chlorite (2%) apatite (trace)
Mount Karimui									
21NG 0594A	Olivine basalt. Ferruginised.	Phenocrysts only 20 (An65)	Phenocrysts only 10	2-3	-	-	-	?	Altered groundmass 60-70% calcite (trace)
21NG 0594B	Ferruginized	25(An61-63)(P)	19(P)	-	-	-	-	-	Ferruginised glass 50%; zeolite 5%; chlorite, calcite (trace)
21NG 0594C	Ferruginized olivine basalt (high K?)	50(Andesine?) (P)	30(P)	Pseudomorphed (5)	-	-	10	trace	Goethite, limonite, etc. 10%; calcite, apatite (trace)
21NG 0594D	Ferruginised olivine basalt (high K?)	Similar to 0594C More Fe oxides; patches of zeolite (gismondine?)							
21NG 0594E	Ferruginised basalt	20(An55) (P)	10(P)	Altered	-	-	-	trace	Ferruginised glass (60%); calcite (1-2%)
21NG 0594F	Olivine basalt (high K?)	60(An50-52)(P)	20-25(P)	5(P)	-	-	5-10	trace	Apatite (1-2%) calcite (trace)
21NG 0594G	Altered olivine basalt	Similar to 0594C & D; at least 10% opaques; olivine all altered.							
21NG 0594H	Basaltic olivine andesite	60(An62-63)(P)	20-25(P)	3-5(P)	-	-	5-10	trace	Zeolite (1%) quartz (1%)
21NG 2859A	Olivine shoshonite (?)	60(An62-63)(P)	25(P)	7(P)	-	-	5-7	1	Apatite (2%)
21NG 2859B	Olivine shoshonite (?)	75(An50) (P)	15(P)	5(P)	-	-	5	1-2	Apatite (trace)
21NG 2859C	Olivine basalt (high K?)	65(An46) (P)	20(P)	5(P)	-	-	5	trace	Glass (5%)
21NG 2860A	Olivine basalt (high K?)	70-75(An40-62) (P)	15(P)	5(P)(g)	-	-	2-3	1	Apatite (1-2%)
21NG 2860B	Olivine-biotite basaltic andesite (high K?)	70(An40-41)(P)	15(P)	5+(P)	-	-	5-7	?	Biotite (2-3%) apatite (trace)
21NG 2862A	Olivine basaltic andesite (high K?)	70-75(An45)(P)	10-12(P)	7-8(P)	-	-	4-5	1-2	Apatite (trace)
21NG 2862B	Olivine basaltic andesite (high K?)	70(An38) (P)	15(P)	5(P)	-	-	5	trace	Apatite (1%)
21NG 2862C	Olivine basaltic andesite (high K?)	70-(An38-40) (P)	15(P)	5(P)(g)	?	-	5	?	Apatite (1%)
21NG 2862D	Olivine basaltic andesite (high K?)	70-(An46) (P)	20(P)	5(P)	-	-	5	trace	Apatite (trace)
21NG 2862E	Olivine basaltic andesite (High K?)	70+(An43) (P)	20(P)	5(P)(g)	-	-	2	?	Apatite (1-2%)
21NG 2864	Olivine basaltic andesite (high K?)	70-(An42-47) (P)	15-20(P)	5(P)(g)	-	-	2+	2-3	Apatite (1-2%)
Crater Mountain									
21NG 0592C	Hornblende-quartz mugearite (?)	70(An35) (P)	-	-	-	7	2-3	10+	Quartz (5%); apatite (trace)
21NG 2853	Shoshonite (?)	50-(An62) (P)	40(P)	7(P)(g)	-	-	2-3	5	
21NG 2855	Shoshonite (?)	50-55(An66)(P)	35-40(P)	1(g)	-	1(relict)	5	2-3	Apatite (trace); biotite (rare)
21NG 2858	Basaltic andesite	55+(An40-50)	25(P)	3-4(P)	-	pseudomorphed	7-8	?	Quartz (1%), apatite (trace)
21NG 4033C	Hornblende- 2 pyroxene basalt	65(An57-65)(P)	20(P)	-	5+(P)	5	2	-	Enstatite (?)(trace) Apatite (1%)
21NG 4033D	Olivine basalt	40(?)(rare P)	30(P)	25-(P)(g)	-	-	5+	trace	
21NG 4033E	Olivine basalt(high K?)	60(An56-57)(P)	20+(P)	10(P)	-	-	5	trace	Apatite (trace)
21NG 4033F	Hornblende-augite andesite	70(An31) (P)	10 (P)	-	-	10	1	trace	Quartz (1%); apatite (trace); altered glass (5%)
21NG 4033G	Hornblende-augite basalt	50-55(An50)(P)	25 (P)	-	-	7-10	5+	-	Apatite (trace)

* Presence of phenocrysts of these minerals denoted by "P".

\+ Presence in the groundmass indicated by "g".

ø Usually magnetite.

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Under the microscope, the rocks are seen to consist of the following phenocryst assemblages set in a fine-grained feldspathic groundmass:

1. Plagioclase, augite, and olivine (39 specimens)
2. Plagioclase, augite, olivine, hornblende, and hypersthene (3)
3. Augite and olivine (2)
4. Plagioclase, augite, and hypersthene (2)
5. Plagioclase and hornblende (2)
6. Plagioclase, augite, hornblende, and hypersthene (5)
7. Plagioclase, augite, olivine, and hornblende (4)
8. Plagioclase, augite, and hornblende (7)
9. Plagioclase, augite, olivine, and hypersthene (1)

The plagioclase is labradorite or andesine, usually with strong oscillatory zoning and complex albite-Carlsbad twinning; alteration to muscovite and epidote is common, particularly in the cores. Augite is usually idiomorphic, and is a very pale green-brown with slight dispersion and a 2V of about 60°; hypersthene forms elongated euhedral prisms (Fig. 40) pleochroic from a faint green to pale pink. The amphibole is a basaltic hornblende (or lamprobolite) which is very strongly pleochroic with α pale yellow or yellow-brown, β deep yellow-brown and γ dark to very dark brown, red-brown or blood-red. It forms elongated euhedral prisms which are marginally to completely replaced by fine-grained magnetite ± augite (Figs 36 and 39). Olivine forms idiomorphic to subidiomorphic crystals (Fig. 39) which in some samples are altered, in varying degrees, to "iddingsite" or "bowlingite". In rocks which also contain hypersthene, olivine grains have a narrow rim of fine-grained orthopyroxene.

Plagioclase phenocrysts commonly form aggregates, and in rocks with augite and olivine, these minerals are commonly found as composite phenocrysts, usually with pyroxene enveloping olivine. In a few samples 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.

In almost all cases the groundmass consists of small plagioclase laths, augite (except in 2 samples), magnetite ± olivine ± hypersthene ± alkali feldspar, and accessory apatite. Nepheline was found in two specimens (Fig. 38), quartz in four, analcite in one and zeolites in one. The plagioclase of the groundmass is andesine or sodic labradorite; the augite is pale green to colourless and forms equant grains, as does olivine, which is completely "iddingsitized" in most cases. Groundmass hypersthene is in the form of small, elongated prisms and in many examples is stained yellow-brown, presumably by oxidation. Alkali feldspar occurs in several of the specimens as mantles on plagioclase phenocrysts and microlites, and in some cases also as interstitial patches in the groundmass (see Figs 36, 37, 38 and 39). It has very low relief and birefringence, and is faintly pinkish, suggesting that it may be anorthoclase. Glass is present in eight samples, and forms 60 to 70 percent of one specimen from Mount Karimui.

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

The rock types fall into two groups (Table 4): hypersthene-free and hypersthene-bearing. There are also a few samples which have petrographic features of undersaturated alkaline rocks (e.g. 21NG4045B, from Mount Suaru), and some which have petrographic features similar to calc-alkaline basalts and andesites (e.g. 20NG1199, 21NG3040). Samples of all of these types have been collected from Mount Suaru, and all except the undersaturated alkaline type have been collected from Mounts Hagen and Giluwe and Crater Mountain. Of nineteen 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) described lavas with phenocrysts of labradorite, augite, and olivine ± hypersthene, in a groundmass of plagioclase, augite ± potash feldspar ± biotite ± olivine ± hypersthene; alkali feldspar commonly mantles the plagioclase phenocrysts. She also noted types similar to these, but without labradorite phenocrysts. These rocks she calls "shoshonites" and "absarokites" respectively, and places them in a "shoshonite association" with other rocks having a high K_2O:Na_2O ratio relative to the otherwise similar alkaline series. Many of the hornblende and hypersthene-free samples from the Highlands volcanoes satisfy the petrographic criteria of Joplin's shoshonites or (rarely) absarokites. Several samples, containing labradorite, augite and olivine ± hypersthene but lacking significant quantities of potash/alkali feldspar may be shoshonitic, or perhaps high potash calc-alkaline. Samples containing hornblende and augite, with or without hypersthene and/or olivine are difficult to assign to any series on petrographic character alone; they could be calc-alkaline, possibly potash rich, or even shoshonitic. The first alternative seems most likely. Specimens containing hypersthene but no hornblende could be calc-alkaline (particularly those with hypersthene reaction rims on olivine), or shoshonitic. Chemical data, not available at the time of writing, are required to solve the nomenclature problem.

The analcite-bearing lavas and absarokites from the Miocene Daulo Volcanic Member are also high potash lavas, but they are unlike those of the Highlands volcanoes in that they are more highly undersaturated. The Daulo Volcanic Member, however, does contain hypersthene-bearing lavas, which are common in the Highlands volcanoes.

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

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

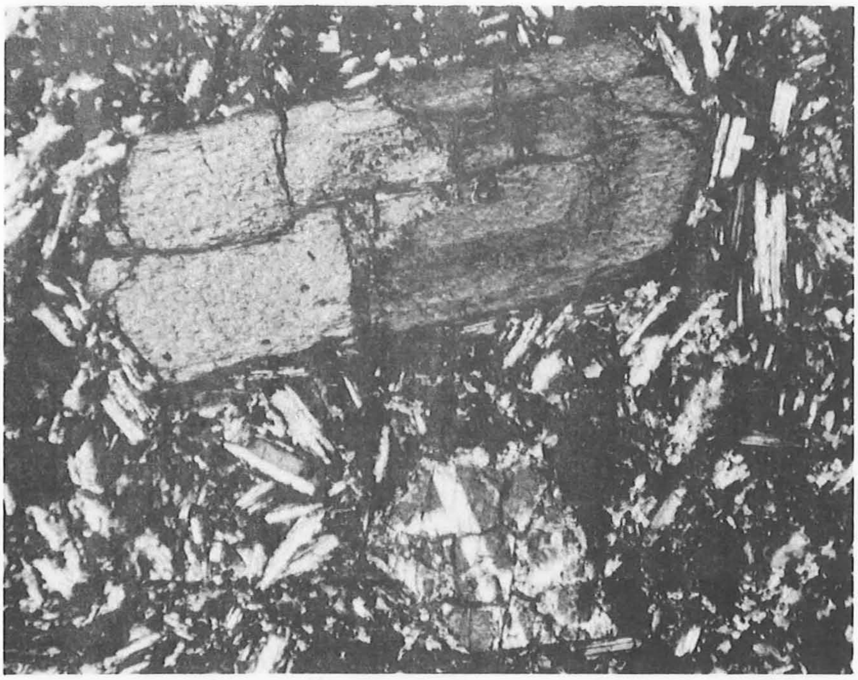

Fig.36 High-potash olivine basalt from Mount Hagen (specimen 11NG 0059), showing euhedral augite phenocrysts (note zoning in larger crystal) in a groundmass of labradorite, augite, interstitial alkali feldspar and magnetite. Olivine does not appear in this view. X83, cross polarizers. Neg.M/1021.

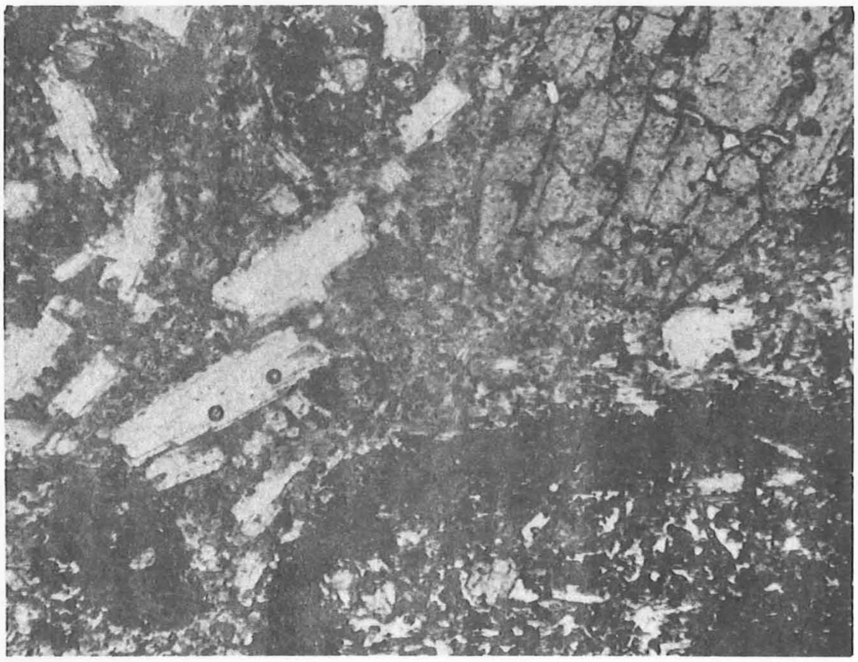

Fig.37 Shoshonite, from Mount Sauru (specimen 21NG 1383C), showing phenocrysts of augite, labradorite, olivine, and hornblende pseudomorphed by pyroxene and magnetite, in a groundmass of labradorite, augite, magnetite and glass. Alkali feldspar forms clear mantles on plagioclase.
X83, plane polarized light. Neg. M/1021.

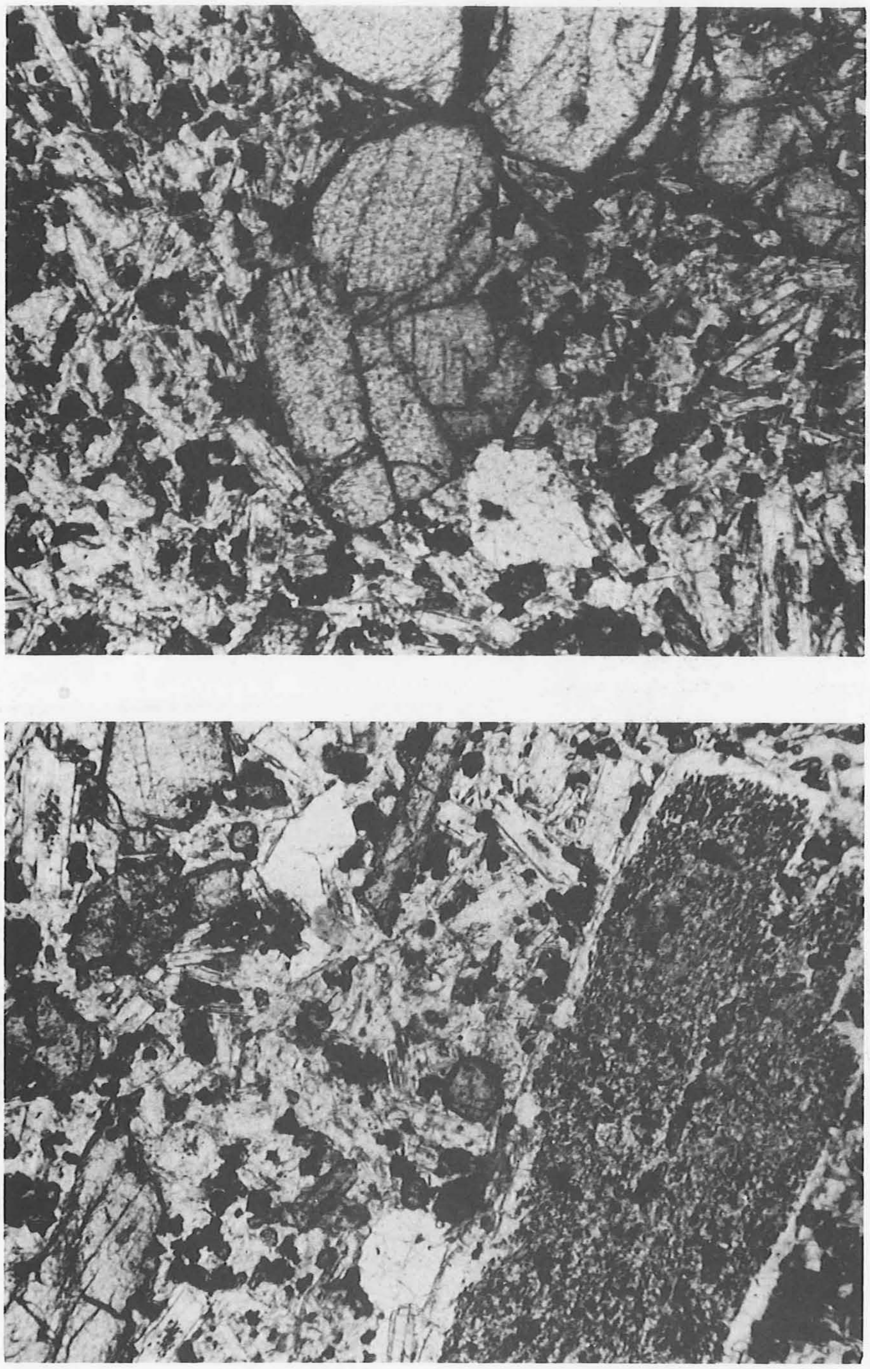

Fig. 38 Shoshonite, specimen 2ING4045B, from Mt. Suaru. Photomicrographs from two parts of the specimen show phenocrysts of augite (light grey), olivine (v. pale, high relief - top centre) and andesine (large crystal with inclusion-filled core, clear rim of sodic plagioclase and potash feldspar), set in a groundmass of andesine, augite, magnetite and alkali feldspar (clear rims on plagioclase laths). Clear patches with low relief are nepheline. 83X, plane polarised light.

Neg. M/1021.

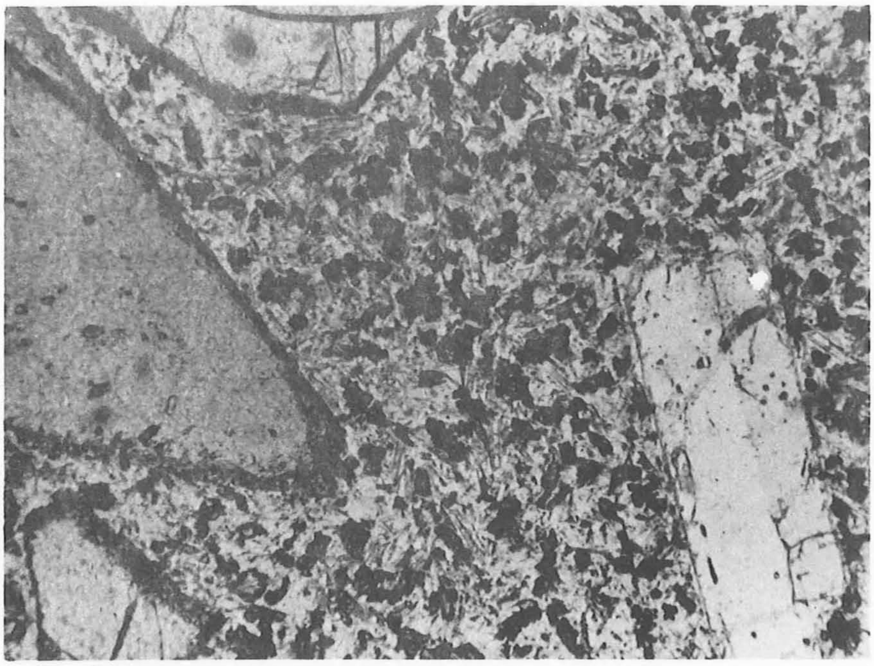

Fig.39 High potash olivine andesite, or shoshonite, from Mt.Karimui (specimen 21NG 2862A). Large phenocrysts of augite, olivine, and andesine mantled by alkali feldspar in a groundmass of andesine, augite, magnetite and interstitial alkali feldspar (sanidine). 83X, plane polarized light. Neg. M/1021.

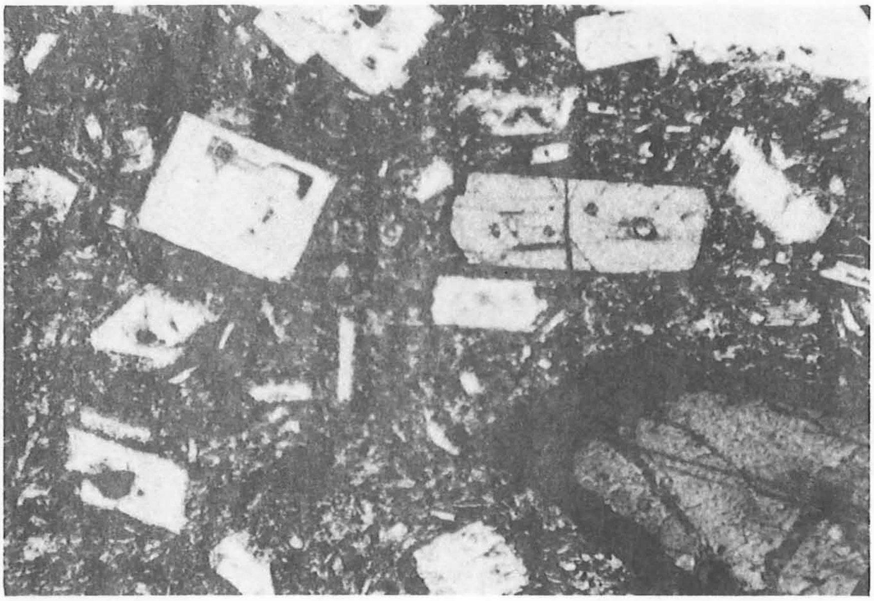

Fig.40 Hornblende-2-pyroxene basalt (21NG4033C) from Crater Mountain. Phenocrysts of labradorite, augite (extreme left), hornblende with magnetite reaction rim (lower right) and hypersthene (upper right) in a groundmass of labradorite, augite and magnetite. 83X, plane polarized light. Neg. M/1021.

The part of the New Guinea Highlands discussed in this report has undergone late Tertiary orogeny, and early Pleistocene uplift accompanied and/or followed by volcanism (Perry, 1965). It is now a relatively stable region. Gravity data from New Guinea (St John, 1967) indicate that there is a thick sialic crust beneath the Highlands volcanoes; geological evidence (this Record, and D.A.L. Jenkins, pers. comm., 1970) shows that the basement is strongly folded on a large scale. Palaeozoic basement is exposed at 4,000 m above sea level in the Kubor Range, but is at 6,000 m below sea level less than 40 km to the southwest in the Southern Highlands Basin (Australasian Petroleum Company, 1961).

It is fashionable at present to relate the composition of magma erupted at the surface to depth to the Benioff zone in island arc areas (e.g. Dickinson & Hatherton, 1967). Jakeš and White (1969) have related the change in magma type - from tholeiitic in the northern New Guinea arc to shoshonitic in the Central Highlands - to a Benioff zone which meets the surface in the Bismarck Sea and dips below northern New Guinea. The best available seismic data (Johnson, 1970, and plots made by the writer) 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.

Wahgi Fanglomerate

All unconsolidated recent and sub-recent alluvial fan deposits in the Wahgi Valley are here called Wahgi Fanglomerate.

The fans which are 10-100 m thick and have gently sloping (1^{o}-3^{o}) upper surfaces, are commonly coalesced, and cover most of the floor of the Wahgi Valley from Kerowagi to west of Banz, an area measuring 40 km by 12 km (Plate 1). A small residual deposit occurs at Kundiawa near the Chimbu-Wahgi river junction. Similar, though smaller deposits, which interfinger with and overlie extensive lake sediments, are common outside the map area in the Baiyer River and Goroka valleys.

The fanglomerate consists of unconsolidated Pleistocene fluviatile clay, silt, sand, pebble, cobble and boulder gravel derived mainly from the 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 variables being source materials and grain size. This variation is reflected in the topographic expression of the individual deposits (cf. Haantjens, 1970).

The source areas of the Wahgi Fanglomerate are on both sides of the Wahgi Valley. The Kubor Range contributed mostly plutonic and metamorphic detritus whilst the Jimi-Wahgi divide shed mostly volcanic, sedimentary, and minor plutonic rock material into the rapidly formed fans. Detritus from these two areas entered the valley from at least six points on the northern side and four on the southern side. Interfingering lacustrine deposits at the western end of the formation indicate that the fanglomerate formed while the Wahgi Valley was a lake (Pleistocene to Recent). The clays in some deposits are finely laminated and have the appearance of varved clay formed by fluvioglacial processes. Since the source areas were glaciated during the late Pleistocene (Reiner 1960;

Löffler 1970) it is likely that fluvioglacial detritus forms part of these deposits. However there is clearly more material in the deposits than could have been derived from the observable glacial landforms in the Kubor Range and Jimi-Wahgi divide (E. Löffler, pers. comm., 1970). The greater part of the detritus in the Wahgi Fanglomerate probably resulted from a period of greatly accelerated erosion due to recent uplift or, during a period of intense earthquake activity (cf. Torrecelli Mountains, Simonett, 1967). Tuff beds attest the existence of contemporaneous volcanic activity: the source of the tuff has not been determined. It is probably from Mount Hagen or another of the Highlands volcanoes, or may even be from volcanic centres in the Bismarck Sea.

RECENT

Alluvium

The alluvial deposits of the Wahgi Valley (Figs 1, 17), include the Wahgi Fanglomerate; deposition of extensive flat-lying lacustrine deposits (sand, silt, gravel and mud with a covering of soil) in the western end of the Wahgi Valley between Mount Hagen airport and Banz is believed to have been initiated in the Pleistocene. These deposits probably resulted from infilling of a lake that formed when growth of Mount Hagen volcano dammed the ancestral Wahgi River, which had been flowing north into the Yuat River (Haantjens, 1971). The lake, when filled with sediment began to overflow to the east, where the new Wahgi River was captured by the Chimbu River. These deductions are well supported by the present topographic features - the flat, mature upper Wahgi Valley (Figs 43, 44), the increasing incision of the river to the east (Fig. 42), the youthful gorge upstream from the Wahgi-Chimbu confluence, and the rejuvenated gorge downstream from this junction (Figs 9, 2, 21; also Figs 1 and 17).

The lacustrine deposits of the upper Wahgi, partly veneered by younger alluvium, are now being eroded. Alluvial terraces are developed along the present channel of the Wahgi River, with two distinct terrace levels present below the level of the Wahgi Fanglomerate deposits. Small terraces on bends in the Wahgi River below the Chimbu River junction are approximately 15 to 30 m above mean river level.

Other alluvial deposits are developed on the Chimbu River, just east of Kundiawa, on the Kaugel River upstream from the Kaugel Gorge (extreme left of Plate 1) and in the Goroka Valley (McMillan and Malone, 1960). Valley fill deposits cover the floor of the broad, open valley in the headwaters of the Mai River (145°13'E 6°S), and also the valleys of the upper and middle reaches of several tributaries of the upper Wahgi River.

Talus and scree

Extensive deposits of angular scree and talus, with admixed soil and alluvium are developed below the scarps of the Chimbu and Nebilyer Limestones (Plate 1). These deposits, particularly in the area west and northwest of Mount Elimbari, have moved considerable distances downslope and can be traced on the airphotographs as lobate, mud-flow-like masses covering Cretaceous strata.

Fig. 41 Wahgi Valley north of Minj with fanglomerates in the foreground, Cretaceous dislopes (right skyline) and Triassic limestone (extreme right skyline). View to the southeast. Neg. GA2378

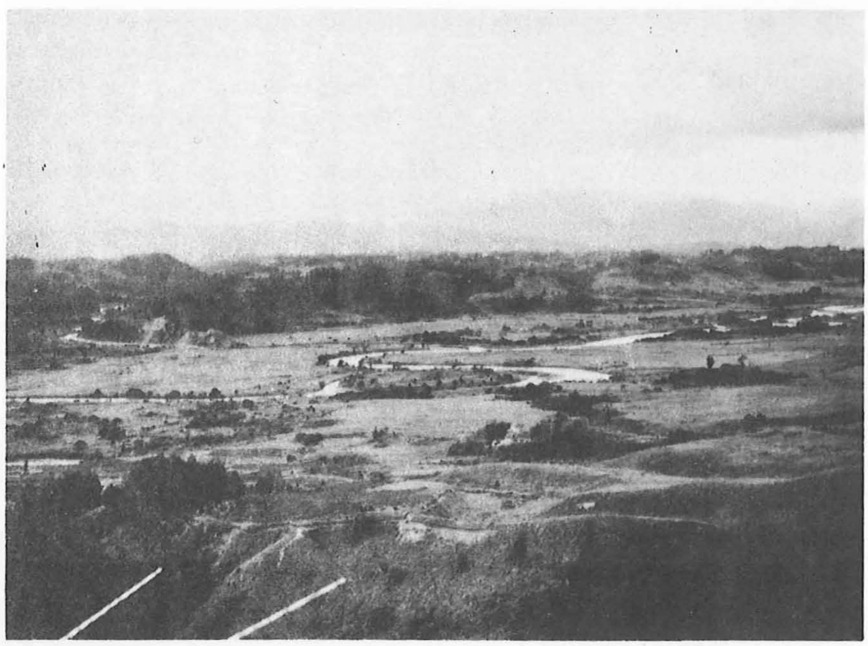

Fig. 42 Wahgi Valley showing fanglomerate deposits flanking the present floodplain. Neg. GA2375.

Fig.43 The upper Wahgi Valley, looking south-east. Flat-lying Quaternary lacustrine and fluviatile sediments have buried an earlier topography. Neg. GA2373

Fig.44 The Kaip Valley and part of the upper Wahgi Valley. Mount Oga on the extreme right; the Wahgi-Jimi divide in the distance. Neg.GA2382

On the northern slopes of Mount Michael, there are extensive deposits of diorite boulders, sand and admixed silt, mud and soil, derived from the Michael Diorite. The boulders are generally weathered and partly rounded, despite the close proximity to the source area. Because the summit area of Mount Michael has been glaciated, it is possible that these deposits are partly reworked glacial outwash material, and/or the product of more recent erosion of weathered boulders from the nearby diorite bluffs and prominent "sugarloaf" hills.

Minor deposits of scree and talus, and juvenile alluvial fans occur beneath the steeper slopes and bluffs bordering areas of alluvium such as the Wahgi Valley.

INTRUSIVE ROCKS

Kubor Granodiorite

The Kubor Granodiorite (Rickwood, 1955) is a collective name applied to several plutonic intrusive masses in the core of the Kubor Anticline. The main intrusion in the western end of the anticline is a composite body 26 km by 39 km which includes some roof pendants of Omung Metamorphics (as indicated by stream boulders). Smaller stocks occur 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 further west. Kubor Granodiorite is also exposed in windows in Maril Shale 15-20 km west of Gumine, and in Ambaga Creek, 10 km west of Minj.

The Kubor Granodiorite has intruded low-grade metamorphosed sediments and volcanics of the Omung Metamorphics, and is overlain unconformably by Kuta Formation (late Permian to early Triassic), Upper Triassic Kana Formation, and, in places, Upper Jurassic Maril Shale and/or Lower Cretaceous Kondaku Tuff. In the Kuta area, at the western end of the Kubor Anticline, on Mount Oga, and near Gurumugl, limestone of the Kuta Formation rests unconformably on Kutor Granodiorite. At all these localities, there are arkoses between the granodiorite and the limestone.

Contacts between granodiorite and country rock are either intrusive with hornfels zones of varying widths, or faulted with much shearing. In most places, the hornfels zones are only a few tens of metres across, but in some places, such as the Omung River, Minj River and the valley south of Kudjip, they extend for several hundred metres. Numerous small intrusive stocks and dykes indicate that larger plutons may exist beneath these hornfelsed areas. The hornfelses themselves are discussed with the Omung Metamorphics.

Rock types of the Kubor Granodiorite range from unaltered to completely metamorphosed and gneissic. Evidence from stream boulders, and rarely from outcrops, indicates that the xenoliths of country rock and inclusions of other intrusive rock are rare in the Kubor Granodiorite. They are found only in areas near intrusive contacts, and where there has been interaction of intrusive and country rocks caused by faulting (e.g. localities 21NG1551 and 1554, west of Mount Kubor). The granitic intrusive rocks are cut by numerous dykes of aplite, and, in the Maril River area,

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pegmatite dykes; the aplite dykes are associated with potash metasomatism in the surrounding granodiorite. In the Maril River, dykes of aplite and pegmatite show concentric folding, without any evidence of brittle fracture. This is taken as evidence of deformation at high temperature.

The bulk of the intrusive rocks which make up the Kubor Granodiorite are granodiorite and tonalite. These are generally coarse-grained, and weathered and/or altered to varying degrees. Diorite, gabbro and adamellite are relatively minor and appear to occur as small stocks and dykes. Gabbro is the most common of these minor rock types, and occurs mainly as small masses marginal to larger granodiorite-tonalite plutons.

Isotopic dating by K-Ar and Rb-Sr methods (Page 1971) shows that the bulk of the Kubor Granodiorite, including pegmatites and aplites which intrude the granitic rocks, is around 240 million years old. This age is in accordance with the tentative Permo-Triassic (about 235 m.y.) age of the overlying Kuta Formation, and allows 5m.y. for the unroofing and deep erosion of the Kubor intrusives.

Petrography

A total of 46 samples of plutonic rocks from the Kubor Range were examined in thin section (Table 5). A number of samples show evidence of metamorphism. These rocks are mainly hornblende gabbro and diorite in which the hornblende has been replaced by actinolite, chlorite and epidote. Some have been recrystallized to amphibolite with relict igneous texture.

The relatively unaltered, unmetamorphosed specimens fall into six main categories: (a) tonalite (13 thin sections), (b) granodiorite (11), (c) gabbro (9), (d) diorite (7), (e) adamellite (2), and (f) aplite (2).

Diorite xenoliths were found in two specimens, one a diorite, the other a tonalite.

Biotite-hornblende tonalite is by far the most common rock type of those examined. Twelve specimens were found to have between 10% and 40% quartz, together with oscillatory or normally zoned oligoclase to andesine (50% to 70%), pleochroic green hornblende (1% to 20%), dark brown to pale yellowish biotite (1% to 8%), and little or no potash feldspar. One specimen of tonalite contains 1% biotite and 7-8% chlorite, which has replaced most of the biotite, and possibly also hornblende.

The granodiorites fall into three categories: (a) biotite-hornblende (5 specimens), (b) biotite (5), and (c) hornblende granodiorite. These rocks contain up to 15% ferromagnesian minerals, which, in several specimens, are partly to completely altered to chlorite, epidote, sphene and opaque grains. The other constituents are quartz (10% to 40%), oligoclase-andesine (45-75%) and potash feldspar (5-20%). The potash feldspar is orthoclase, with patchily developed cross-hatched microcline twinning in several samples; the orthoclase is usually microperthitic. It forms large, irregular masses up to and exceeding 1 cm across, and poikilitically encloses other minerals.

Table 5 - Estimated Modes of Specimens of the Kubor Granodiorite

Sample No.	Name	Plagioclase % (comp)	K-feldspar* (%)	Quartz (%)	Hornblende (%)	Biotite (%)	Muscovite (%)	Clino-pyroxene	Accessories+	Other + (secondary)
20NG 0580A	altered hornblende diorite	70 (An_{38})	-	-	25	1-2	-	-	mt, ph, ap.	op, chl, 1%
20NG 0580B	mixed pyroxene-hornblende gabbro alt. to qtz diorite	60-65 (An_{55-68})	5-10	2-5	5	-	-	15	mt, sp, sph.	chl, pr (ea. 1%)
20NG 0580C	altered hornblende gabbro	65 (An_{37-6}	5	1	30	-	-	-	mt, ap, sph	act 7-10% op
20NG 0580D	biotite-hornblende tonalite	60-65 (An_{23-45})	2-3	15	2-3	4-5	2	-	mt, ap, sph, zirc.	chl, 2-3% ap.
20NG 0580E	hornblende-biotite tonalite hornblende-quartz diorite	60-65 (An_{22-37})	5	25	3-4	2-3	trace	-	mt (1-2%), sph, ap. mt (2%) ap. (1%) sph.	chl (2-3%) chl. ep. (cu.1%)
Xenolith in above		70 (An_{22-45})	5	3-5	15	-	1	-		
20NG 0580G	hornblende-biotite tonalite	55 (An_{33-34})	2-3	25	5	1	-	-	ilmen. (1%) sph(1%) ap.	chl (5%) ep
20NG 0580I	hornblende-biotite tonalite	60+ (An_{46-20})	5	20	5	2	-	-	mt, sph, ap.	chl (2%) op
20NG 0592	hornblende quartz diorite	70+ (An_{18-39})	5-10(P)	5	7	1	-	-	mt, ap.	chl, ep
20NG 1148J	altered pyroxene gabbro	50+ (An_{65})	-	-	-	-	1	30	mt(1-2%), ap(1%), sph	ep (5-10%) chl
20NG 1148L	altered hornblende-quartz diorite	60+ (An_{18-48})	-	5	5(15% actinolite)				sph(5%) ilmt (1-2%) ap	chl (1-2%)
20NG 1148M	altered pyroxene gabbro	Same as 1148J; pyroxene coarse-grained								
20NG 1148N	altered pyroxene gabbro	Ditto; pyroxene still coarser, more altered; veins of prehnite								
20NG 1194	Leucocratic, altered hornblende biotite tonalite	50 (An_{30})	2-3	40	1-2	1	-		sph	ep, chl
20NG 1197	altered granodiorite porphyry	45	10-15	20	5	-	-	-	mt (alt to hem)	chl 7% ep 5%
20NG 1198A	aplitic biotite-muscovite adamellite	30 (An_{29-30})	20+(M)	40	-	1	1	-	garnet (1-2%), sph	chl, ep.
20NG 1198B	quartz-rich biotite granodiorite	50- (An_{20})	5	40+	-	3-4	trace	-	sph, mt ap, rare garnet	ep, chl.
20NG 1198C	hornblende-biotite tonalite	65 (An_{36})	5	15	5+	5	trace	-	sph, mt, ap	ep, chl.
20NG 1198D	metamorphosed hornblende-biotite gabbro	55 (An_{74-75})		-	30	4-5	2-3	-	mt/hem	ep
20NG 1198E	ditto	similar to 1198D; finer-grained, more recrystallized; more biotite; some K-feldspar								
20NG 1198F	part. rextall (quartz-) hornblende diorite	60 (An_{37-51})	-	1-2	30	-	1-2	-	mt/ilm(3%) ap	ep(2-3%)
20NG 1198G	quartz-hornblende-biotite diorite	70 (An_{29-61} av. An_{35})	-	5	15	7-8	1	-	mt(1%), zirc. sph.	ep
20NG 1198H	metamorphosed hbl. gabbro	60 (An_{58-63})	-	-	Actinolite 35-40	1	-	-	mt(?) 1-2%	-
20NG 1198K	biotite adamellite	40 (?)	20(M.P.)	30	-	3-4	1	-	mt, sph.	chl (1-2%) musc. (1%)
20NG 1198N	hornblende-biotite tonalite	65-70 (An_{42})	2-3	15+	5	5	-	-	mt, sph, ap.	ep, chl.
20NG 1198P	hornblende-biotite granodiorite	50 (An_{20-40})	10	20-25	10+	5	trace	-		ep.
20NG 1198Q	biotite-hornblende tonalite	55 (An_{35+})	5	30	3	5	-	-	mt/ilm, ap.	chl, ep
20NG 1198S	biotite-hornblende tonalite	60 (An_{40})	1	20	5	7	-	-	py, sph, ap.	chl, ep
xenolith	hornblende-biotite diorite with mafic xenolith	30			60	5			mt(?)	chl, ep
20NG 1198 U	hornblende-biotite granodiorite	60-65	7-8	20	5	1	trace	-	sph, mt/ilm	chl (5%), ep, musc.
aplitic phase		10	35(M)	50	chloritized biotite, sphene, monazite } — 5%					

Table 5 - Estimated Modes of Specimens of the Kubor Granodiorite (contd)

Sample No.	Rock Name	Plagioclase % (comp)	K-feldspar* %	Quartz %	Horn-blende %	Biotite %	Mus-covite %	Pyro-pyroxene %	Accessories+	Other+ (secondary)
20NG 1287B	hornblende-biotite granodiorite	60-(An_{30-40})	15	20	2-3	5	trace	-	mt/ilm, sph. ap.	calcite, ep., chl.
21NG 0514	altered biotite granodiorite	40 (An_{33})	20(M,P)	35	-	chlor-itized	-	-	ilm(½-1%), sph (2%)	chl (7-8%), ep (1%)
21NG 0517	hornblende-biotite-tonalite	60 (An_{40})	-	10	20	1	-	-	sph. (1%), ap, mt/ilm	chl. 2%, ep 2% musc. 2%
21NG 0521	quartz-bearing hornblende gabbro	75(An_{58-77})	-	2	15	1	-	1	sph, ilm/mt ap.	chl, musc. ep
21NG 1028	hornblende-pyroxene gabbro	60(An_{67-72})	-	-	5	-	-	10	ilm/mt 1-2% sph.	act. 15% ep. chl. 5%
21NG 1032	altered biotite tonalite	45(An_{28-35})	-	40	-	1	-	-	sph, ilm/mt	chl 7-8%; musc. 2% ep. 1%
21NG 1048	hornblende-biotite (-px)quartz diorite	80+(An_{35})	-	5-8	5-8	2-3	-	1	ilm/mt	act. 2%, musc., ep.
21NG 2542	biotite-hornblende granodiorite	55*	10-15	18	2	8-10	-	-	ilm/mt, ap	chl, clay mineral
21NG 2544A	biotite granodiorite	55+(An_{31})	20(P)	15	-	3-5	-	-	ap., zirc., ilm/mt	clay mineral
21NG 2544B	garnet-biotite-muscovite aplite	15-20	25-30	50	-	1	0.5	-	garnet 1%	
21NG 2547	hornblende-biotite tonalite	70 (An_{42})	-	10	10	5-8	-	-	ilm/mt, ap. zirc.	chl. 1-2%
21NG 2736	altered biotite granodiorite	70-75	5-8	10-12	-	-	-	-	ilm/mt 1%	chl. 5%; ep. 2-3%
21NG 2739	altered biotite granodiorite	60	5	25						chl. 5%; calcite 1%; ep. 3%
21NG 2791	hornblende-biotite granodiorite	45-50	10(P)	20	10	5	-	-	ilm/mt, ap.	chl. 4-5%; ep, clays
21NG 2800	hornblende-biotite tonalite	65-70	-	15	10	5			mt/, ap	

* M denotes microcline; P denotes microperthite

\+ Abbreviations: act. = actinolite, ap = apatite; chl = chlorite, ep. = epidote or epidote-clinozoisite; hem. = hematite, mt. = magnetite, musc. = muscovite, ilmt = ilmenomagnetite; ilm. = ilmenite, pr. = prehnite, Py. = Pyrite, sph. = sphene, ser. = sericite, zo. = zoisite, zirc. = zircon.

Most of the gabbros are somewhat altered, or slightly metamorphosed. They consist of zoned calcic plagioclase (An_{50} to An_{77}) and either green hornblende (in one case with pale green clinopyroxene), clinopyroxene alone, or hornblende and biotite. In all cases the hornblende is overgrown and partly replaced by actinolite and/or partly altered to chlorite and opaque minerals. Some of the pyroxene-free gabbros contain a little potash feldspar (up to 5%) and/or quartz (up to 2%).

The majority of the diorites of the Kubor Granodiorite are quartz-bearing and grade with increasing silica content into tonalites; two of the seven specimens lack quartz. Apart from plagioclase (zoned An_{18-50}, 60% to 80% by volume), the diorites contain up to 35% ferromagnesian minerals, made up of dark brown to pale yellowish biotite and/or green hornblende, and up to 5% potash feldspar.

The two samples of adamellite are quartz-rich, leucocratic types which contain about 20% by volume of large, poikilitic microcline crystals and small amounts of muscovite and/or biotite, as well as calcic oligoclase.

Accessory minerals in the rock types described above are magnetite (possibly titaniferous) or ilmenite, with lesser sphene (in most samples), apatite, and rarely, garnet and zircon. Epidote and chlorite are common secondary minerals, replacing primary ferromagnesian minerals. Calcite partly replaces plagioclase and hornblende in a few specimens.

Aplites are quite common in the Kubor complex, but only two specimens were examined in thin section. One consists of quartz (50%), microcline (35%), oligoclase (10%) and minor chloritized biotite, sphene and monazite, with a fine-grained mosaic texture, in which the grain boundaries are curvilinear to sutured. The other specimen is a fine-grained granular aggregate of quartz (50%), orthoclase/microcline (25-30%) and oligoclase (15-20%) with biotite, pink garnet and muscovite in small amounts.

Kimil Diorite

The Kimil Diorite is made up of several intrusive bodies, with associated minor dykes and sills, which intrude rocks of the Kana Formation, Balimbu Greywacke and Mongum Volcanics in the Jimi-Wahgi divide. The name Kimil is derived from the Kimil River, a tributary of the Wahgi River. Only the southern extremities of one intrusive mass, north and northwest of Banz, were seen in 1968 but photointerpretation, and traverses in the Jimi Valley in 1967 and 1970 indicate that north of the area of Plate 1, there are several other small intrusive bodies similar to the one in the headwaters of Banz Creek.

The contact between Kimil Diorite and Balimbu Greywacke is mostly faulted, but dykes of "granodiorite" (field term) are present in the latter. There is a complex intrusive relationship with Kana Volcanics: numerous dykes, sills and apophyses of "granodiorite" intrude the hornfelsed sedimentary and volcanic rocks. Mapping in the Jimi Valley in 1967 and 1970 disclosed/the Upper Jurassic Maril Shale is intruded by (/that) Kimil Diorite, which is in turn intruded by basaltic and andesitic dykes. Thus although an upper age limit cannot as yet be put on the Kimil Diorite, it cannot be older than Upper Jurassic.

All specimens of the Kimil Diorite are altered to varying degrees; some contain sulphides and show signs of metasomatism. The rock types range from fine-grained dark green-grey (dioritic) rocks to coarse-grained leucocratic hornblende-biotite tonalites and granodiorites. Fine-grained varieties include microdiorite and microgranodiorite . A specimen of the latter (20NG0611A) has hypidiomorphic to panidiomorphic granular texture resembling that of a metamorphic rock; the ferromagnesian mineral is pseudomorphed by chlorite. Coarser-grained specimens include: (1) metamorphosed hornblende diorite or gabbro (20NG0611B), (2) altered hornblende-quartz diorite (20NG0614), (3) altered hornblende tonalite (20NG1223A), (4) metamorphosed hornblende tonalite or granodiorite (20NG0613A), and (5) altered hornblende-biotite tonalite (20NG1223B).

All of these specimens contain plagioclase (usually andesine) in various stages of alteration, hornblende which has been partly recrystallized to fibrous actinolite, varying amounts of quartz (from 2-3% in 2 to 35% in 5) and small amounts of secondary chlorite (replacing hornblende, and replacing biotite in 5. Potash feldspar is present in 2, 4 and 5, and is heavily altered in all three. Biotite is present only in the tonalite 5, where it is largely altered to chlorite, epidote and sphene. Accessory minerals include magnetite or titanomagnetite, apatite, sphene, and, in 1 and 2, pyrite. Specimen 1 has been partly recrystallized and has patches of equant plagioclase and hornblende with a panidiomorphic granular texture. Specimen 2 contains small relict grains of augite enclosed in hornblende, and minute veinlets of potash feldspar which cut across other minerals. In specimen 4, the pre-existing ferromagnesian mineral, presumably hornblende, has been completely recrystallized to prismatic and fibrous actinolite; a small amount of prehnite, replacing feldspar, is also present.

Three specimens collected from the northern margin of the Kimil Diorite in the Jimi Valley in 1967 are:

(1) metamorphosed granodiorite or adamellite, now quartz-plagioclase-muscovite gneiss (20NG2532)

(2) weathered hornblende-biotite tonalite (20NG2535); and

(3) altered (partly chloritized) augite basalt, intruding granodiorite (20NG2536).

The Kimil Diorite forms a discontinuous chain of small plutons between the middle Miocene Maramuni Diorite and Bismarck Intrusive Complex. It is within the belt of middle Miocene intrusive rocks which extends from Wau to the West Irian border. The Kimil intrusions are also similar in type and degree of alteration, and in size, to the middle Miocene Oipo Intrusives (Dow & Dekker, 1964). Preliminary isotopic dating of one sample of Kimil Diorite indicates an age no greater than Miocene (Page, pers. comm., 1971). For these reasons, the Kimil Diorite is regarded as middle Miocene in age. Extensive alteration and metamorphism of the Kimil (and Oipo) plutons may have been caused by post Miocene faulting which splayed around the larger, unaltered Maramuni and Bismarck batholiths.

Bismarck Intrusive Complex

Previous work

Stanley (1922) reported boulders of granitic rocks in rivers flowing from the mountains southwest of the Ramu River, and Noakes (1939) described from this area plutonic rocks, varying from diorite to granite which he termed collectively "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 (1957), McMillan and Malone (1960), and Dow and Dekker (1964) studied various parts of the "Bismarck Granodiorite" in more detail. The name Bismarck Intrusive Complex now replaces "Bismarck Granodiorite" because it indicates the varied lithology of the plutonic mass.

Distribution and topography

The main mass of the Bismarck Intrusive Complex is a composite intrusive body of batholithic dimensions which is exposed over an area 51 km by 19 km, and extends from just east, to well north of the map boundary (Plate 1). Several small satellite intrusions in Palaeozoic Goroka Formation occur to the southeast of the batholith, east of the map area.

The entire area of the main Bismarck Intrusive Complex is one of high relief; many peaks reach to over 3,000 m above sea level, and the range is dominated by Mount Wilhelm (4,509 m; Fig. 2). Streams are deeply incised into steep-sided valleys, and the dense drainage pattern is largely controlled by joints and faults. Three main sets of lineaments may be distinguished on the airphotographs; these trend 300°, 360° - 030°, and 160° - 170°. The dominant 300° - trending set is parallel to the long axis of the batholith, to the regional tectonic grain, and to the Bismarck and Bundi Fault Zones of Dow and Dekker (1964).

Intrusive relationships and age

In general, the batholith has smoothly-curving normal intrusive contacts, with few mappable embayments (one is near Mount Kworu), and a narrow contact metamorphic aureole. In some places, such as north of the Daulo Pass, the intrusive mass is fault-bounded.

The Bismarck Intrusive Complex is middle Miocene in age. Isotopic age determinations by Page (1971) show that the age of the bulk of the Complex is about 12.5 m.y. and that parts of it, in the Goroka-Mount Otto and Yandera areas, are 7-10 m.y. old. Some of the small intrusive bodies mapped by McMillan and Malone to the southeast of the batholith belong to a much earlier (180-190 m.y., early Jurassic) phase of intrusion; Page named these the "Asaro Intrusives". The gabbroic northwestern end of the Bismarck Intrusive Complex intrudes Upper Cretaceous to upper Te Asai Shale, but elsewhere the Complex intrudes rocks no younger than Upper Triassic (Kana Volcanics). Dow and Dekker stated that the gabbros at the northwestern end of the batholith are "very similar in composition" to gabbros on the summit ridge of Mount Wilhelm, but correlated them with the Tertiary Oipo Intrusives of the Jimi Valley.

The remainder of the Bismarck batholith they deduced to be "(?)Lower Jurassic" on the grounds that it has intruded only Upper Triassic Kana Volcanics and Palaeozoic(?) Goroka Formation, and that in one area Kana Volcanics, but not nearby Maril Shale, are mineralized. However, absence of sulphide mineralization in the Maril Shale in that area is probably due to the marked compositional and lithological differences between the shale and the volcanics. Petrographic and isotopic age determination data obtained after the work of Dow and Dekker (1964) show that there is no reason to separate the gabbroic northwestern end from the remainder of the Bismarck batholith.

Petrography

Most of the specimens from the Bismarck Intrusive Complex collected during the 1968 survey are medium to coarse and very coarse-grained gabbro and diorite. These were obtained from the southern and southwestern extremities and the southwest side of the batholith, and from small intrusions to the south. McMillan (1957), and McMillan and Malone (1960) collected specimens from four main areas in the Bismarck Intrusive Complex:

(1) Hornblende-biotite tonalite and granodiorite, granite and aplite from the north-eastern side of the batholith (Yandera -Bononi area).

(2) Hornblende-biotite-pyroxene tonalite and granodiorite, diorite and amphibolite (from dykes) in the Asaro Valley, on the south-eastern end of the batholith.

(3) Tonalite (containing andesine, hornblende, pyroxene, biotite, and in some cases actinolite, and up to 20% quartz) and dykes of quartz diorite, basalt and quartz-hornblende andesite in the Kerigomna plateau area (about 20 km north of Chuave).

(4) Gabbro (pyroxene, with minor hornblende and biotite), a hornblendite, and specimens from a layered dunite-peridotite-anorthosite complex about 30 metres thick, in the Mount Wilhelm area.

McMillan (1957) noted that with the increasing altitude from which the specimens were collected, the plagioclase becomes more calcic, pyroxene more prominent, ferromagnesian minerals increase and quartz and potash feldspar decrease in quantity. It should be pointed out, however, that this may be a lateral change rather than a vertical one as suggested by McMillan.

Joyce (1965) described seven specimens collected by Dow and Dekker (1964); these were a diorite porphyry, two microtonalites, two micromangerites (both with some augite) and two microgranites. These specimens were collected from the area northwest of Mount Kworu, near the northern boundary of Plate 1. Dow and Dekker also mapped gabbros in the northern end of the batholith, some of which are foliated, especially along the north-eastern contact. Flow alignment of crystals and foliation were observed in a few specimens, and compositional banding was observed in one specimen and in several stream boulders during the 1968 survey.

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TABLE 6 : ESTIMATED MODES OF SPECIMENS OF THE BISMARCK INTRUSIVE COMPLEX

Sample No.	Rock Name	Plagioclase % (composition)	K-feldspar %	Quartz %	Hornblende %	Augite %	Olivine %	Biotite %	Others	Secondary Minerals
20NG 0620 B	Altered porphyritic pyroxene microdiorite	65 (An_{30})	-	-	-	20	-	-	Ilmenite 5%, apatite (trace)	Chlorite 5%, epidote 2%
20NG 0621 *	Hornblende-augite gabbro	85 (An_{76})	-	-	5-7	5@	-	-	Magnetite 1-2% apatite (trace)	
20NG 1270 A	Hornblende-biotite (pyroxene) mangerite	60+(An_{30-35})	5-7	7-10	7-8	1-2@	-	5-7	Opaques 1-2% apatite(tr)	Chlorite (1-2%) epidote (tr)
20NG 1270 B	Hornblende-biotite tonalite	70 (An_{32-68})	-	15	10	-	-	1-2	Opaques 1-2% apatite(tr) sphene (tr)	Chlorite (tr)
20NG 1270 C	Hornblende (-augite) quartz diorite	70 (An_{50})	-	1	20	2-3@	-	tr	Chalcopyrite 2-3% apatite 2% sphene 1%	Chlorite 1%, muscovite (tr)
20NG 1270 D	Hornblende (-augite) diorite	60 (An_{48-49})	-	-	30-35	2-3@	-	-	Chalcopyrite 2% ilmenite 1% sphene, apatite (tr)	
20NG 1270 E	A mixed pyroxene hornblendite, fine-grained hornblende - andesite - quartz- schist and hornblende-pyroxene@ gabbro. 6% magnetite, 3% pyrite, 1-2% chalcopyrite.									
20NG 1270 F	Hornblende-augite (-olvine) diorite porphyrite	20 (An_{40})	-	1-2	70	10@	1-2	-	Opaque minerals including sulphides 3%, apatite, zircon (trace)	Calcite 1-2%, muscovite(tr)
20NG 1270 G	Pegmatitic hornblende gabbro	65 (An_{74})	-	-	30	-	-	-	Magnetite 3-4% sphene 1%	Chlorite 1%, epidote (tr)
20NG 1270 H	Hornblende quartz diorite	60 (An_{53-40})	-	5	25-30	-	-	1-2	Sulphide 1-2% apatite (tr) sphene (tr)	Chlorite 2-3%, epidote(tr)
20NG 1270 J*	Augite-hornblende-olivine gabbro	70+(An_{83})	-	-	7	10@	5	-	Magnetite 5%	Chlorite (trace)
20NG 1270 K	Hornblende gabbro	60 (An_{60})	-	1	35	-	-	-	Magnetite 2% apatite 1-2% sphene(tr)	
20NG 1270 L	Hornblende (-biotite) gabbro	60 (An_{60})	-	-	30-35	-	-	1-2	Magnetite 2-3% apatite 1-2%	Chlorite (trace)
20NG 1270 M*	Augite-hornblende gabbro	60 (An_{81-87})	-	-	7-8	20-25@	-	-	Magnetite 4-5%	
20NG 1270 N	Hornblende-augite gabbro	60 (An_{62})	-	-	30	5-6	-	-	Magnetite 2%, apatite 1%, sphene (tr)	Chlorite 1%, epidote (tr)
20NG 1270 O	Hornblende gabbro	60-65(An_{30-87})	-	-	35-40	-	-	-	Magnetite (?)1% sphene (tr)	Chlorite, calcite (tr)
20NG 1270 P*	Hornblende - augite gabbro	60-65(An_{88})	-	-	15	15@	-	-	Magnetite 5%	
20NG 1270 Q	Hornblende-biotite-augite-quartz gabbro	65(An_{58-38})	-	1-2	25	5@	-	5-7	Magnetite 1%, sphene (tr) apatite 1%	Chlorite (1%), epidote (tr)
20NG 1270 R	Hornblende-biotite-quartz diorite	60 (An_{47})	-	5	25	-	-	5@	Magnetite 1-2%; zircon, sphene, apatite (tr)	Chlorite (trace)
20NG 1270 T*	Hornblende-augite gabbro	60 (An_{84})	-	-	25	10@	-	-	Magnetite 2%, apatite (tr)	
20NG 1270 U*	Hornblende(-augite) gabbro	65(An_{89-90})	-	-	30	1-2@	-	-	Magnetite (?) 2-3 %	

* Gabbro with bytownite and augite mantled by hornblende. @ Augite with reaction relationship to hornblende.

Twenty-eight samples of Bismarck Intrusive Complex from five areas of the Central and Eastern Highlands were examined in thin section (Table 6). Two samples collected from the Kerigomna plateau area were found to be a porphyritic pyroxene microdiorite and a hornblende-augite gabbro. The gabbro consists of bytownite (85%) which forms a granular aggregate of prismatic crystals, 0.2 to 4.0 mm, tending to have rounded convex boundaries, and irregular masses of pale green hornblende which wholly or partly enclose plagioclase grains and partly replace ragged pale brown augite grains (Figs 45, 46).

A collection of nineteen specimens from the Kworu (Koro) River which drains the western slopes of Mounts Kworu and Wilhelm consists of twelve gabbros, five diorites, a tonalite and a mangerite. The gabbros are all hornblende-bearing, six of them being very basic bytownite-hornblende-augite gabbros with textures as described above (Figs 45 and 46); the others are hornblende gabbros (3), a hornblende-biotite-pyroxene-quartz gabbro, a hornblende-biotite gabbro, and a hornblende-augite-olivine gabbro, again with the characteristic 'granular' texture. They contain very calcic plagioclase, and there are reaction relationships between augite and hornblende, and between olivine and hornblende. The diorites consist of strongly zoned andesine to labradorite with hornblende (in two samples), or with hornblende-augite-quartz, hornblende-augite-olivine or hornblende-biotite-quartz (one of each). 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, late crystallizing hornblende. The texture resembles cumulus or eutectic texture, with grain boundaries tending to be curvilinear and plagioclase with convex boundaries against hornblende. The less basic rocks have less pyroxene (in a more advanced stage of decomposition), and greener hornblende. Potash feldspar is absent in all but one of the specimens.

Of the twenty-eight samples examined in thin section after the 1968 survey, none could be classified as granodiorite. The dominant rock type is gabbro (13 samples), with lesser diorite (7), tonalite (2), and one mangerite; one specimen is intermediate between diorite and gabbro. Of all the specimens previously described, only the rocks from the north-eastern and south-eastern extremities of the batholith are predominantly granodiorite. Of the others, the majority are tonalite, mangerite and gabbro. Systematic sampling would probably show that the dominant rock type in the Bismarck Intrusive Complex is gabbro or diorite.

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

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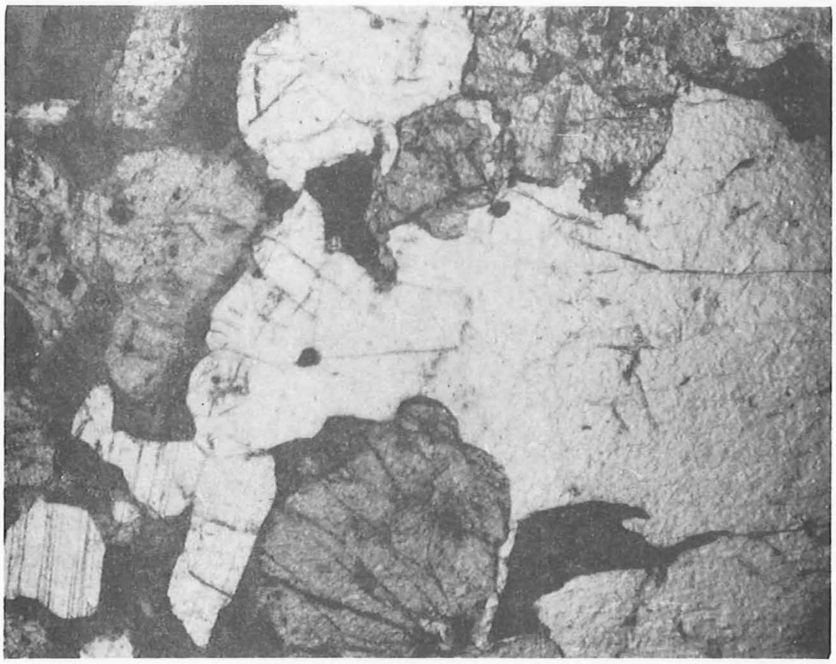

Fig.45 Hornblende-augite gabbro, 20NG 1270M, from the Bismarck Intrusive Complex, in the Mt. Wilhelm - Mt. Kworu area. Very pale areas are bytownite, light grey augite; darker grey hornblende forms patches in and mantles on augite. Opaque mineral is magnetite. 45X, plane polarized light. Neg. M/1021.

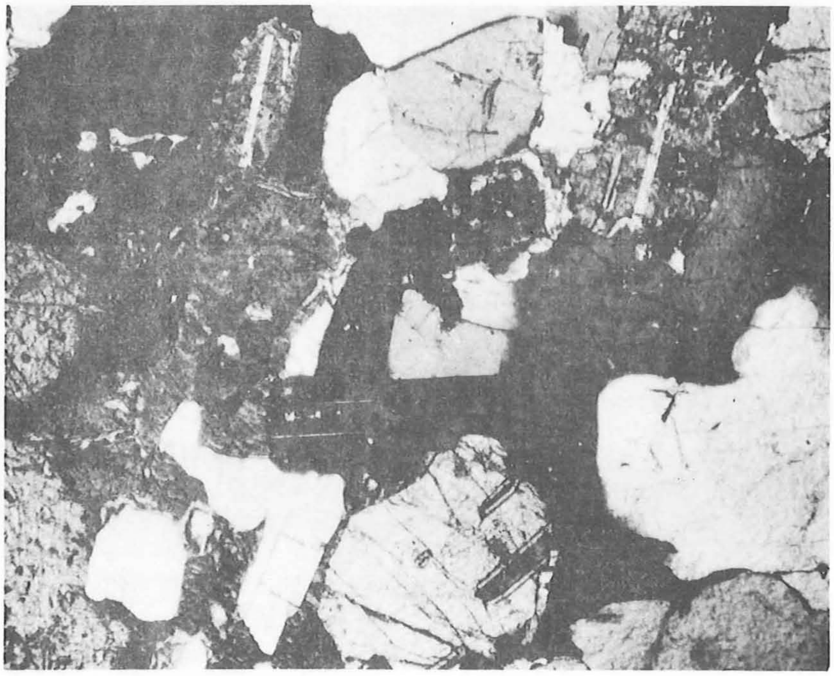

Fig.46 Same as above, with crossed polarizers. Shows twinning in bytownite and augite, reveals granular texture. Neg. M/1021.

Michael Diorite (new name)

Michael Diorite is the name proposed for a large (6 x 10 km) hypabyssal pluton that forms Mount Michael (4000 m a.s.l.), 15 km east of the Wahgi-Asaro River junction. The main rock type, is a light to dark grey coloured microporphyritic hornblende diorite with small elongate hornblende phenocrysts, and square, cloudy white plagioclase phenocrysts. Many specimens contain finely-crystalline mafic inclusions and one specimen contains a fragment of volcanic rock which is made up of feldspar fragments in a yellowish glassy groundmass.

Petrography

Eight specimens of Michael Diorite from widely scattered localities were examined in thin section and all were found to be microporphyritic hornblende diorite of remarkably similar appearance.(Table 7). The only significant differences between specimens is the degree of alteration. The diorite consists of a finely crystalline quartzo-feldspathic groundmass (about 40 percent), and small (0.5 to 4 mm) phenocrysts of hornblende (10 to 20 percent) and andesine (about 35-40 percent).

In the unaltered rock, plagioclase phenocrysts are squat tabular euhedral crystals with sharp boundaries and rounded corners. Most crystals are twinned, many complexly, and show strong normal and oscillatory zoning. Some crystals enclose small rounded plagioclase grains, and the rims of many crystals are sieved with small inclusions; the plagioclase is also commonly fractured and veined, and partially replaced by potash feldspar. Hornblende phenocrysts average about 0.5 mm with some up to 2 mm long. The euhedral crystals are zoned, twinned, and very elongate. Most crystals are strongly pleochroic with colours ranging from pale yellowish-green to deep green and greenish-brown. In some specimens, hornblende has been replaced by patches of calcite, actinolite, chlorite, prehnite, and opaques, and by chlorite and sericite pseudomorphs. Potash feldspar (sanidine) forms up to 5 percent of the rock and occurs as veins in plagioclase, interstitial patches up to 1.0 mm across, generally moulded around the ends of plagioclase phenocrysts, and smaller interstitial patches between quartz and plagioclase granules in the groundmass. Phenocrysts of quartz were seen in only one specimen where they formed only a very small part of the rock. Small rounded opaque grains (pyrite), with many inclusions, form up to 2 percent of the rock; most grains are moulded on plagioclase or replacing plagioclase and hornblende. In some specimens there are aggregates of small granules of pyrite, commonly surrounded by sericite and epidote. The groundmass consists of a very fine-grained irregular mosaic of quartz, plagioclase and hornblende with interstitial potash feldspar and rare sphene. In altered specimens the groundmass contains cloudy feldspar, epidote (or allanite?), chlorite, prehnite, sericite, and opaques. One specimen has a sericitized, finely recrystallized glassy quartzo-feldspathic groundmass.

The mode of occurrence of the potash feldspar indicates that the intrusive has suffered some late stage high temperature potash metasomatism. The sulphides (almost entirely pyrite) were probably introduced during this stage. Weathering or hydrothermal alteration has modified most specimens to some extent. Hornblende has been pseudomorphed by chlorite; plagioclase, hornblende and chlorite are sericitized, and in some specimens potash feldspar has been partly replaced by chlorite, calcite and prehnite.

Intrusive relationships and Age

Textures and minerals indicate that the pluton is a very high level intrusion. Corroborative evidence is obtained by examination of the intrusive relationships of the pluton and the doming produced in the enclosing sedimentary rocks. These show that the pluton rose to within 1500 m of the surface and possibly much closer. The presence of many small patches of Movi Beds conglomerate and siltstone capping the summit area suggests that at least part of the roof of the pluton is still preserved. Streams on the mountain are deeply incised and diorite crops out some 2000 m below the summit in the peripheral parts of the intrusion. Therefore it is possible that the uppermost 2000 m of the pluton, including part of the roof, are exposed on the slopes of Mount Michael. The diorite was emplaced largely by doming of the intruded rocks although stoping must have played a part as some beds are truncated by the intrusion; there is no major peripheral faulting or deflection of strata.

Preliminary isotopic age determinations on two specimens of the diorite have yielded an age of 7.3 ± 0.2 m.y. (R.W. Page, 1971). The youngest rocks intruded by the diorite are lower Tf shale, sandstone, and conglomerate of the Movi Beds which are in turn overlain by lower Tf volcanolithic sediments of the Asaro Formation and volcanics of the Daulo Volcanic Member. The respective ages of the Michael Diorite and Daulo Volcanic Member and their close proximity suggest that they may be intrusive and extrusive equivalents. However, this seems unlikely for the Daulo Volcanic Member is largely undersaturated, strongly potassic or sodic (analcitites), and contains augite and subordinate brown basaltic hornblende. The Michael Diorite on the other hand contains up to 10 percent or so of quartz, only 2 to 5 percent of late stage K-feldspar, 10 percent of green hornblende, and no augite.

Mineralization

Elsewhere in eastern New Guinea, (e.g., Frieda River, Dow et al., 1968) hypabyssal and subvolcanic porphyries of similar appearance carry considerable amounts of disseminated copper. Although the Michael Diorite contains an average of 1 to 2 percent of pyrite, only rare specks of chalcopyrite were seen. More detailed examination may reveal the presence of larger amounts of copper sulphides. The Michael Diorite differs from the Frieda Porphyry in that the clearly subvolcanic Frieda Porphyry intrudes andesitic and basaltic lavas and volcanolithic sediments, whereas the Michael Diorite intrudes only shale, siltstone, sandstone, conglomerate and limestone. Volcanic rocks crop out close by. Mineralization of economic significance is considered unlikely; no massive sulphides were seen in streams draining the mountain and geochemical stream sediment samples do not yield anomalous values.

Minor intrusives

Kera Sill

Rickwood (1955) recorded a diorite sill which intrudes 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 westward from 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.

TABLE 7 - Estimated Modes of Some Specimens of Michael Diorite

Sample No	Rock Name	Plagioclase % (composition)	K-feldspar %	Quartz %	Hornblende %	Opaques %	Sphene %	Groundmass %	Other	Secondary minerals
2ING2645	Micro-porphyritic (Hbl) diorite	40	5	-	20	trace	-	40	Prehnite	Calcite, Chlorite, Epidote
2ING2636B	Micro-porphyritic (Hbl) diorite	40	2-5	2-5	7-10	2	trace	40	Epidote, Actinolite, Chlorite: 2%	-
2ING1386	Micro-porphyritic diorite (altered)	35-40	5	5-10	10-20	2-5	trace	40	-	-
2ING2638	Micro-porphyritic diorite	30-40	-	-	10-20	1-2	trace	40-50	-	-

Table 8 - Estimated modes of samples of Kenangi Gabbro

Sample No.	Rock Name	Plagioclase % (composition)	K-feldspar %	Quartz	Hornblende	Augite	Olivine	Biotite	Others	Secondary Minerals
2ING 1075 C	Altered augite micromangerite porphyry	55		5	-		-	-	Magnetite (?) 2-3%	Chlorite 5%, green biotite or phlogopite 2-3%
2ING 1075 E	Altered granodiorite porphyry	60+ (?)	10-15	15	1-2	-	-	-	Opaque minerals 1-2%	Chlorite 5%, calcite 1-2% epidote 1%
2ING 1075 F	Altered augite-olivine-biotite gabbro porphyry	50	-	-	-	35	5	3-4	Opaque mineral(s) 2-3% apatite (trace)	
1076 A	Altered augite-hornblende (-olivine)-biotite gabbro	70-75 (An_{55-70})	-	-	5	10	2	3	Opaque, apatite	Green alteration products of olivine, incl. green mica 5-7%
2ING 1076 B	Augite-olivine-biotite mangerite porphyry	45 (?)	10	-	tr.	25	10	5	Apatite 1%	
2ING 2503 F	Metamorphosed hornblende diorite	ca40 (?)	?	1-2	Ca-10				Actinolite 40%	
2ING 2681	Altered porphyritic augite gabbro	60 (?)	-	1-2	-	20	-	-	Magnetite(?) 1-2%	Calcite 2-3%, chlorite 10-15%, epidote (trace)

Boulders of similar dioritic rock occur in a few of the streams farther west, indicating the presence of intrusives related to the Kera Sill in that area.

In hand specimen, samples from the Kera Sill vary from fine-grained grey-green rocks to medium/coarse-grained, black and white speckled types. Coarser-grained types are confined to the interior portions of the sill, and the grainsize decreases towards its contacts. Only a small number of specimens from the Kera Sill were examined in thin section; all are dioritic in composition and are altered to various extents. One specimen (21NG1141) consists of large grains (up to 6 mm) of yellow-brown to red-brown hornblende with relict cores of augite, ophitically enclosing euhedral plagioclase prisms. Other minerals are pale green chlorite (pseudomorphing biotite), large apatite prisms, opaques, sphene, and alteration products of plagioclase. Specimen 21NG1143, collected from an outcrop west of 21NG1141, is an altered pyroxene-hornblende microdiorite (or andesite) with scarce corroded augite phenocrysts (1.0 mm) and small phenocrysts (0.5 mm) of brownish-green, partly chloritized hornblende, in a groundmass of altered plagioclase (65%, average size 0.3 to 0.5 mm), augite, altered hornblende, ilmenite, apatite, a trace of alkali feldspar, and various secondary minerals. Specimen 21NG2580A is a medium-grained altered pyroxene-hornblende diorite consisting of partly altered prisms of andesine (70%, 1.5 to 2.0 mm long), colourless augite (10%) which tends to be moulded on to plagioclase, fine-grained aggregates of green chlorite (10%) pseudomorphing ophitic hornblende, small euhedral crystals of ilmenite (extensively altered to leucoxene; 3-5%), sphene (3-4%) a little biotite, and accessory apatite. Specimen 21NG2580B is similar except that the pyroxene is very cloudy and more euhedral, and the ilmenite (5%) forms greatly elongated (up to 8 mm) skeletal crystals; pyroxene makes up 10% of the rock, chlorite after hornblende 5%, and plagioclase 80%.

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

Close to point 2554, at 2550, a small intrusion of pale grey rhyodacite or rhyolite porphyry was sampled. This rock consists of phenocrysts (about 2 mm) of euhedral quartz, sanidine and oligoclase prisms, all with glomeroporphyritic tendencies, in a fine-grained mosaic of feldspar and quartz. Green biotite and chlorite form small wispy aggregates in the groundmass, and there are a few small muscovite crystals.

Dykes and sills of microdiorite intruding the Maril Shale are common in the area west of Gumine, where extensive replacement by calcite has taken place. Large masses of coarsely crystalline white to pink calcite may be found on the road west from Dirima, where material from these intrusions have been used as paving stone.

Kenangi Gabbro (name varied)

Sills, dykes and stocks of "granodiorite, and hornblende gabbro" mapped by McMillan and Malone (1960), and by us, in the Kenangi-Watabung area are here named Kenangi Gabbro. Similar dykes, sills and small stocks occur

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throughout the Movi Beds and Asaro Formation south and southeast of the Kenangi area. Gabbro is the most common rock type in these intrusive bodies.

In the area northeast of Chuave, samples of gabbro, mangerite and granodiorite (21NG 1075 C, E & F, 1076 A & B) were collected from small dykes 1 to 10 m across, and stocks up to 2 km across. Sills of hornblende mangerite porphyry from 1 m to 100 m thick crop out in the Asaro River north of Lufa; these sills have irregular contacts and thermal aureoles up to 12 m wide.

Samples from the Kenangi Gabbro examined in thin section (Table 8) range from gabbro to mangerite and granodiorite, are commonly porphyritic, and most are altered to various degrees. Pyroxene, olivine, and potash feldspar are common components, but hornblende is less common than in the Bismarck Intrusive Complex. Biotite is present in the groundmasses of three olivine- bearing porphyritic specimens, indicating high potash (shoshonitic) or alkaline affinities. The Kenangi Gabbro is petrographically distinct from, and is probably genetically unrelated to the Bismarck Intrusive Complex. There are, however, strong petrographic similarities between the intrusive rocks of the Kenangi Gabbro and the lavas of the Daulo Volcanic Member, which is intruded by them. Thus the Kenangi Gabbro may be genetically related to the Daulo volcanics.

Benembi Diorite (new name)

The Benembi Diorite is the name given to a small hornblende-quartz diorite porphyry plug, 6 km southwest of Mount Hagen. The diorite has intruded volcanolithic and tuffaceous sandstones of the Kondaku Tuff and has produced some hornfels. In hand specimen, the rock is a yellowish porphyry with white to yellowish plagioclase phenocrysts up to 4 mm long and small black elongated hornblende prisms in a fine-grained yellowish-grey groundmass. Microscopic examination of the rock in thin section (Table 5, 20NG0592) shows the following features. Subhedral prisms (average size 1 mm) of altered plagioclase zoned from core of An_{39} to rims of An_{18} make up 70% of the rock. Potash feldspar (5-10%) forms interstitial grains and irregular patches in plagioclase; there is some evidence of exsolution. Quartz (5%) is also interstitial, and partly chloritized hornblende (averaging 0.7 mm) forms euhedral prisms with α very pale brown or pinkish-brown (nearly colourless), β brown-green to greenish-brown, and γ pinkish-brown with a green tinge. Other minerals are green biotite (heavily chloritized), magnetite, apatite and other secondary minerals (epidote-clinozoisite and sphene) in plagioclase and hornblende.

Intrusive rocks probably equivalent to the Benembi Diorite, which have intruded the Kondaku Tuff, have been considered responsible for the gold mineralization at Kuta (Ward 1949; Rickwood, 1955). It is therefore possible that similar mineralization is present in the vicinity of the Benembi Diorite.

STRUCTURE

The Central Cordillera (or Central Highlands Orogenic Belt of Thompson and Fisher, 1965) is composed of two fundamental structural units: the New Guinea Mobile Belt and the stable crust block (Fig. 48). These have been briefly described by Dow et al. (1968).

The stable crust block (Palaeozoic Australian continental block) in the central Highlands consists of Palaeozoic metamorphic and igneous rocks overlain by several thousand feet of Mesozoic and Tertiary sediments (Australasian Petroleum Company 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 exposed in the Kubor Range (Kubor Anticline) and Muller Range (Muller Anticline) (Fig. 48). Sediments on the southern flanks of these anticlines have been subjected to gravity sliding and diapirism (Jenkins & Martin, 1969). The northern limbs are truncated by the faults of the Mobile Belt (a tectonically active zone which wraps around the northern edge of the stable continental block). The Bismarck and Lagaip Fault Zones (Dow et al., 1968) 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., 1968).

The Kubor Anticline

The Kubor Anticline was named by Noakes (1939) and the name was formalized by Rickwood (1955) who mapped the northern and eastern limits of the Palaeozoic core and the sediments of the northern limb (Fig. 50). Igneous and low grade metamorphic basement forms the triangular shaped core which crops out at elevations of up to 3,960 metres a.s.l. The anticline is a broad, gentle arch at least 50-60 km wide (Figs 1 and 47) and 125 km long. The anticlinal axis has a sinuous east-southeast trend, and can be traced from Mount Hagen town to Mount Michael where it plunges below the Tertiary cover. The axis plunges gently to the east and more steeply to the west where it is covered by Pleistocene volcanics. The north and south limbs midway along the fold dip at angles varying from 10^{o} to 40^{o}, with local variations in dip up to 70^{o} caused by minor folds and faults.

The maximum exposed width of basement is 35 km, approximately 20 km from the western end of the anticline. It is in this area that the maximum doming has occurred and also where the bulk of the granitic rock is exposed. The arched basement is overlain by a variable thickness of 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, straight, and are mostly radial to the margin of the crystalline core. In the region south of Mount Digini they have small vertical displacements. The majority of the faults are interpreted as tensional fractures resulting from doming of the basement.

Numerous small subsidiary folds are developed 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 developed near the axis of the main anticline are commonly small, monoclinal and faulted, and are difficult to recognize on the airphotographs. Consequently there has been no attempt to show these on the accompanying maps.

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

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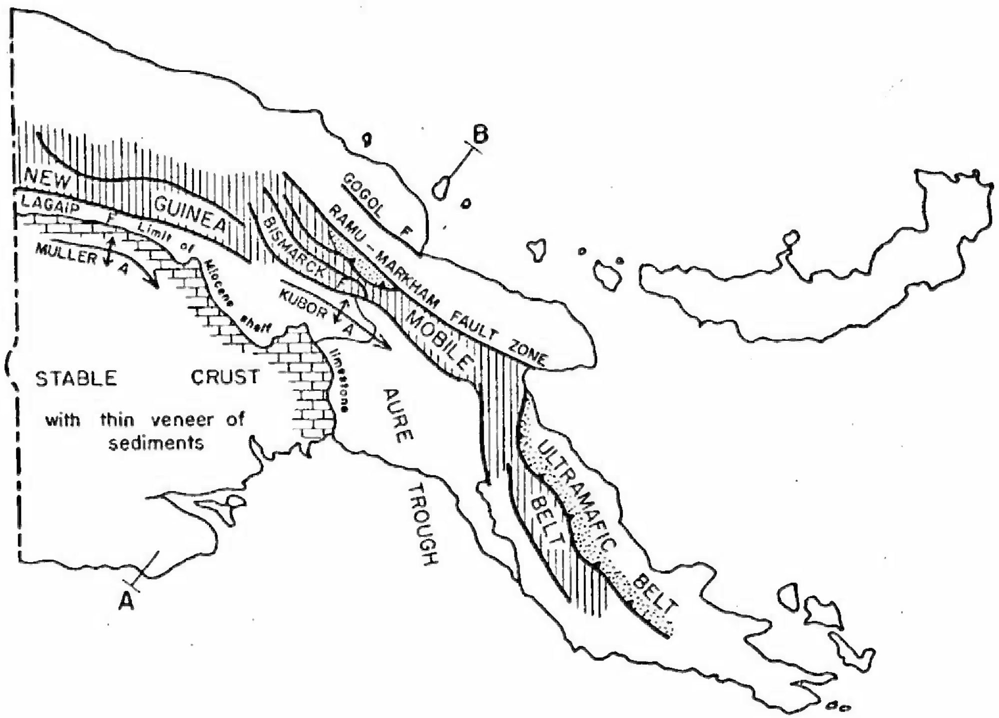
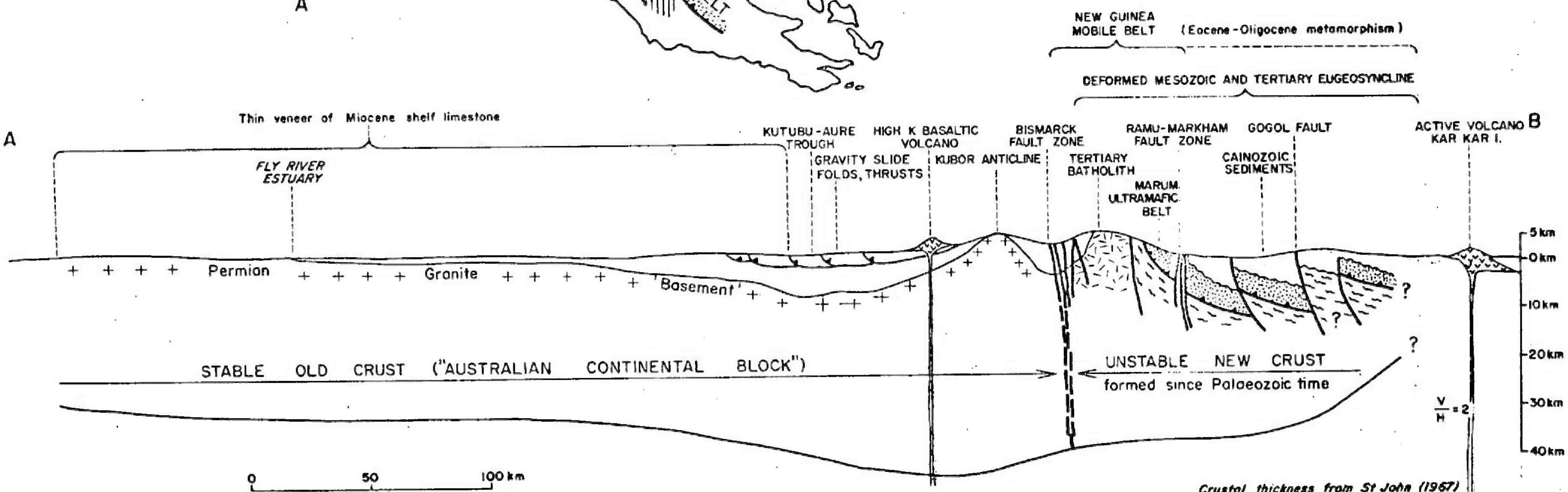
Fig. 47 South eastern nose of the Kubor Anticline.
39RT-5RGL M718 338RS, 1948, 6" 26,000 feet CPE 7614.

Fig. 48

STRUCTURAL SKETCH MAP OF NEW GUINEA





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East of the Mount Suaru, on the southern flank of the anticline, numerous small folds with east to southeast trending axes about 2-4 km apart are shown on the map. Some have been photo-interpreted while others have been detected only by ground traverses. Many are part of an east-trending synclinorium, the Pima Syncline.

Further 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 highly deformed Chim Formation sediments. Anticlines are not preserved in the Darai Limestone. Many of the synclines are box-like and have squared-off ends (e.g. 15-20 km south of the Tua-Kaugel River junction); others have tapered ends. These box folds have slightly offset axes parallel to the Kubor Anticline. In many places these synclinal limestone plates rest unconformably on near vertical Chim Formation sediments. By analogy with similar structures further west near Kagua and Pangia (Jenkins & Martin 1969, Smith 1965) they are thought to be detached diapiric folds above a décollement plane 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 Chim Formation sediments were injected into the cores of the tight parallel anticlines which formed in the early stages of sliding. Continued sliding and diapirism in the Upper Miocene and Pliocene resulted in the synclinal limestone plates overriding some areas of highly disturbed Chim Formation.

The Yaveufa Syncline

The Yaveufa Syncline is a Tertiary structure with a sinuous, arcuate trend subparallel to the eastern end of the Kubor Anticline axis. 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 Diorite and disrupted and offset by the Kami and other faults immediately east of the map area. Within the map area, the outer limbs of the syncline are composed of steeply-dipping, cliff-forming Eocene-Oligocene Chimbu Limestone. The limestone is overlain by a small thickness of Te and Tf marl and siltstone in the western end, and by a much thicker sequence of coarse volcanolithic sediment and lava to the southeast. West of the Mai River, the Tertiary sequence thins considerably and the syncline narrows from about 25 km to about 10 km in width within the Bismarck Fault Zone. Deformation of the syncline within the Bismarck Fault Zone has been so intense that the original synclinal form has been almost completely obliterated. Down plunge to the southeast, the considerable thickness (up to 3000 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 southward 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 to Tf tuffs are not exposed in the eastern limb. The syncline was probably a sinking basin of deposition during most of the Tertiary. It was certainly so when the lower Tf volcanics (Asaro Formation) were laid down.

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The Bismarck Fault Zone

The Bismarck Fault Zone was first named by Rickwood (1955) and its north western extension was mapped by Dow (1961, 1962) and Dow et al. (1968) as far as the Sepik plains. This survey has found that the fault zone in the Chimbu Valley is much wider and more complex than shown by Rickwood (1955), and that the large number of southeast-trending faults of small displacement that cross the Asaro River in the vicinity of Lufa constitute the southeastern extension of the Bismarck Fault Zone in the map area. However, the zone is not as well defined in the intervening country as it is 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 map area, the Bismarck Fault Zone is a 20 km wide, highly disturbed zone of subparallel anastomosing faults and tight overturned folds. There is at least 3,000 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 Kana Volcanics have been thrust over Maril Shale, and Balimbu Greywacke has been thrust over Chim Formation.

Large vertical movements probably occurred on only a small number of faults, such as that separating Maril Shale and Miocene limestone and siltstone in the Chimbu River Valley. Most of the 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 are interpreted as having developed as a result of southwards sliding, folding, and overthrusting of the thin Tertiary limestone-siltstone sequence 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 limestone scree slopes and shale landslips have buried most contacts.

Although overprinted by the upper Miocene-Pliocene deformation, it appears that the Bismarck Fault Zone has been active since at least Cretaceous time (Fig. 49). This is indicated by the fact that 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 upper Miocene and/or Pliocene. Dow et al. (1968) have suggested that considerable transcurrent movement may have occurred along the Bismarck Fault Zone. We have found no evidence within the map area to support or disprove this contention.

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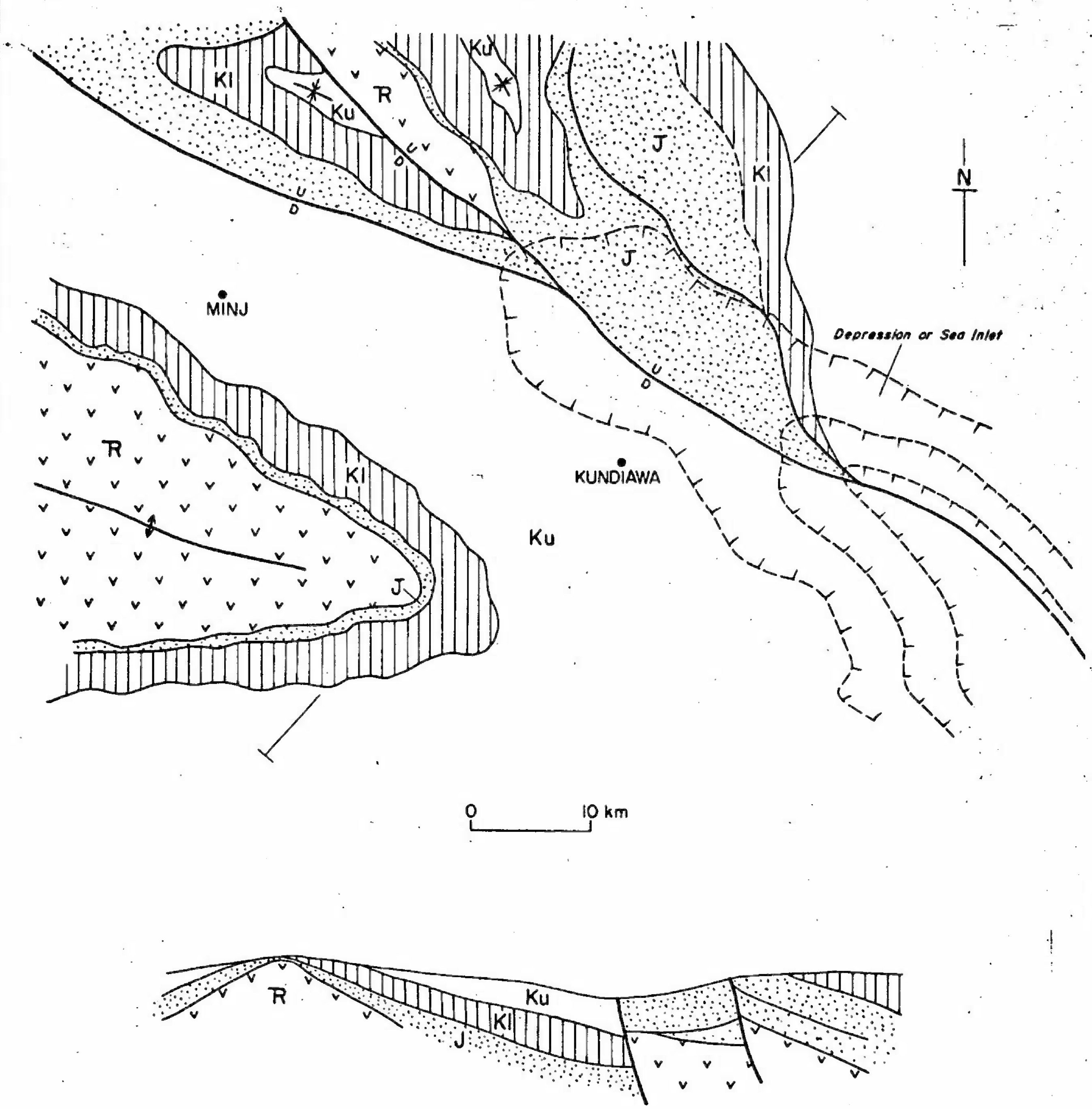
Fig. 49A DEVELOPMENT OF THE BISMARCK FAULT ZONE



A. *Late Cretaceous – early Tertiary deformation in the Bismarck Fault Zone and formation of depression towards the south-east. (Present site of Yoveufa Syncline)*

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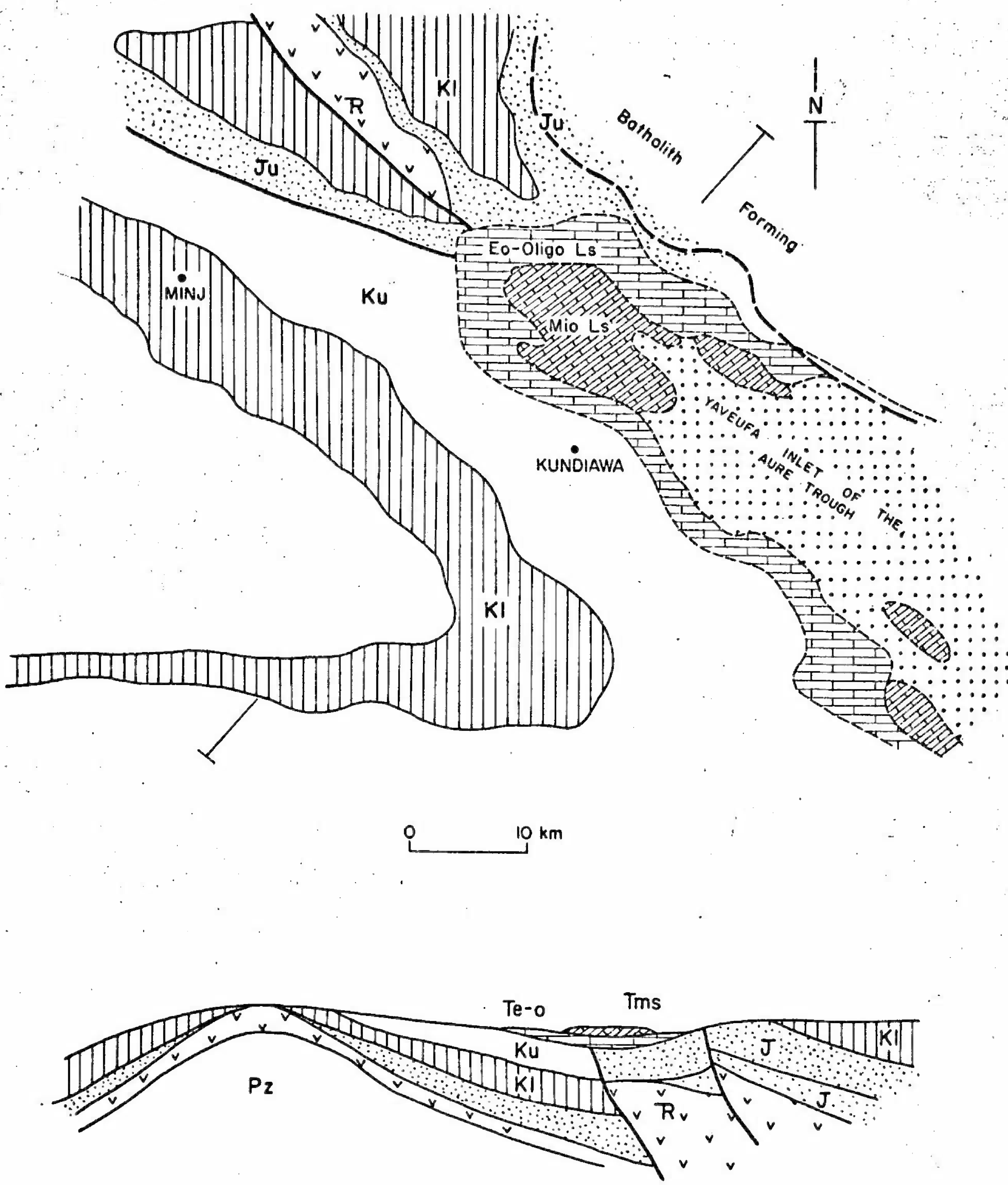
Fig. 49B DEVELOPMENT OF THE BISMARCK FAULT ZONE



B. *Early Tertiary deposition in the Yaveufa inlet. (Eocene Oligocene Chimbu Limestone and Miocene Movi Beds limestone and siltstone). — Sequence thickens from 500m in the north-west to 4000m in the south-east.*

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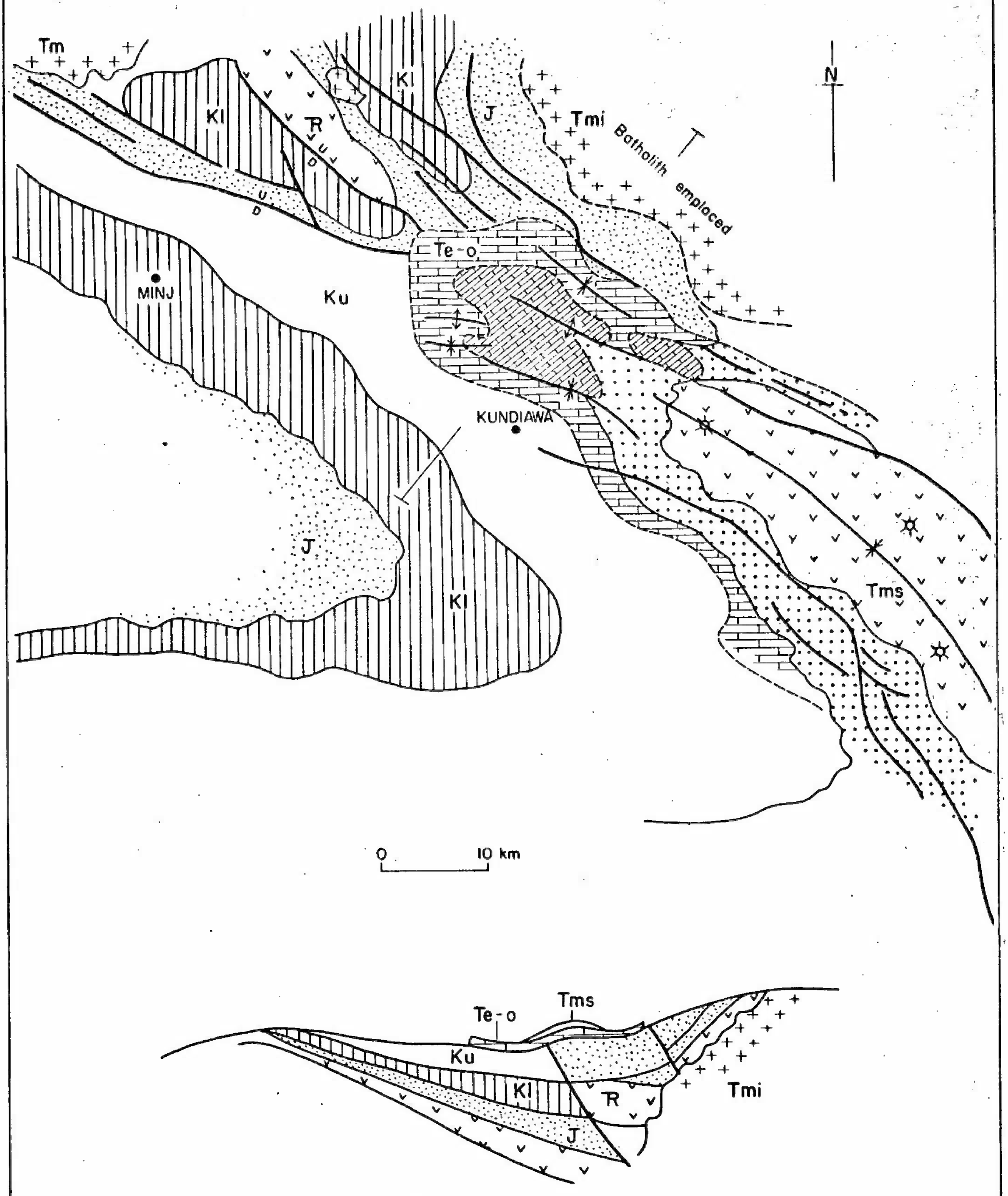
855/A/20

Fig. 49 C DEVELOPMENT OF THE BISMARCK FAULT ZONE



C. *Deformation of the Tertiary sequence commences in the Middle Miocene with the emplacement of the Bismarck batholith and reactivation of the Bismarck Fault Zone. Simple synclines and anticlines form in the thin sediments near Kundiawa and the Yaveufa Syncline forms to the south-east. The Middle Miocene volcanics appear to have formed along the line of the pre-Tertiary Bismarck Fault Zone.*

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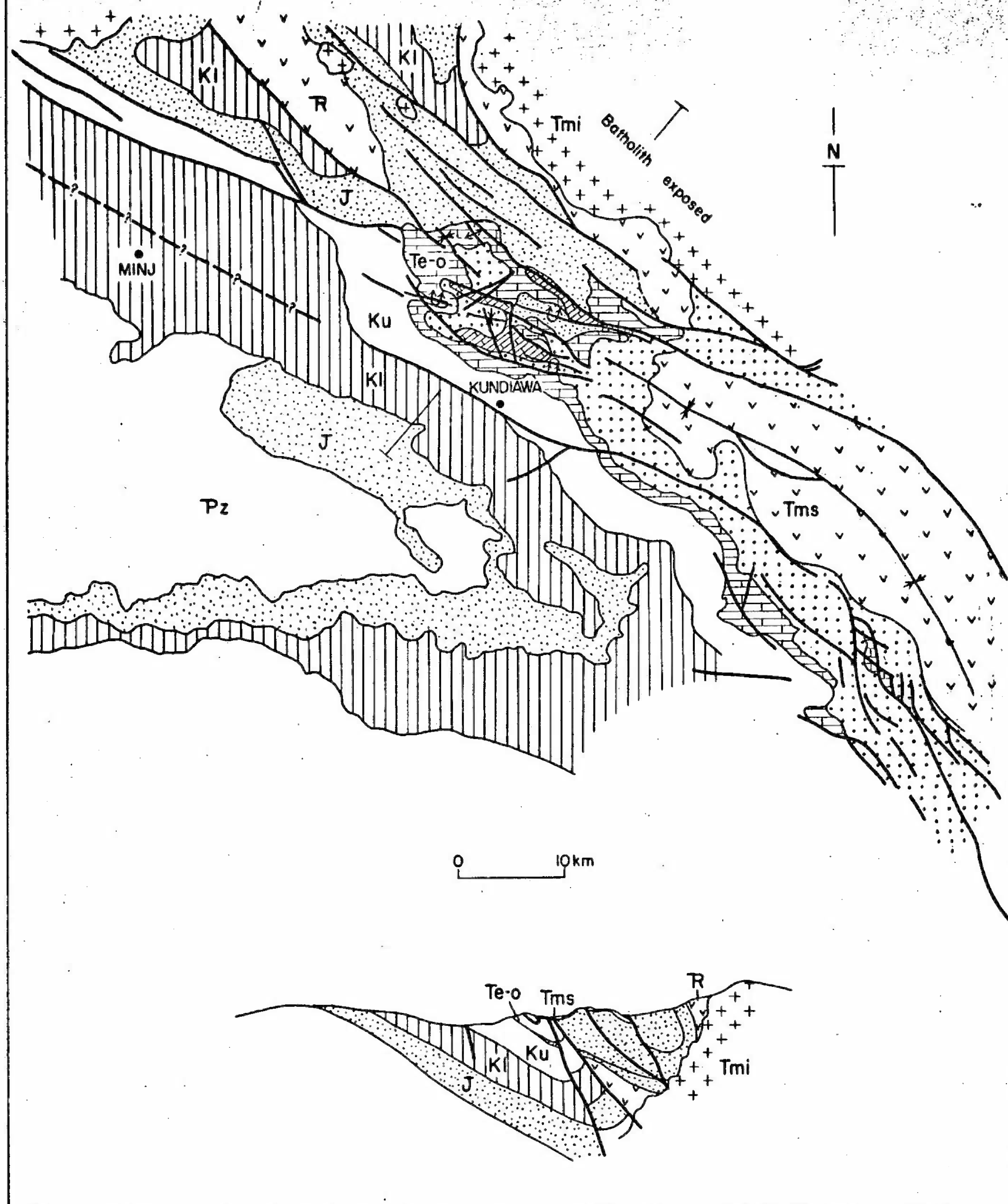
Fig. 49D DEVELOPMENT OF THE BISMARCK FAULT ZONE



D. *Reactivation of the Bismarck Fault Zone and emplacement of the Bismarck batholith are complete by the late Miocene and Pliocene. The thin Tertiary sediments are folded into tight overturned folds and the Miocene sediments thrust over the Eocene–Oligocene limestone. The Yaveufa Syncline is now well developed; near the Bismarck batholith its northern limb is overturned and strongly faulted.*

655/A/22

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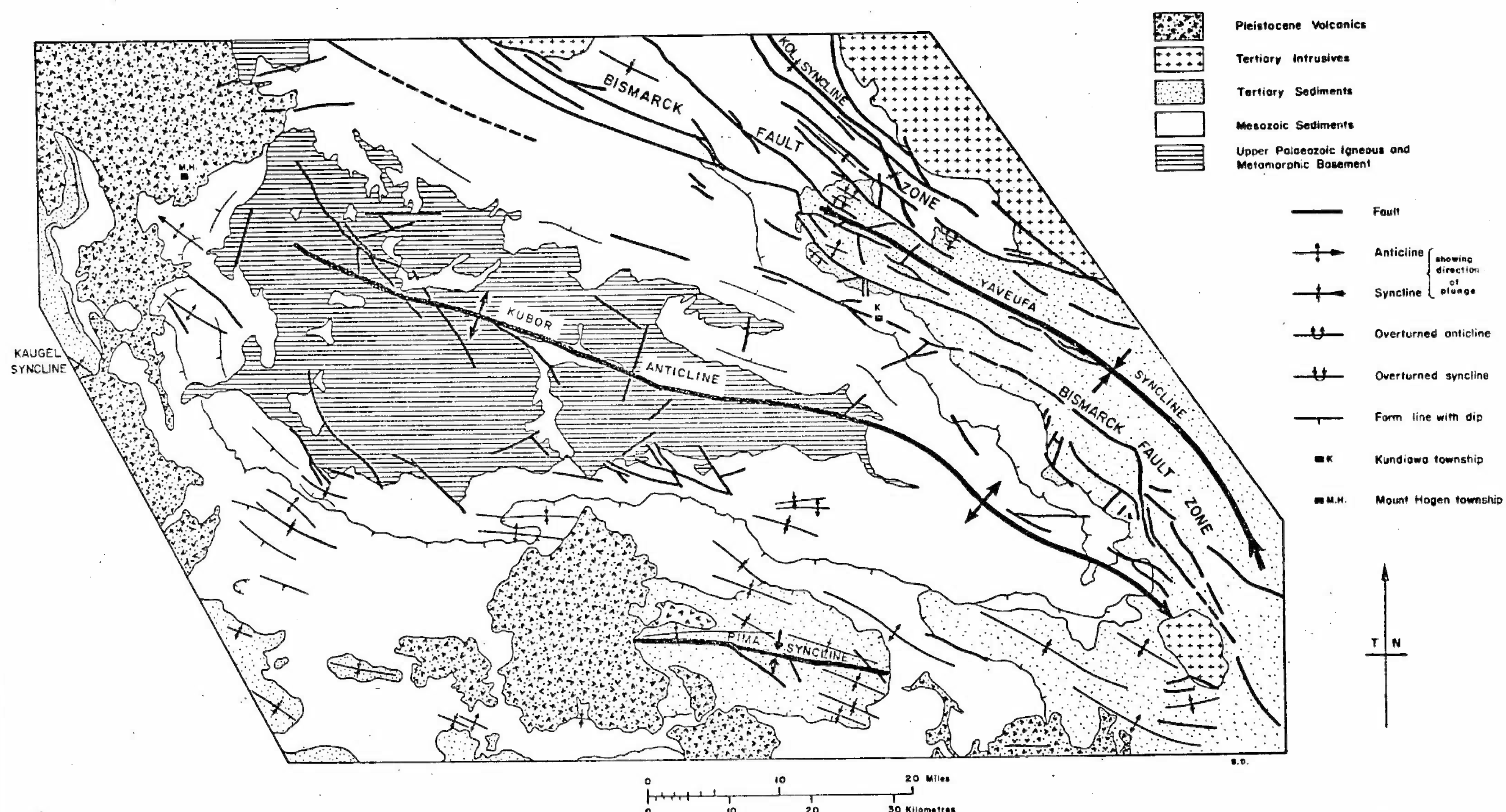
Fig. 50

STRUCTURE



To accompany Record 1970/79

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GEOLOGICAL HISTORY

In the Palaeozoic, fine-grained sediments and volcanics were laid down in a deep water environment, and were subsequently deformed and metamorphosed (Omung Metamorphics). In the late Permian (about 240 m.y. BP), the metamorphics were intruded by composite plutons of acid to basic composition (Kubor Granodiorite). Within a period of about 5 m.y. the igneous and metamorphic complex was uplifted and eroded, and the igneous rocks exposed. This was the first development of a topographic high in the Kubor area and precursor of the Kubor Anticline. Arkose and sandy limestone reefs (Kuta Formation) were laid down on and around the exposed igneous and metamorphic rocks during late Permian and early Triassic time. Uplift continued and was accompanied by further erosion of the basement complex and the limestone reefs.

Submergence followed, then came a period in Upper Triassic time of acid to basic volcanism which formed a number of volcanic islands and a large thickness of dacitic and basaltic volcanics and volcanolithic sediments (Kana Volcanics) in the surrounding seas. The greatest thickness of volcanics accumulated to the northeast of the Kubor area in a northwest trending trough or basin.

In Lower Jurassic time, the Kubor area was again uplifted and eroded. Most of the Kana Volcanics were removed and the resulting sediments were deposited to the north as Balimbu Greywacke. During the Middle Jurassic, basic volcanics (Mongum Volcanics) were extruded onto a small area of sea floor north of the Kubor landmass (Kol Syncline). Sediments were deposited over a much larger area in Upper Jurassic time as shallow seas transgressed over most of the Kubor area, and various thicknesses (up to 2000 m) of pyritic black shale and minor arkosic sandstone (Maril Shale) were deposited.

In late Lower Cretaceous time, uplift and erosion was followed by further subsidence and a period of volcanism. Shale, siltstone, massive feldspathic and tuffaceous greywackes and marine volcanics were laid down (Kondaku Tuff; now unconformably overlying Maril Shale). The source of the volcanic material in the Kondaku Tuff moved northwards to the northern Bismarck Mts and Schrader Range area in the Upper Cretaceous. In the Lower Cretaceous, soon after commencement of deposition of Kondaku Tuff, the Kubor area started to rise. This was the first stage in the development of the Kubor Anticline. Calcareous shale, siltstone, sandstone and very minor volcanics (Chim Formation) were deposited on the Kondaku Tuff, and lapped off the emergent area during the early Upper Cretaceous. Deposition of siltstone around the Kubor landmass probably ceased in Cenomanian time, and did not resume until at least the Upper Palaeocene.

The Bismarck Fault Zone, active during late Cretaceous-Palaeocene time (and possibly since the Triassic) resulted in vertical, scissor, and possible horizontal displacements of the Mesozoic sediments north of the Kubor Range (Fig. 49).

The Kubor and Bismarck areas remained land in upper Palaeocene time and were actively eroded. At the same time, calcareous siltstone (not differentiated from Chim Formation) was laid down in the Nebilyer Valley area, and reworked Kondaku Tuff and Chim Formation (Pima Sandstone) was deposited south of the Kubor Range.

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During Eocene/Oligocene time, shelf limestone (Nebilyer Limestone) was deposited at the western end of the Kubor landmass while reef limestone (Chimbu Limestone) formed in a marine inlet (Yaveufa Inlet, Fig. 49) along its northeastern flank. All sedimentation within the map area ceased during the late lower 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. These two basins were linked to the south of the Kubor Range by extensive shallow seas which extended southwards to the Torres Strait-Gulf of Papua area. The nature of sedimentation in these submerged areas during the lower and middle Miocene varied according to depth of water and proximity to landmasses and volcanic sources (Fig. 26a). A great thickness of bioclastic limestone (Darai Limestone) formed in the shallow shelf areas, while calcareous siltstone, sandstone and greywacke (Aure Group) formed in the basins.

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

Starting in upper Tf time, there followed a period of major folding, faulting, thrusting, uplift, and erosion which probably reached a peak during the Pliocene. This orogeny reactivated the Bismarck Fault Zone (Fig. 49), formed the Yaveufa Syncline, and further arched the Kubor Anticline. Gravity sliding and diapiric folding of the Tertiary and uppermost Cretaceous limestone and siltstone occurred on the southern flank of the Kubor Anticline, resulting in a 50 km wide belt of thrust-faulted diapiric folds parallel to the axis of the anticline. Numerous minor folds and faults in the Mesozoic and Tertiary rocks also formed during this period, and a hypabyssal pluton (Michael Diorite) was emplaced in the south-eastern nose of the Kubor Anticline (probably in Upper Miocene time). The whole region was uplifted and eroded during late Pliocene and early Pleistocene time.

In the southern and western parts of the map area, several large strato volcanoes (Highlands Volcanoes) were formed during early Pleistocene time (Crater Mountain possibly started to form in the late Pliocene) on a land surface as deeply eroded as that of the present day. Thick, gently-sloping volcanic aprons now mantle much of the country surrounding the volcanic centres. These aprons have been deeply gullied by recent erosion. Late Pleistocene to recent glaciation modified the summit areas of the highest volcanoes and other mountain ranges which rise to elevations of more than 3000 m. Fluvioglacial processes have contributed some sediment to the alluvial fans and lacustrine deposits which formed in the Wahgi Valley at the time as a result of damming of the valley by Hagen volcano. Recent uplift has resulted in dissection of these alluvial deposits and the formation of narrow slit gorges in the bottom of most valleys.

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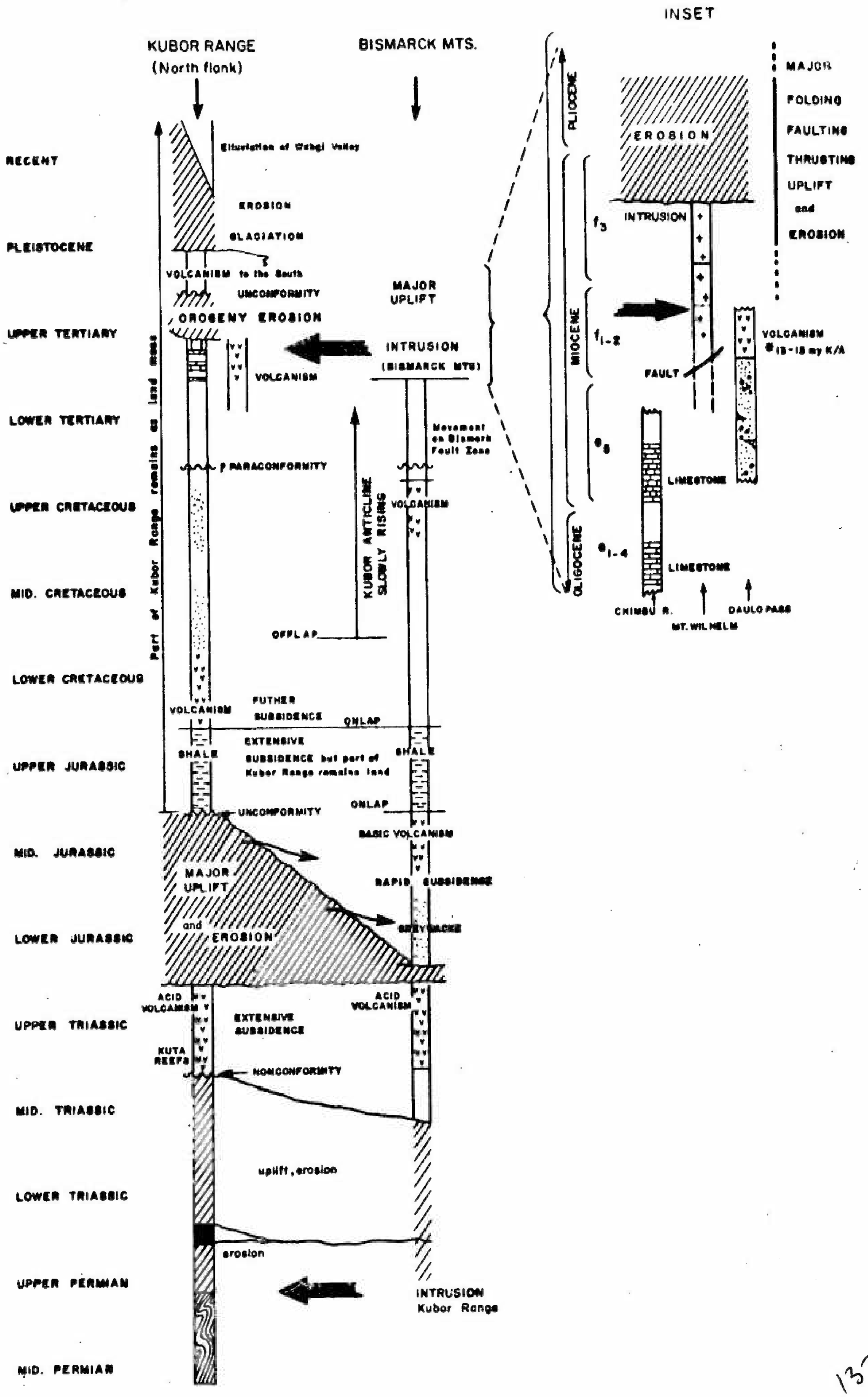
GEOLOGICAL HISTORY

Fig. 50a



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S.D.

ECONOMIC GEOLOGY (Fig. 51)

Gold

Auriferous gravel deposits near Kuta, 8 km south of Mount Hagen were discovered by the Leahy brothers in 1932 while accompanying the first Government Patrol into the area. Between 1935 and 1949, 87,085 gm of 753 fineness gold valued at $71,366 were produced (Ward, 1949). Production has now all but ceased. The main workings extended more than 1 km along the eastern bank of Kunimo Creek; 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. Its thickness ranges from about 10 cm to 2.4 m, and it is overlain by soil and unconsolidated volcanic ash. Ward (1949) suggests that the gold may have been derived from stringers and veinlets of quartz associated with small dioritic dykes and sills that intrude the Kondaku Tuff near Kuta (see Benembi Diorite).

Alluvium filling small valleys on the eastern 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. Thus they too may contain gold in payable quantities.

Small patches of auriferous river gravel in the Jimi Valley north of Banz provide a subsistence income for a small group of people. The gold is thought to have been derived from the Kimil Diorite. Although these deposits lie outside the map area there is every reason to believe that gold has also been shed southwards from the Kimil Diorite into the Wahgi Valley. Thus the alluvial deposits in streams draining the southern side of the Jimi-Wahgi divide near Banz almost certainly contain some gold, and should be tested.

The large unconsolidated, stratified sand and gravel deposits (Wahgi Fanglomerate) in the Wahgi Valley have been derived directly from the adjacent mountain ranges, probably by fluviatile and fluvio-glacial processes. The deposits probably accumulated rapidly from source areas that are not known to contain rich gold lodes, and it is unlikely that they contain rich concentrations of gold. However, they probably contain at least small quantities of gold, and where they have been reworked by the Wahgi River there may be significant concentrations of the metal. The accessibility, size, and unconsolidated nature of the deposits, and the ready availability of water with a large enough head for sluicing, may well make even low concentrations of gold payable. Testing of both the fanglomerate deposits and the recent river alluvium may be warranted.

Small alluvial terraces in the Wahgi River gorge between Kundiawa and the Wahgi-Asaro junction may contain gold. Large-scale exploitation of these deposits would not be possible because of extremely difficult access and small size of the deposits. However, should these deposits prove to be auriferous, exploitation by individuals or small groups of native miners may prove possible. There have been unsubstantiated reports of gold from the Minj River south of Minj.

Copper

Apart from a few flecks of chalcopyrite in some specimens of Kimil Diorite, Bismarck Intrusive Complex, and Michael Diorite, no copper mineralization has been found. However, the emphasis of our survey was on regional mapping rather than the search for mineralization, and it is possible that more detailed mapping might reveal significant zones of copper mineralization. Prospective areas are indicated in Figure 51. These have been selected on the assumption that porphyry copper deposits are most likely to occur in association with hydrothermally altered high level (hypabyssal or sub-volcanic) intrusive bodies, especially where they intrude volcanics. In the case of large composite batholiths (Bismarck Intrusive Complex), such 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 and hence most interesting from the point of view of porphyry copper mineralization. The Benembi Plug is not well exposed, and pyrite was absent in the few specimens collected. However, it is believed to be related to the Tertiary intrusives that shed gold to the Kuta alluvial deposits. Pyrite occurs in all specimens of Michael Diorite, and commonly as much as 2 or 3 percent pyrite is found in specimens from the summit areas 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 very minor chalcopyrite occur in the contact zone of the Kimil Diorite where it intrudes Kana Volcanics in the headwaters of Banz Creek. This intrusive body has also shed gold into the Jimi Valley. Molybdenum, copper, and zinc sulphides and gold have been found localized in small quartz veins and shears throughout the contact region of a small stock of Kimil Diorite which has intruded acid to intermediate Kana Volcanics in the Marramp River, about 30 km northwest of Banz (Jones, 1970). Other bodies of Kimil Diorite outside the map area are also regarded as potential copper/gold sources. The southwestern margin of the Bismarck Intrusive Complex, where it intrudes the Kana Volcanics, is a possible zone of copper and gold mineralization. Pyrite and chalcopyrite occur elsewhere in the Bismarck Intrusive Complex (in basic gabbros, and andesitic and monzonitic porphyries at Yandera , but little is known about their distribution. The Yandera area is being explored by Kennecott Explorations (Australia) Pty Ltd. McMillan (1955) remarked on the likelihood of reef gold occurring near the margin of the Bismarck Intrusive Complex where he observed much quartz veining and associated pyrite.

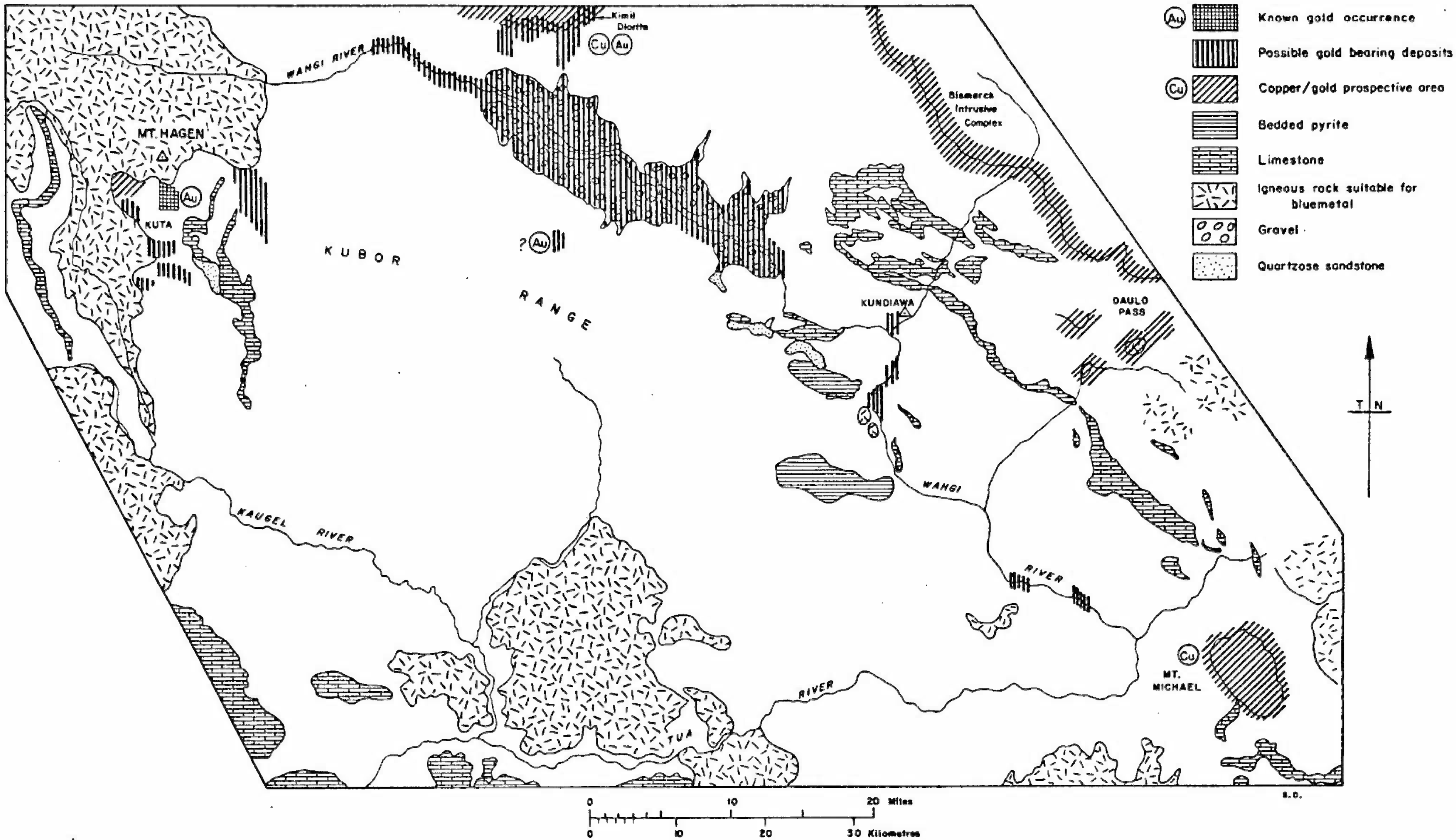
A number of small intrusions, some consisting of Kenangi Gabbro, and some possibly related to the Bismarck Intrusive Complex, occur in and near the Daulo Volcanic Member in the headwaters of the Mai River. Most are gabbroic, but little is known of their petrography or petrogenesis, or whether or not they are mineralized. Closer examination is warranted before these bodies could be dismissed as unprospective.

Bedded Pyrite

Pyrite occurs as beds, nodules, and disseminations, within the Maril Shale. Within the more pyritic areas near Gumine and Genabona it is primarily the high pyrite content that distinguished the Maril Shale from the overlying Cretaceous shale beds.

Fig. 51

ECONOMIC ROCK AND MINERAL DEPOSITS



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Fist-sized ovoid nodules and fine-grained disseminations are the most common forms of pyrite mineralization, and locally they form up to 3 or 4 percent of the rock. Some nodules are hard and compact, but more are friable. Thin beds of friable pyrite occur only in the most pyritic areas. Near Genabona a large pyrite/shale breccia body (21NG2591) forms an 8 m high waterfall, and averages about 10 percent pyrite over a 12 m width. A 25 cm-wide vein containing 70 percent pyrite occurs within a 3 m wide zone that contains about 20% pyrite. A specimen of the breccia has been assayed for copper and gold, but was found to contain no significant concentrations of either.

Limestone

Extensive deposits of limestone surround the Kubor Range (Fig. 51); most are easily accessible by road, but deposits south of the Kubor Range are very inaccessible, and likely to have little economic significance in the foreseeable future. Talus from the Chimbu Limestone, east of the lower Wahgi River, is presently quarried and used as a surfacing material on adjacent roads. Talus reserves are more than 40 million cu m. The Nebilyer and Kuta Limestone and limestones near Mount Michael and within the Maril Shale would all be suitable for crushing and use as road surfacing material. Some, especially the Nebilyer Limestone, have well-developed talus deposits similar to that developed beneath the Chimbu Limestone cliffs.

Limestone from Mt Elimbari (Chimbu Limestone) is a pure white foraminiferal variety, and appears 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 economic activity conducted by the native inhabitants of the map area (Hughes, 1969). The supply of raw material to this industry involved the earliest known mining operations in the Highlands. Chappell (1966) has shown that almost all the stone used for tool manufacture was quarried at five sites within the map area, and eight sites in the adjacent Jimi Valley. All major stone quarries have been developed in contact-metamorphic zones, most commonly within Maril Shale, but also in the Omung Metamorphics.

Only the two major quarries - Abiamp (Plate 5) and Dom (Plate 10) were located during the course of our survey, although the approximate locations of three others as indicated by Chappell (1966) are shown on Plates 6 and 7. The quarries have not been worked for thirty years or so, and are now almost completely buried by landslip material, or concealed by overgrowth. Although it is difficult to estimate the original size of the workings, Chappell's study showed that, considering the primitiveness of the excavating tools and operators, there was a major quarrying operation at Abiamp. He described an aligned series of pits and drives from which over 2,500 metric tons of rock have been quarried with sharpened sticks, yielding an estimated 40 percent of useful tool stone. The physical and petrographic properties of the tool stone from Abiamp and twelve other quarries are listed by Chappell (1966, p. 106). Briefly, the rock types 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 sites of manufacturing operations, although some raw materials were traded from the larger quarries (Chappell, 1966, p. 103). All of the known accessible occurrences of suitably hornfelsed Maril Shale (albite-epidote and albite-epidote-actinolite hornfels) within the central Highlands have been quarried, as has the only known occurrence of Omung Metamorphics (actinolite-epidote-albite hornfels) sufficiently hard (6 on the Mohs' scale) for axe manufacture. No other contact metamorphic rocks suitable for stone axe manufacture were located during our survey. It appears that the primitive stone miners were aided by efficient prospectors.

Blue Metal

The distribution of gabbroic intrusions and formations which contain basaltic and andesitic lavas suitable for crushing and use as blue metal for road surfacing or concrete constructions is shown on Fig. 51.

Gravel

Extensive deposits of stratified sand, clay and gravel (Wahgi Fanglomerate) in the Wahgi Valley contain much material suitable for road construction.

Quartzose Sandstone

Soft to hard, friable sandstone varying from white, nearly pure quartz sandstone to more felspathic arkosic types may be useful in cement and concrete constructions for nearby bridges and culverts or in the townships of Kundiawa and Mt Hagen. The main deposits occur near Gurumugl, southeast of Kundiawa, and smaller, more felspathic deposits occur southeast of Kuta.

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APPENDIX 1 - GEOGRAPHICAL LOCALITIES MENTIONED IN TEXT

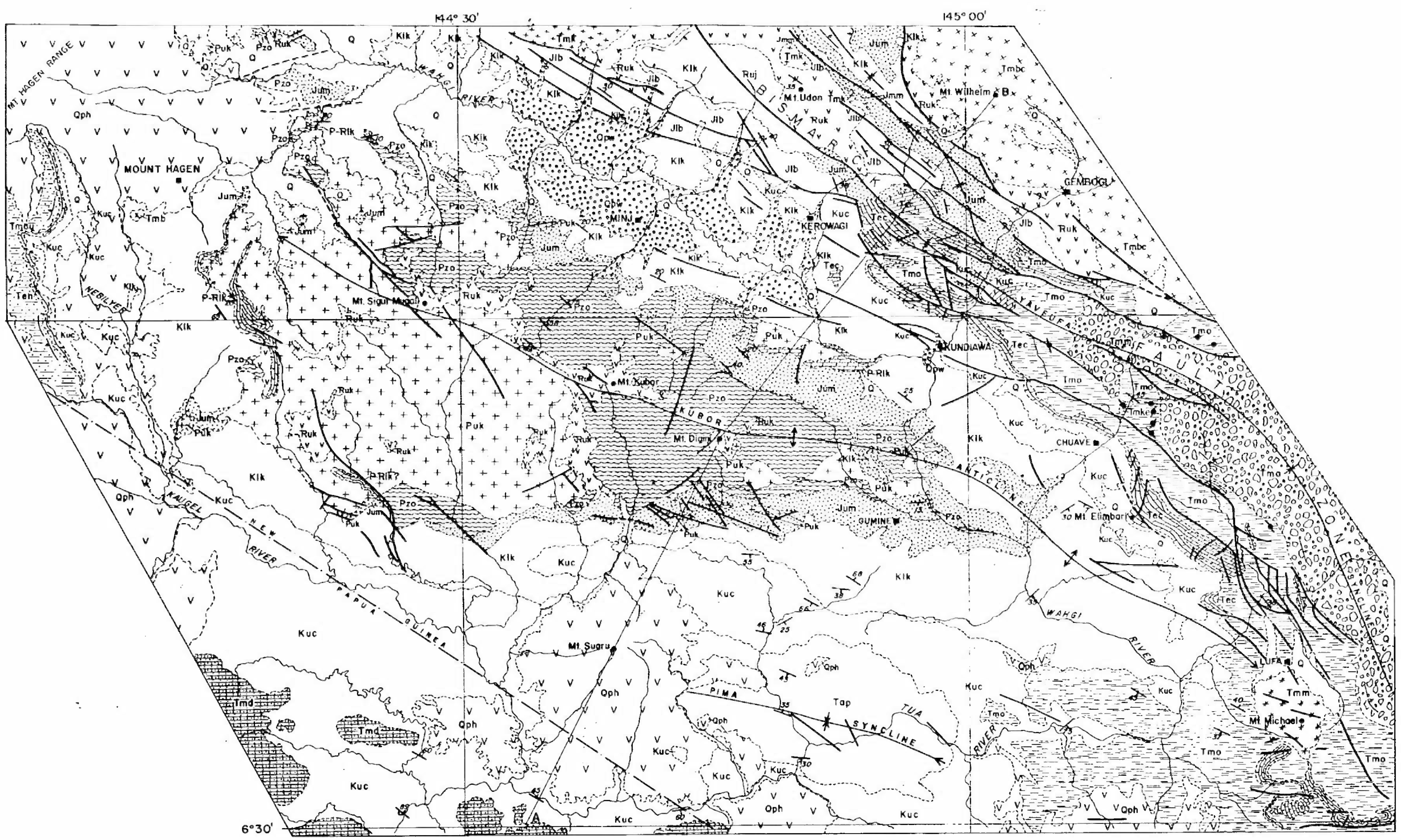
Agotu Mission	Plate	16
Aiyura		145°55'E, 6°20'S
Ambaga Creek		5
Asaro River	Plate	12, 16
Asaro Village		12
Asaro-Wahgi divide		11
Aure Trough	Fig.	26a
Aziana River		145°40'E, 6°45'S
Baiyer River		144°10'E, 5°35'S
Balimbu Creek		144°55'E, 5°40'S
Banz, Banz Ck.	Plate	5
Benembi Plateau		4
Bismarck Fault Zone		6, 11, 16, 17
Bismarck Mts		7
Bismarck Sea		northeast of N.G.
Bogo Rest House	Plate	6
Bukapena		2
Burgers Mts		143°15'E, 5°05'S
Central Highlands, Eastern, Western & Southern Highlands		141°E to 146°E
Central Cordillera, Central Ranges		141°E to 146°E
Chimbu River	Plate	7, 10
Chuave		11
Crater, Mt Crater volcano		145°05'E, 6°35'S
Daulo, Daulo Pass	Plate	11
Dek		6
Dirima		10
Erave River		144°20'E, 6°40'S
Erun Anticline		145°10'E, 6°35'S
Gai River		144°10'E, 5°20'S
Gembogl	Plate	7
Genabona		10
Gilabe hamlet		144°35'E, 6°35'S
Gogimp Valley	Plate	4
Goroka, Goroka Valley	Plate	12
Gumine		10
Gurumugl		10

Mt Hagen	Plate	4
Mt Ialibu		8
Mt Kerigomna, Kerigomna Plateau		7
Mt Karimui		144°45'E, 6°35'S
Mt Kworu	Plate	6
Mt Michael		16
Mt Oga		5
Mt Sigul Mugal		5
Mt Suaru		14
Mt Udon		6
Mt Wilhelm		7
Muller Range, Muller Anticline		142°05'E, 5°25'S
Nambaiyufa	Plate	11
Neragaima Mission		10
New Guinea Mobile Belt	Fig.	48
Nomane Mission	Plate	16
Nondugl		6
Numans Creek		6
Okapa		145°35'E, 6°35'S
Oliabai (or Olu) Creek	Plate	15
Omkalai		10
Omung River		10
Pangia		144°05'E, 6°20'S
Pima River (Oima River), Pima Syncline	Plate	15
Poru River		13, 14
Purari River		145°00'E, 7°00'S
Purari Plateau	Fig.	7
Schrader Range		144°30'E, 5°10'S
Tambul		143°55'E, 5°55'S
Tobe Creek	Plate	4
Torres Strait		143°E, 10°S
Tsau River		144°40'E, 5°40'S
Tua River	Plate	14, 16
Wabag		143°45'E, 5°30'S
Wahgi River, Wahgi Valley, Wahgi Gorge	Plate	4, 5, 6, 10, 16
Watabung		11
Western Papua		west of 144°E
Wilde River	Plate	9
Yandera-Bononi area		145°10'E, 5°45'S
Yaveufa Syncline	Plate	11, 17
Yuat River		144°00'E, 5°00'S

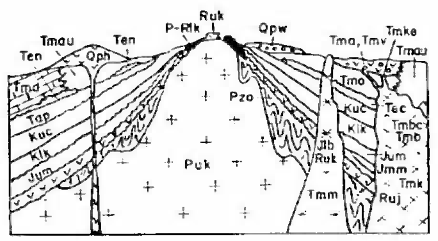
THE KUBOR ANTICLINE

CENTRAL HIGHLANDS OF NEW GUINEA

Geology by: J.H.C. Bain, D.E. Mackenzie, 1968, 1970.
D.B. Dow, R.W. Page, R.J. Ryburn, I.E. Smith, R.J. Tingey. 1968
Compiled by: J.H.C. Bain, D.E. Mackenzie, 1970.

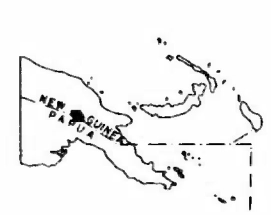


DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS

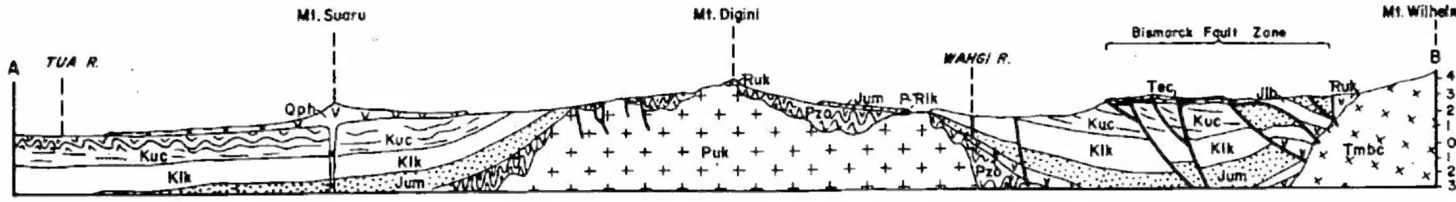


SCALE 1:500,000

LOCALITY MAP



SECTION A-B



INDEX TO 1:250,000 SHEETS

WABAG	RAMU	MADANG
LAKE KUTUBU	KARIMUI	MARKHAM
AWORRA RIVER	KIKORI	WAU

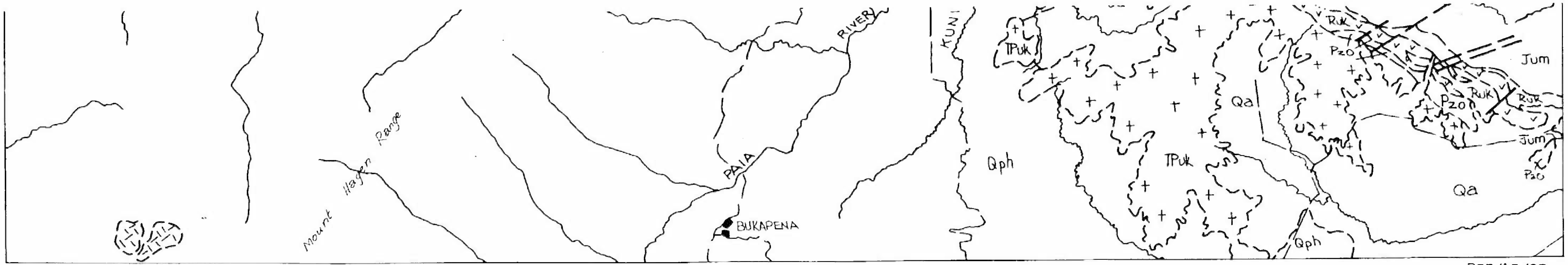
CAINOZOIC	QUATERNARY	Pleistocene to Recent		Q	Alluvium, talus, moraine
			Wahgi Fanglomerate	Qpw	Alluvial fan deposits
		Pleistocene	Highlands Volcanoes	Qph	Basaltic lava, pyroclastics, lahar deposits
	TERTIARY	Upper Miocene	Michael Diorite	Tmm	Porphyritic hornblende microdiorite
		Mid. Miocene	Benembi Diorite Kenengi Gabbro	Tmb Tmkg	Porphyritic microdiorite Gabbro, hornblende mangerite, granodiorite
			Bismarck Intrusive Complex	Tmbc	Gabbro, diorite, mangerite, granodiorite, tonalite
			Kimil Diorite	Tmk	Diorite, tonalite, granodiorite
			Asaro Formation and Daulo Volc Memb	Tma	Andesitic volcanics, volcanolithic sediments, limestone
		Upper Oligocene to Mid. Miocene	Darai Limestone	Tmd	Limestone
			Aure Group (undift.)	Tmau	Mudstone, greywacke, limestone
		Lower to Mid. Miocene	Movi Beds	Tmo	Tuffaceous sediments, limestone
		Eocene to Oligocene	Nebilyer Limestone	Ten	Limestone
			Chimbu Limestone	Tec	Limestone, calcarenite
		Upper Palaeocene	Pima Sandstone	Tap	Lithic sandstone, siltstone, mudstone
MESOZOIC	CRETACEOUS	Upper	Chim Formation	Kuc	Shale, siltstone, tuffaceous sandstone
		Lower	Kondaku Tuff	Klk	Volcanolithic sandstone, tuff, agglomerate
	JURASSIC	Upper	Maril Shale	Jum	Pyritic shale, sandstone, arkose, limestone, basal breccia
		Middle	Mongum Volcanics	Jmm	Basic submarine volcanics
		Lower	Balimbu Greywacke	Jlb	Greywacke, siltstone
	TRIASSIC	Upper	Kana Volcanics	Ruk	Intermediate to acid lavas, tuff, volcanolithic sediments
			Jimi Greywacke	Ruj	Greywacke, conglomerate, shale
MESOZOIC PALAEOZOIC		Upper Permian or Lower Triassic	Kuta Formation	P-Rlk	Limestone, calcarenite, arkose
PALAEOZOIC	PERMIAN	Upper	Kubor Granodiorite	Puk	Granodiorite, tonalite, diorite, gabbro
	PRE PERMIAN		Omung Metamorphics	Pzo	Metagreywacke, phyllite, metavolcanics, hornfels

-------	Geological boundary
	Anticline
	Syncline
——	Fault
--------	Concealed fault
—·—	Territorial boundary
MINJ ■	Government administrative centre
35	Strike & dip of strata, measured
	Overturned strata
	Trend line

B55/A/13

GENJIGI 1:100,000

PLATE 2

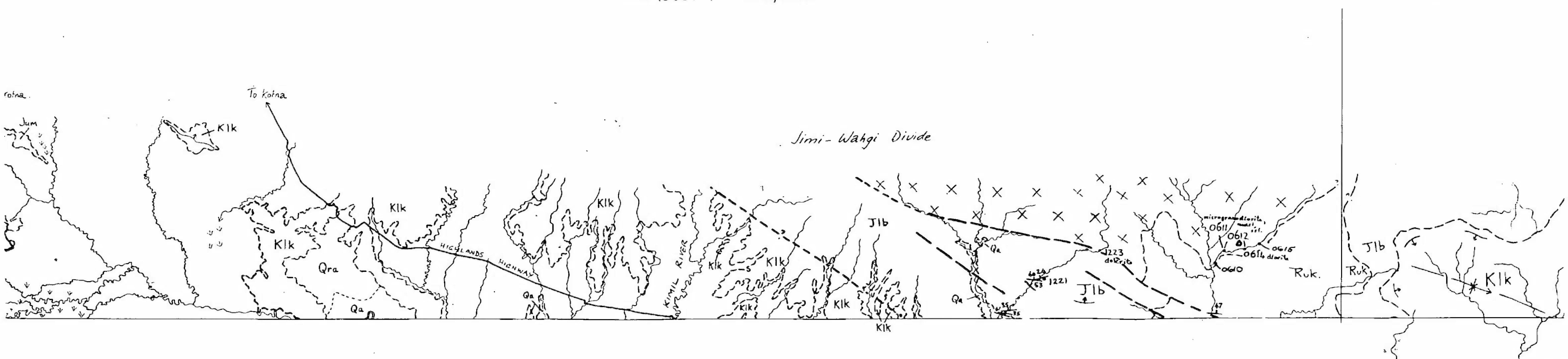


To accompany Record 1970/79

B55/A5/23

JIMI (South) 1:100,000

PLATE 3

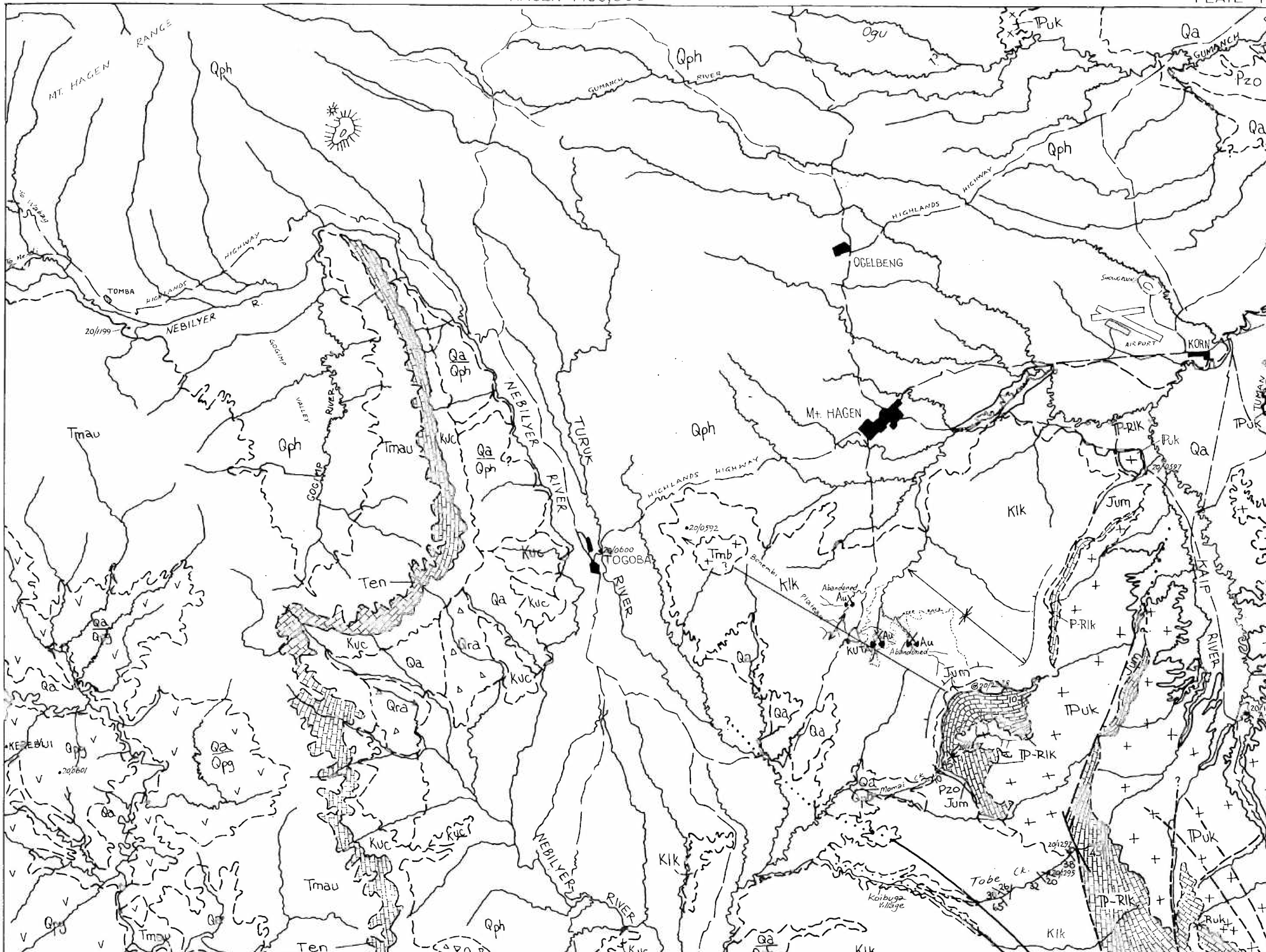


To accompany Record 1970/79

B55/A5/24

HAGEN 1:100,000

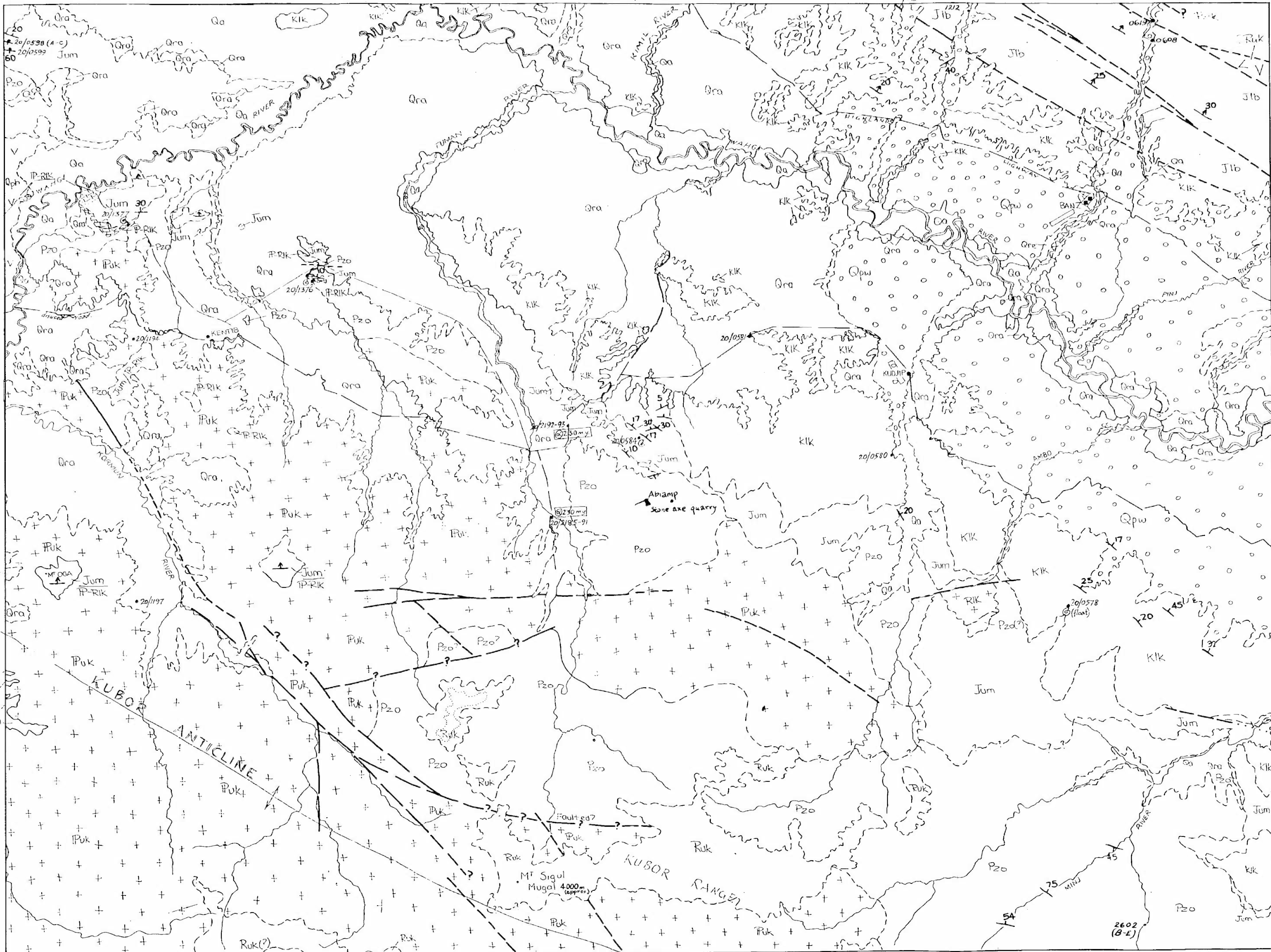
PLATE 4



B55/A9/25

WAGI 1:100,000

PLATE 5



To accompany Record 1970/79

B55/A9/26

KEROWAGI 1:100,000

To accompany Record 1970/79

B55/A9/27


Lake
Mt Wilhelm
4509m
Tmbc
BISMARCK
L. Pinde
L. Aunde
Qtm
KEGLSUGL
Mondal Creek
Qa
Ruk
Jum
Agua Creek
GEMBOGL
Kumanigl
Stone Axe
Quarry
Jlb
Chimbu River
Mai Creek
Tmo
Tec
Tmb
Dinga Creek
Q
Tma
Mt Kerigomna
Gerringl
20/0561
20/0563
20/0564
20/0565
20/0567
20/2680
20/2685
20/2687
20/2671
20/2670
20/0621
Upper Triass.

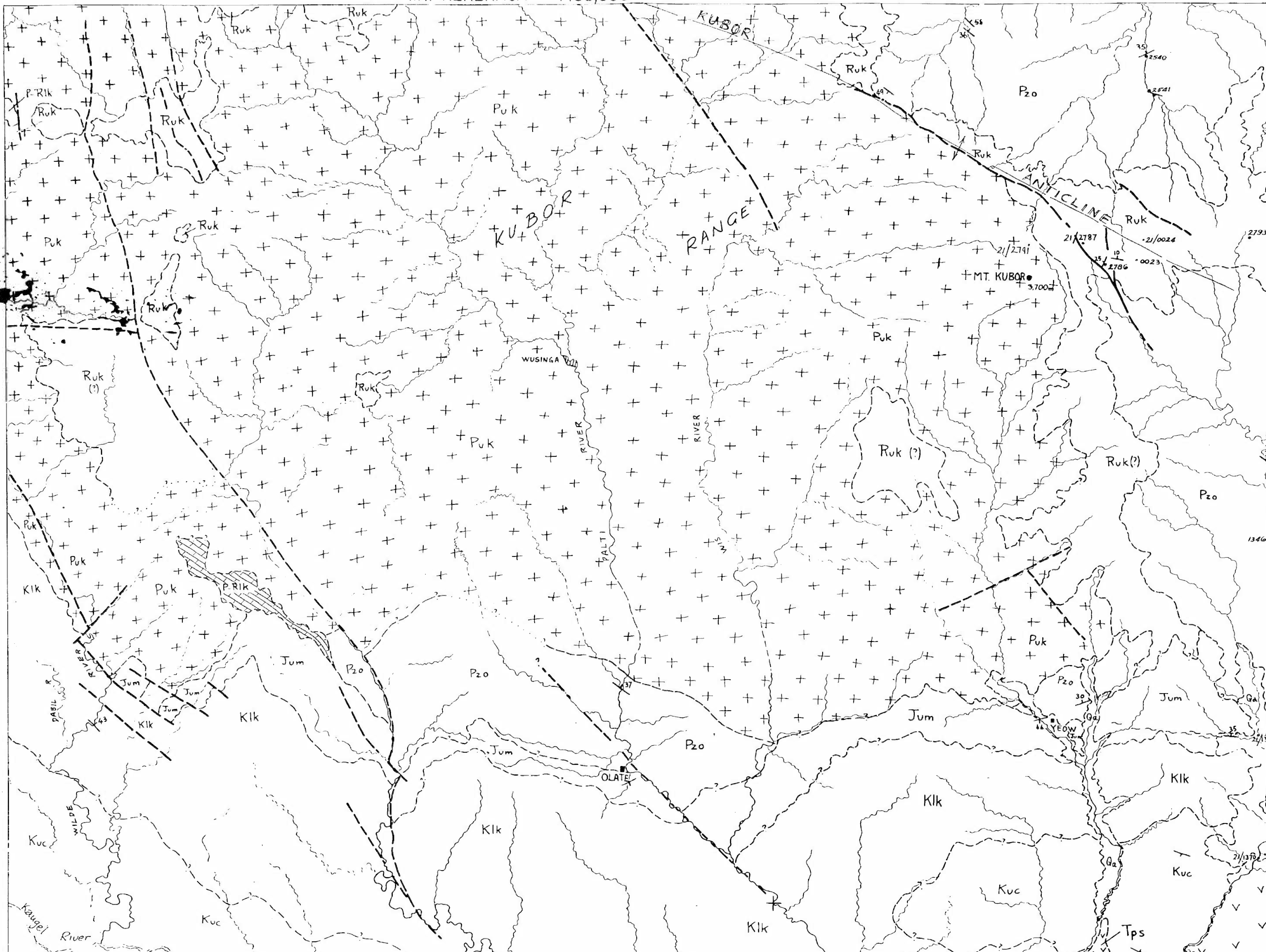
IALIBU 1:100,000

PLATE 8

To accompany Record 1970/79

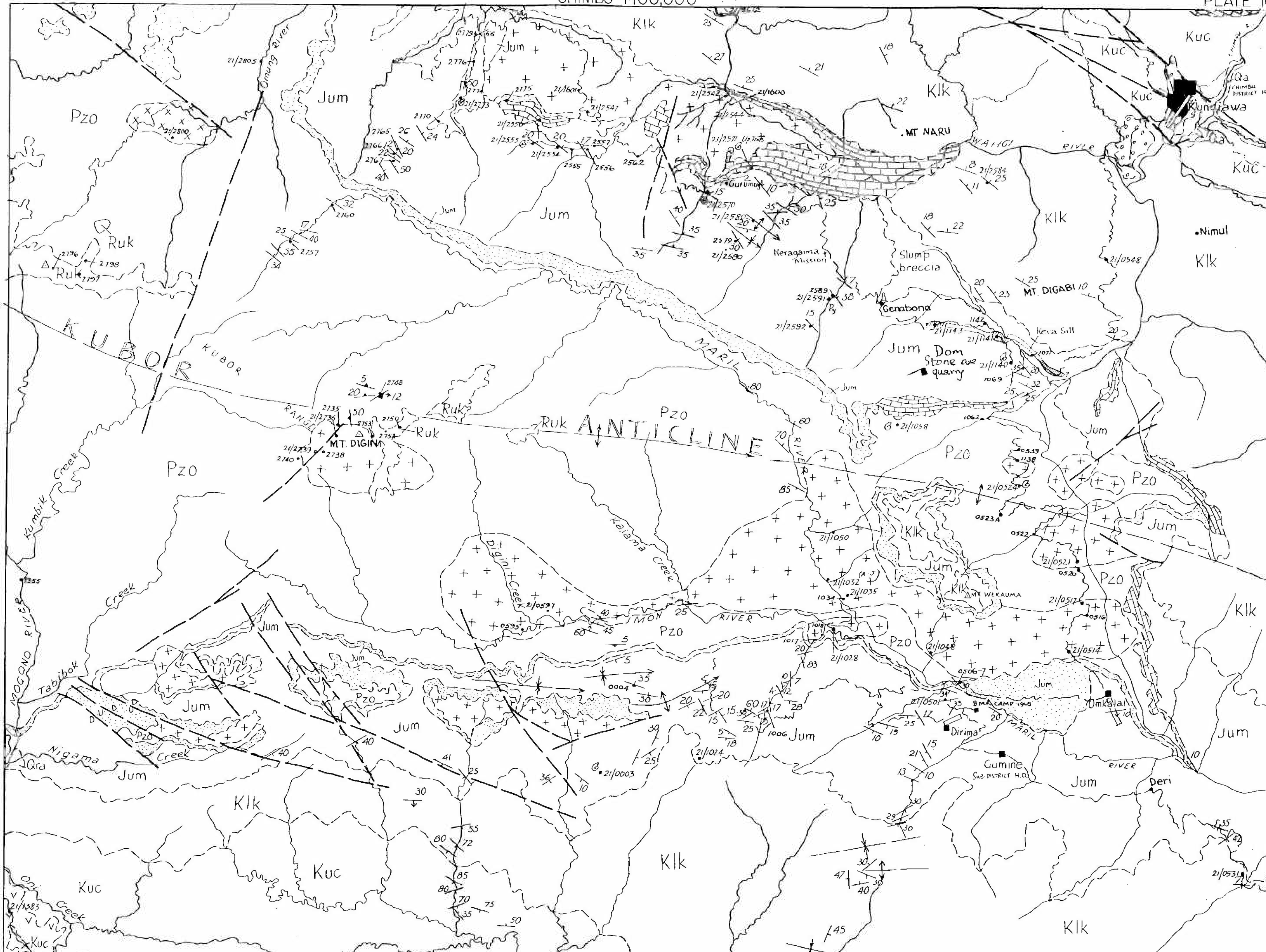
B55/A9/2

MT. KERERAGA 1:100,000

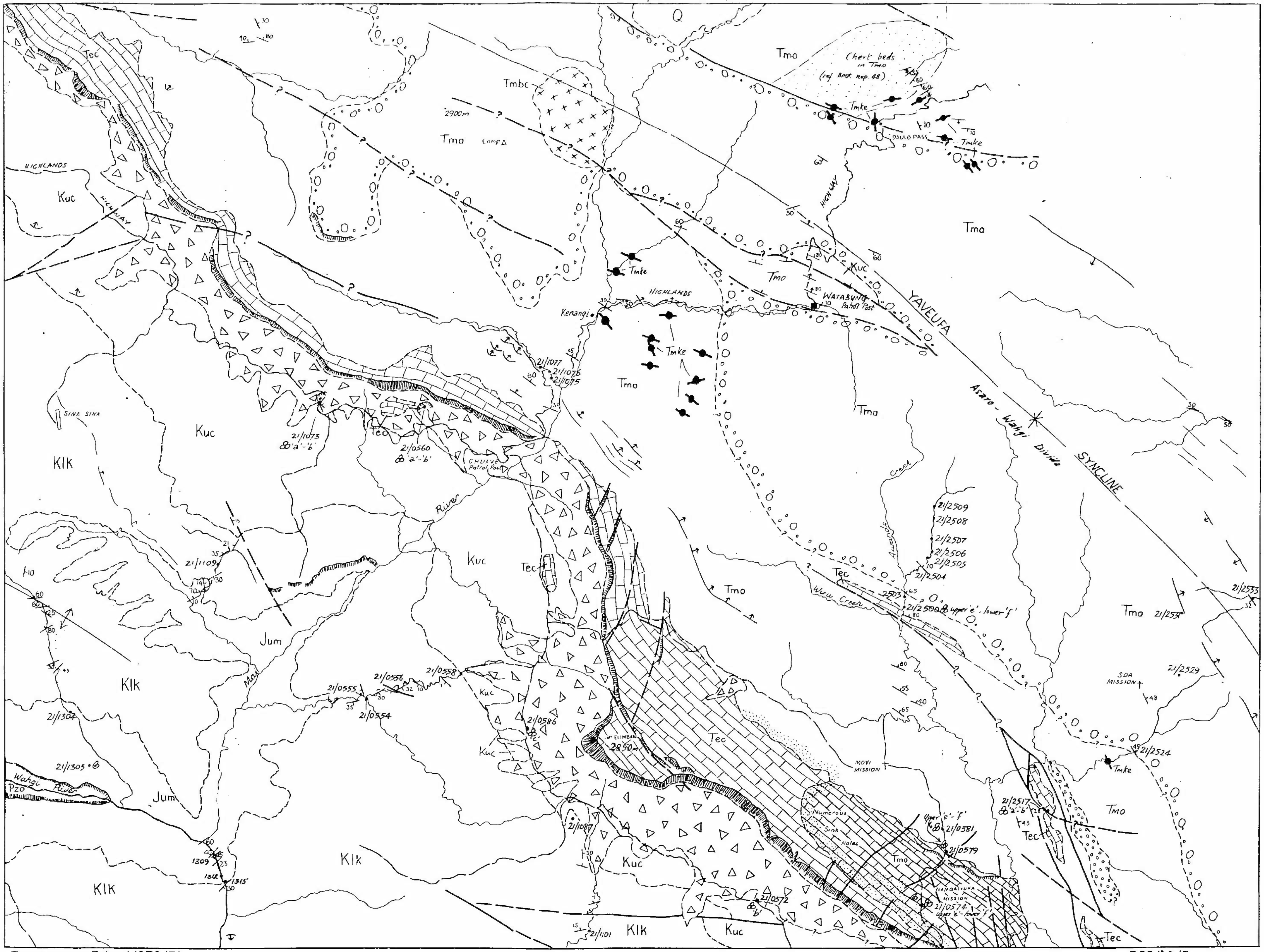


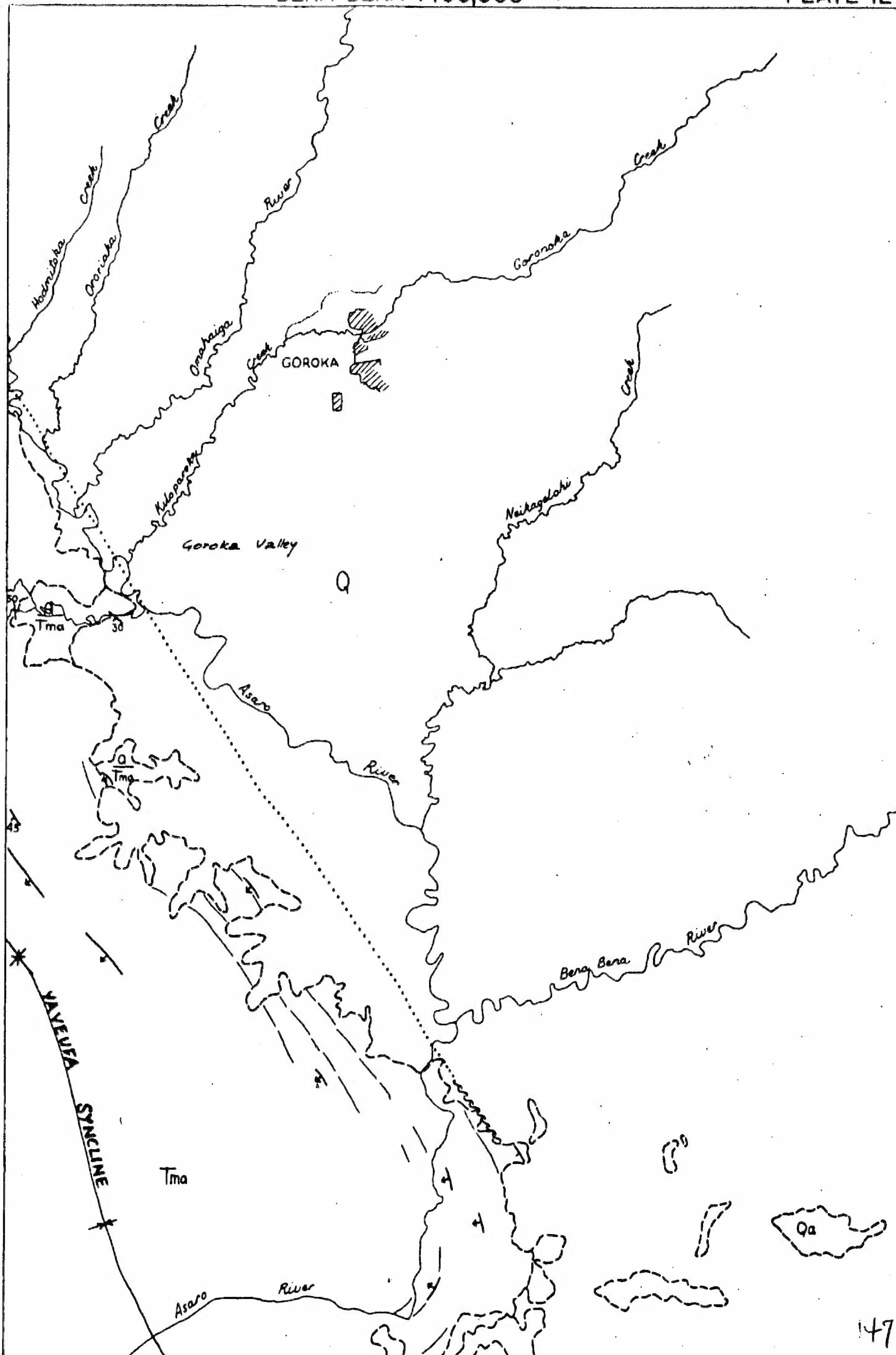
To accompany Record 1970/79

B55/A9/3

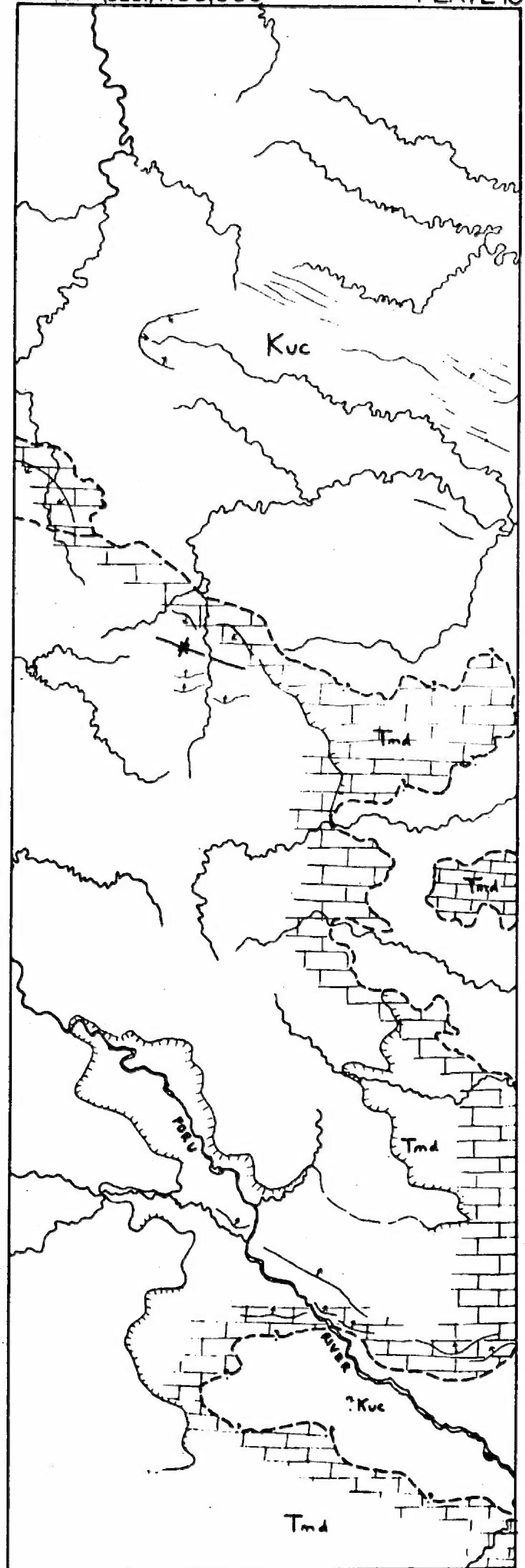

Klk
Kuc
Qa
Kundiawa
CHIMBU DISTRICT HQ.
Jum
Pzo
Omung River
Ruk
MT NARU
WAHGI RIVER
Gurumuf
Neragaima Mission
Slump breccia
MT. DIGABI
Nimul
Gembona
Kera Sill
Dom
Stone axe quarry
KUBOR
KUBOR RANGE
MARIL
RIVER
ANTICLINE
MT. DIGINI
Kumbik Creek
Kelama Creek
Digini Creek
MON RIVER
MT WEKAUMA
MOGONO RIVER
Creek
Tabibok
Nigama
Qra
Dirima
BMA CAMP 1968
Gumine
Sub-DISTRICT H.Q.
Omkalai
Deri
Oni Creek

CHUAVE 1:100,000 PLATE II

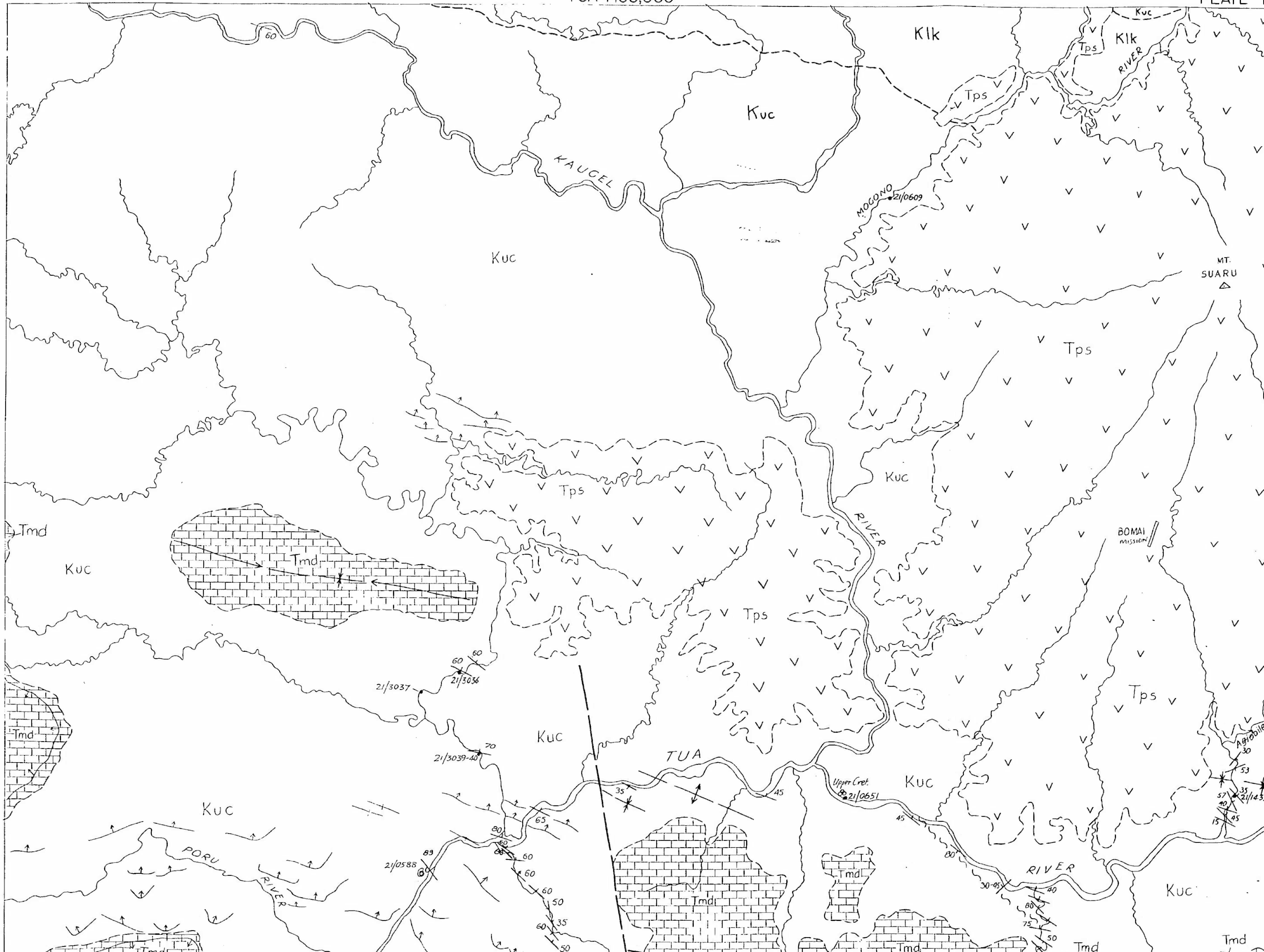



Hodmitoka
Creek
Oroniaka
Creek
River
Omahaiga
Creek
Kilopaneng
GOROKA
Goronoka
Creek
Creek
Neikagolohi
Goroka Valley
Q
Tma
Asaro
River
Q
Tma
Bena Bena
River
YAVEUFA
SYNCLINE
Tma
Qa
Asaro
River

147

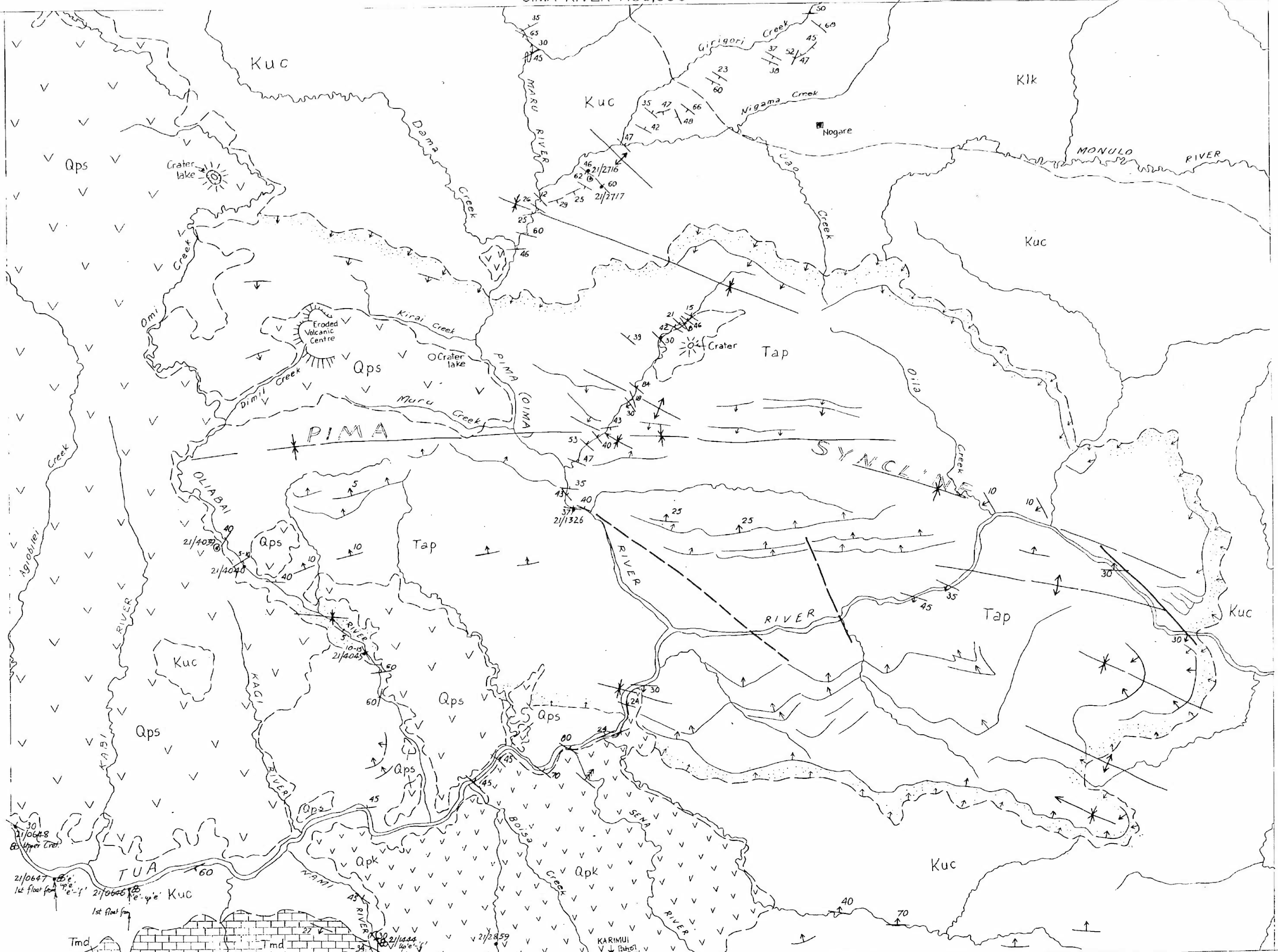


148



Klk
Kuc
Tps
RIVER
KAUGEL
MOGONO
21/0609
MT. SUARU
Tmd
BOMAI MISSION
TUA
PORU RIVER
21/3037
21/3036
21/3039-40
21/0588
Upper Cret.
21/0651
Agiabilei Ck
21/1435

OIMA RIVER 1:100,000



To accompany Record 1970/79

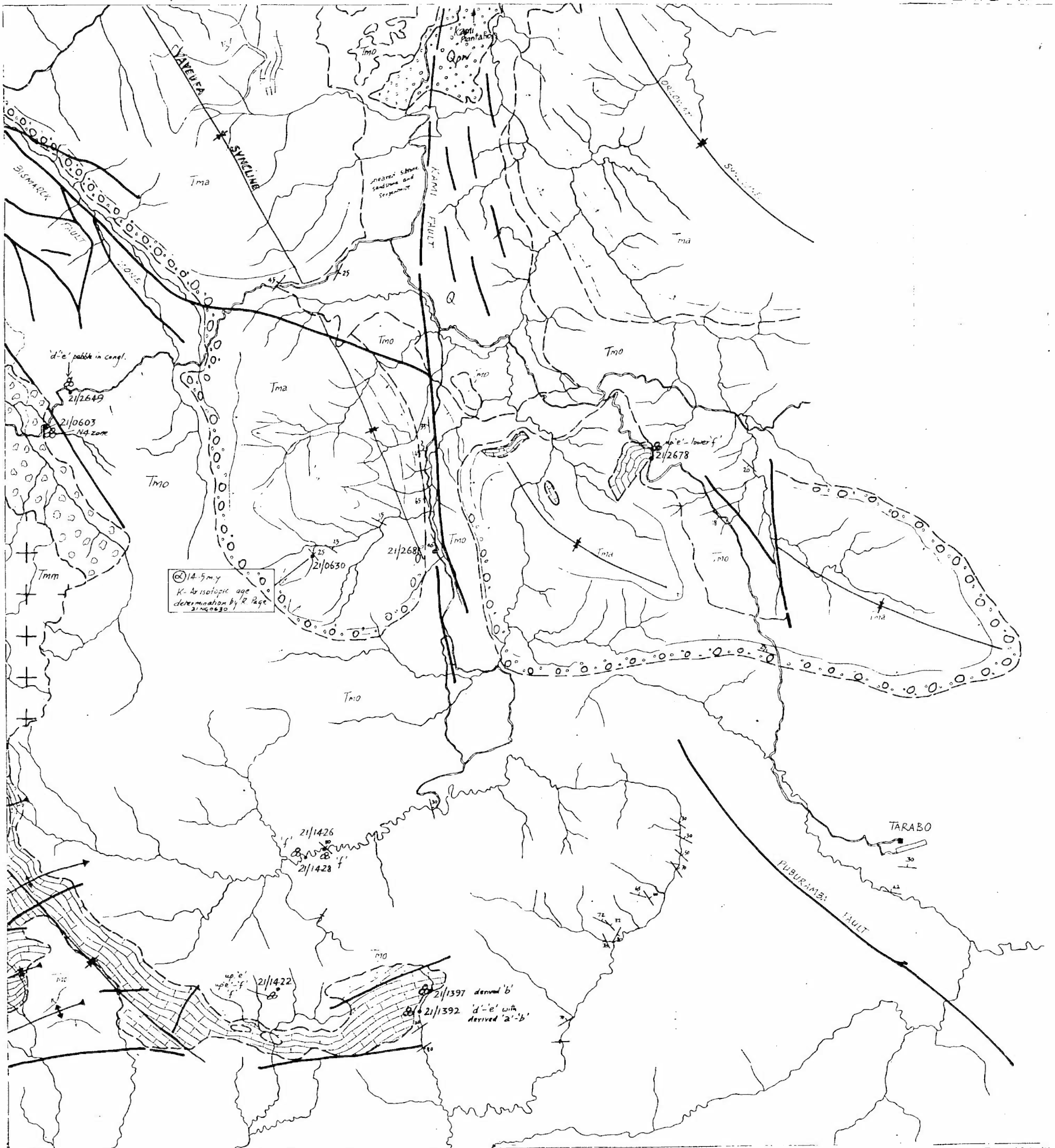
B55/A9/9

PLATE 16


KUBOR ANTICLINE
AGOTU SYNCLINE
WAHGI RIVER
ASARO RIVER
TUA RIVER
LUFA
SUB-DISTRICT H.Q.
MOUNT MICHAEL
Isotopic age: 7.3 m.y.
Klk
Kuc
Tmo
Qpc?
Qpc
Qa
21/1321
21/0593
21/0592
21/2638
21/1385
21/1384
21/2850
21/2833
21/2836
21/0600
GONO MISSION
RORONOMBI
PIBORO
HARUBI
MAISE
GUASSI

GONOMI 1:100,000

PLATE 17



To accompany Record 1970/79

B55/A9/11

THE KUBOR ANTICLINE

PLATE. 18

CENTRAL HIGHLANDS OF NEW GUINEA

Geology by J.H.C. Bain, D.E. Mackenzie, 1968, 1970
D.B. Dow, R.W. Page, R.J. Ryburn, I.E. Smith, R.J. Tingey 1968
Compiled by J.H.C. Bain, D.E. Mackenzie, 1970

CAINOZOIC	QUATERNARY	Pleistocene to Recent		Q	*Alluvium, talus, moraine*
			Wahgi Fanglomerate	Qpw	*Alluvial fan deposits*
		Pleistocene	Highlands Volcanoes	Qph	*Basaltic lava, pyroclastics, lahar deposits*
	TERTIARY	Upper Miocene	Michael Diorite	Tmm	*Porphyritic hornblende microdiorite*
		Mid. Miocene	Benembi Diorite / Kenengi Gabbro	Tmb / Tmke	*Porphyritic microdiorite* / *Gabbro, hornblende mangerite, granodiorite*
			Bismarck Intrusive Complex	Tmbc	*Gabbro, diorite, mangerite, granodiorite, tonalite*
			Kimil Diorite	Tmk	*Diorite, tonalite, granodiorite*
			Asaro Formation and Daulo Volc. Memb.	Tma	*Andesitic volcanics, volcanolithic sediments, limestone*
		Upper Oligocene to Mid. Miocene	Darai Limestone	Tmd	*Limestone*
			Aure Group (undiff.)	Tmau	*Mudstone, greywacke, limestone*
		Lower to Mid. Miocene	Movi Beds	Tmo	*Tuffaceous sediments, limestone*
		Eocene to Oligocene	Nebilyer Limestone	Ten	*Limestone*
			Chimbu Limestone	Tec	*Limestone, calcarenite*
		Upper Palaeocene	Pima Sandstone	Tap	*Lithic sandstone, siltstone, mudstone*
MESOZOIC	CRETACEOUS	Upper	Chim Formation	Kuc	*Shale, siltstone, tuffaceous sandstone*
		Lower	Kondaku Tuff	Klk	*Volcanolithic sandstone, tuff, agglomerate*
	JURASSIC	Upper	Maril Shale	Jum	*Pyritic shale, sandstone, arkose, limestone* / *Basal breccia*
		Middle	Mongum Volcanics	Jmm	*Basic submarine volcanics*
		Lower	Balimbu Greywacke	Jlb	*Greywacke, siltstone*
	TRIASSIC	Upper	Kana Volcanics	Ruk	*Intermediate to acid lavas, tuff, volcanolithic sediments*
			Jimi Greywacke	Ruj	*Greywacke, conglomerate, shale*
MESOZOIC PALAEOZOIC		Upper Permian or Lower Triassic	Kuta Formation	P-Rik	*Limestone, calcarenite, arkose*
PALAEOZOIC	PERMIAN	Upper	Kubor Granodiorite	Puk	*Granodiorite, tonalite, diorite, gabbro*
	PRE PERMIAN		Omung Metamorphics	Pzo	*Metagreywacke, phyllite, metavolcanics, hornfels*

Geological boundary

Anticline

Syncline

Overturned anticline

Overturned syncline

Fault

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.

25 *Strike and dip of strata*

Vertical strata

Horizontal strata

35 *Overturned strata*

Airphoto interpreted dip and strike

Trend lines

45 *Strike and dip of foliation*

Macrofossil locality

'e' 2515 *Microfossil locality with Tertiary letter stage, age and specimen number*

Alluvial workings

Quarry

Stone axe quarry

Au *Minor mineral occurance*

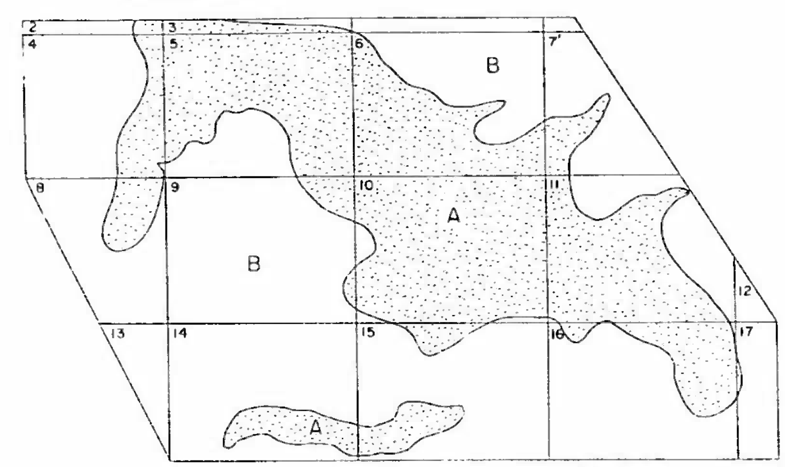
Road

Kundiawa *Township, village or administration centre*

·2000m *Height in metres*

·2865 or 21 2865 *Petrographic specimen locality*

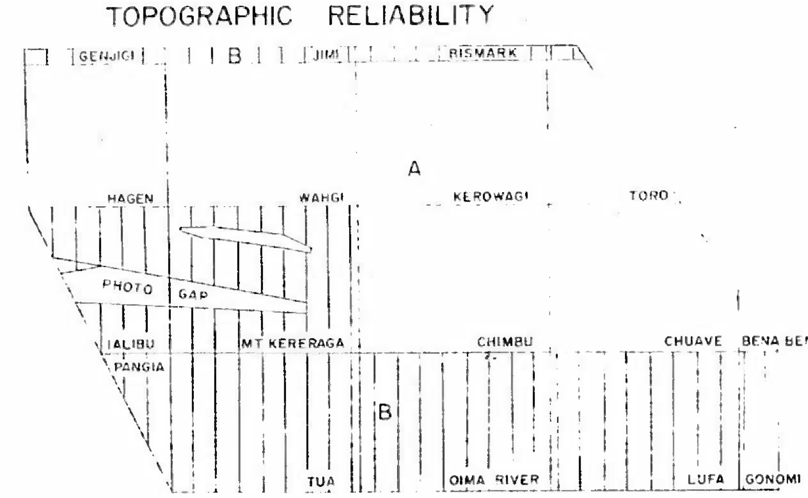
GEOLOGICAL RELIABILITY



A. *Numerous traverses, photo interpretation*

B. *Widely spaced traverses, photo interpretation*

TOPOGRAPHIC RELIABILITY



A. *Topographic base prepared by Division of National Mapping 1:63,360 provisional edition 1957.*

B. *Topographic base prepared by J. Bain and D. Mackenzie, 1969, from uncontrolled photo mosaics.*

B55/A/14