WAU
PAPUA NEW GUINEA

THE UNIVERSITY OF PAPUA NEW GUINEA
DEPARTMENT OF GEOLOGY.

SHEET SB/55-14 INTERNATIONAL INDEX
1:250 000 GEOLOGICAL SERIES — EXPLANATORY NOTES

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COMPiled BY D. B. DOW, J. A. J. SMIT, and R. W. PAGE

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Explanatory Notes on the Wau 1:250 000 Geological Sheet, P.N.G.

Compiled by D. B. Dow, J. A. J. Smit*, and R. W. Page

The Wau 1:250 000 Sheet area in mainland Papua New Guinea lies between latitudes 7°00’ and 8°00’S, and longitudes 145°30’ and 147°00’E. It straddles the northwestern end of the Owen Stanley Range, the backbone of eastern Papua New Guinea, and is jungle-covered and mountainous.

Access

The only road access is in the far northeast, where a well maintained all-weather road connects the agricultural and mining areas of the Bulolo and Watut valleys with the port of Lae on the north coast, 32 km north of the Sheet area. Subsidiary roads of widely varying standard provide access within a small radius of the main road, but over the greater part of the Sheet area there are no roads. A road connecting the main populated area around Menyamya with Bulolo is at present under construction. During World War II a road built between Wau and Bulldog on the southern coastal swamps was used only for a brief period, and is now obliterated by landslips and jungle.

Kerema on the Gulf of Papua is accessible by sea, and the lower reaches of the Tauri and Lakekamu Rivers are navigable by small boats as far as the southern foothills.

Most of the Sheet area is accessible only via walking tracks from airstrips at scattered mission stations and Government administration centres. Even so, the region is poorly served as the only airstrips in addition to those at the more accessible centres of Bulolo (DC3 standard), Kerema (DC3), and Wau (Twin Otter) are at Menyamya, Benula (Langimar), Kainteba, and Aseki, and all are suitable for only light aircraft.

In the populated Wau-Bulolo and Menyamya-Aseki areas there is a good network of graded patrol tracks, but in the sparsely populated jungle-covered west and southeast areas there are only a few poorly defined hunting tracks.

Population, industry, and Government administration

The indigenous population is concentrated in the upper reaches of the Watut, Kapau, Tauri, Langimar, Olipai, Waria, and Ono Rivers, and along the coast near Kerema. The rest of the Sheet area is covered by dense jungle and is either unpopulated or has sporadic small settlements. Most indigenous people are engaged in subsistence agriculture, though small native-owned coffee, cocoa, and coconut plantations have proliferated in the more accessible areas over the past 15 years.

The discovery of gold in the watershed of the Watut River in 1922 stimulated the development of the northeastern corner of the Sheet area, which remains the only developed region apart from copra and rubber plantations centred around

* PNG Geological Survey
Kerema. Coffee and forest products have displaced gold mining as the major industry. Wau, Kerema, and Bulolo have European populations of 200 to 300, and government administrative centres and mission stations have a few European families.

Fig. 1. Administrative districts.

The pattern of Government administration is shown in Figure 1. The northeastern half of the Sheet area is part of the Morobe District, which has headquarters at Lae, and comprises the Menyamya, Wau, and Mumeng Subdistricts. The northwestern corner falls within the Eastern Highlands District, administered from Goroka. The Gulf District, which has headquarters at Kerema and includes the Kerema and Kikori Subdistricts in the Sheet area, covers the southwest. The southeastern corner of the Sheet area falls within the Central District, which is administered from Port Moresby.

Base maps and photographs

The Sheet area is covered by good-quality aerial photographs (1959-1969) at a nominal scale of 1:50 000. The only available photographic map of the whole area, the 1:250 000 Sheet prepared by the US Army and printed by The Royal Australian Survey Corps in 1966, was slightly amended for the geological Sheet.

PHYSIOGRAPHY

The Sheet area can be divided into two physiographic divisions: the Central Mountains and the Coastal Plains and Foothills (Fig. 2).
Central Mountains

The Central Mountains consist of several rugged ranges which form the northwestern end of the Owen Stanley Range. In the east the Kuper and Ekuti Ranges are very rugged, jungle-covered, and 2400 to 3700 m high; the main ridges are broad, massive, and allow reasonable travel, but their flanks are deeply dissected by short steep streams where travel is obstructed by gorges, waterfalls, and cascades.

In the middle of the Sheet area the mountains are 2000 to 3000 m high and more closely dissected, and have characteristically sharp ridges. Most of the region is thickly populated and, as a result of gardening and subsequent burning of secondary growth, jungle is scarce and the hills are covered with Kunai grass, a broad-leaved grass which grows to 1.5 m.

In the west the mountains are lower (1000 to 2500 m), almost completely jungle-covered, and made up of long parallel north-trending ridges which, though not of great relief, make travel difficult.

Parts of the Ekuti Range are above 3500 m, and here the jungle gives way to alpine grass and scrub. Mount Yelia, an isolated peak 3397 m high in the far northwest, presents a rugged skyline and is a dormant volcano with well preserved domes and craters (Branch, 1967).

The Central Mountains are drained by short steep rivers which, because of the high rainfall and continuous jungle cover, carry large volumes of water throughout the year. The southern fall is drained by the Biaru, Eloa, Olipai, Kapau, and Tauri Rivers, and the northern fall by the Buloli, Watut, and Langimiar Rivers.
The Intermontane Basins of the upper Watut and Bulolo Rivers form separate topographic units within the Central Mountains. They are 700 to 1000 m above sea level, and surrounded by mountains up to 3700 m high. The lake sediments that floor the basins have a subdued relief and a cover of Kunai grass. The wide flood plains of the main rivers have been worked by gold dredges and, as no restoration has been attempted, now present a desolate scene of tailings covered with secondary scrub.

Lake Trist is a clear blue lake, 5 km long, set in dense jungle near the eastern edge of the Sheet area at an altitude of about 1800 m. It was formed by recent vertical movements along faults associated with the Owen Stanley Fault, and is of unknown depth.

Coastal Plains and Foothills

The Coastal Plains and Foothills fringe the Central Mountains in the south and southwest. The plains are flat, jungle-covered, and commonly swampy, being drained by sluggish meandering rivers. The foothills consist of long, subdued north-trending ridges which grade with increasing height into the Central Mountains.

CLIMATE

The climate depends largely on altitude. The coastal plains are hot and humid, but in the ranges up to 2000 m the days are warm and the nights cold; at higher altitudes the weather is commonly cold, cloudy, and wet.

The region has a high rainfall fairly evenly distributed throughout the year; June and July are generally the wettest months. The main mountain ranges probably receive more than 5000 mm a year (Asei 4775 mm), but most of the larger valleys seem to be rain-shadow areas with a rainfall of about 1800 mm (Wau 1880 mm, Menyamya 1740 mm).

PREVIOUS INVESTIGATIONS

In 1911 the discovery of oil seepages in the lower reaches of the Vailala River west of the Sheet area led to extensive fieldwork by oil exploration companies over most of the southwestern half of the Wau Sheet area.

The Anglo-Persian Oil Company Ltd (later renamed British Petroleum Development Australia Pty Ltd), acting on behalf of the Australian Government, made geological traverses along the major tributaries of the Vailala and lower Tauri Rivers in 1922, but it was not until 1938, when the Australasian Petroleum Company Pty Ltd (APC) was formed, that more detailed surveys were made. APC carried out reconnaissance traverses and more detailed follow-up surveys along the major southern rivers well into the foothills (Permit 5) both before and after World War II (APC, 1961). In 1955 the same area was licensed to the Papuan Apinaipi Petroleum Company Ltd as Permit 22 and more detailed fieldwork was carried out (Laing, 1959).

In the northern half of the Sheet area geological fieldwork has centred mainly around the Morobe Goldfield. Gold was discovered near Wau in 1922, and in 1932 large-scale dredging began in the Bulolo valley. H. M. Kingsbury, geologist for New Guinea Goldfields Ltd, produced the first geological report on the Wau area (Kingsbury, 1931) and made a reconnaissance traverse up the lower Tauri River (Kingsbury, 1932). During the years before World War II N. H. Fisher and L. C. Noakes surveyed numerous gold prospects (Fisher, 1935c, d; 1936a, b;
Noakes, 1936). Fisher (1945) also made a detailed study of the gold mineralization. The regional geology of the northeastern part of the Sheet area was described by Fisher (1944) as a result of work which included several traverses into the remote Biaru and Langimar areas. Noakes also made a geological survey along the southern fall of the main range (Noakes, 1936).

BMR geologists stationed at Wau continued to survey various gold prospects (Siedner, 1959a, b; Dow, 1958; Dow & Siedner, 1958; Plane, 1962; Horne, 1968) and to map the regional geology (Mackay, 1955; Dow, 1961a to d; Smit, 1965a, b; Smit & Tingey, 1969).

Pitt (1966) completed a study of the sedimentary rocks of Papua, including the Mesozoic and Tertiary rocks of the Sheet area.

Exploration companies have prospected the Sheet area, mainly in the northeast. Lateritic nickel prospects within the Papuan Ultramafic Belt have been tested, and a regional search for base metals was carried out over the Watut and Bulolo Rivers system. In 1967 an aeromagnetic survey of the Papuan Basin and most of the Papuan Ultramafic Belt by Compagnie Générale de Géophysique (CGG) under contract to BMR included the Wau Sheet area; over most of the Sheet area the survey was flown at 4600 m.

**STRATIGRAPHY (Table 1)**

The oldest rocks in the Sheet area, apart from the Mesozoic Papuan Ultramafic Belt, are the Owen Stanley Metamorphics of probable Mesozoic and possible lower Tertiary age, which crop out in the east. Overlying them in the west are upper Oligocene to middle Miocene sediments and subordinate volcanics which

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**Fig. 3. Sedimentary environments, late Oligocene to early Miocene.**
<table>
<thead>
<tr>
<th>Era</th>
<th>Age</th>
<th>Formation</th>
<th>Symbol</th>
<th>Thickness (m)</th>
<th>Rock type</th>
<th>Stratigraphic relations with underlying units</th>
<th>Remarks</th>
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<tbody>
<tr>
<td>TERTIARY</td>
<td>EOCENE</td>
<td></td>
<td>Te</td>
<td></td>
<td>In S siliceous marl and chert; in N lenses of coral limestone with some conglomerate</td>
<td>Occur as fault wedges, so relation with other units unknown</td>
<td>Siliceous sediments correlated with Eocene chert of Fort Moreby Beds to S. Limestone contains Eocene Foraminifera which may be derived, so beds could be Te stage</td>
</tr>
<tr>
<td>MESOZOIC</td>
<td></td>
<td>Owen Stanley Metamorphics</td>
<td>Ko</td>
<td></td>
<td>Predominantly low-grade metamorphics — slate, phyllite, quartz-sericite schist, quartz-chlorite schist, greywacke; rare green metamorphosed tuff. Higher-grade rocks (quartz-albite-sericite, quartz-albite-muscovite schist, and epidote-chlorite-actinolite schist with occasional almandine and amphibole) occur in places. Thick marble lenses and pebble conglomerate beds appear restricted to one stratigraphic horizon. Large areas are less metamorphosed and consist of argillite, calcareous slate, coarse indurated greywacke, grit, and conglomerate, and recrystallized limestone lenses up to 250 m thick which may have been reefs</td>
<td>Base not exposed</td>
<td>Cretaceous fossils at several localities, and most rocks probably laid down in Mesozoic. Pebbles of metamorphics in Omaura Greywacke indicate that main metamorphism occurred in Eocene or early Oligocene, but a metamorphic event in early Miocene (between the lower and upper Te stages) is indicated by regional considerations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Papuan Ultramafic Belt</td>
<td>U</td>
<td></td>
<td>Hartzburgite, dunite, enstatite pyroxenite, serpentinite</td>
<td>Faulted against Owen Stanley Metamorphics</td>
<td>Emplaced probably in the early Tertiary, but age of crystallization unknown. Inferred to be Mesozoic</td>
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<tr>
<td>Age</td>
<td>Formation</td>
<td>Symbol</td>
<td>Thickness (m)</td>
<td>Rock type</td>
<td>Stratigraphic relations with underlying units</td>
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<tr>
<td>MIDDLE MIocene</td>
<td>Morobe Granodiorite</td>
<td>Tmm</td>
<td></td>
<td>Granodiorite, adamellite, subordinate monzonite, diorite and pegmatite</td>
<td>Intrudes Owen Stanley Metamorphics but relation with Omaura Greywacke and Langimar Beds not known</td>
<td>K-Ar and Rb-Sr give age of emplacement as 12 to 14.5 m.y. (mid-Miocene), Could be contemporaneous with basal volcanics of Langimar Beds</td>
<td></td>
</tr>
<tr>
<td>UPPER OLIGOCENE</td>
<td>Geosynclinal facies:</td>
<td></td>
<td></td>
<td>Greywacke and siltstone with minor interbedded marl, calcareous siltstone, argillaceous limestone, tuffaceous greywacke, and tenses of pebble conglomerate. Towards top, pebble and boulder conglomerate with abundant volcanic clasts is common</td>
<td>Base not seen, but conglomerate contains pebbles of metamorphic rocks; therefore, unit probably unconformable on Owen Stanley Metamorphics</td>
<td>Abundant Foraminifera ranging in age from lower Te to upper Tf</td>
<td></td>
</tr>
<tr>
<td>TO UPPER MIocene</td>
<td>lower Te to Tf Aure Beds</td>
<td>Tm</td>
<td>Up to 2900</td>
<td></td>
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<td></td>
<td>upper Tf unnamed unit</td>
<td>Tms</td>
<td>0 to 800</td>
<td>In W consists of massive biothermal limestone and grey-blue marl and mudstone; in E marl, flabby limestone, sandstone, and conglomerate predominate</td>
<td>Conformable on Langimar Beds</td>
<td>Abundant Foraminifera of upper Tf age</td>
<td></td>
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<tr>
<td>UPPER MIocene</td>
<td></td>
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<tr>
<td>MIDDLE MIocene</td>
<td>lower Tf Langimar Beds</td>
<td>Tng</td>
<td>500 to 3600</td>
<td>Lenses of andesitic and basic volcanics up to 600 m thick sporadically distributed at base, minor interbeds of volcanolithic conglomerate; overlain in N and E by coarse arenaceous and conglomeratic sequence up to 3000 m thick, with interbedded marl, mudstone, and detrital limestone lenses. Sediments thinner and finer-grained to S. Lenses of white to cream, locally conglomeratic and coralline dense calcarenite throughout</td>
<td>Unconformable on Omaura Greywacke and Owen Stanley Metamorphics</td>
<td>Abundant Foraminifera in calcareous beds</td>
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<td>SHELF FACIES</td>
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<tr>
<td>UPPER OLIGOCENE</td>
<td>lower Te Omaura Greywacke</td>
<td>Tou</td>
<td>About 3000</td>
<td>Shale, coarse volcanically derived greywacke, siltstone, pebble conglomerate, and lenses of calcarenite. Massive augite and olivine basalt interbedded in places</td>
<td>Unconformable on probable Mesozoic metamorphic rocks N of Sheet area. On basis of derived Eocene Foraminifera in calcarenite, is thought to be unconformable on Eocene chert and limestone</td>
<td>Grade to W into sediments of the trough facies ('Aure group'). Lower Te Foraminifera in limestone lenses</td>
<td></td>
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<td>Age</td>
<td>Formation</td>
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<tr>
<td>Unnamed Unit</td>
<td>Tp</td>
<td>650 to 1600</td>
<td>In E poorly consolidated conglomerate, sandstone, mudstone, tuffaceous sandstone, and interbedded dacite and andesite pyroclastics. In W marine sandstone, siltstone, and mudstone, commonly calcareous or carbonaceous; pebble conglomerate, and coral limestone concretions.</td>
<td>Conformable on upper Miocene (Tg stage) sediments. Overlaps onto Owen Stanley Metamorphics</td>
<td>Abundant Pliocene Foraminifera. Top of succession contains no diagnostic Foraminifera and could be Pleistocene</td>
<td></td>
<td></td>
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<tr>
<td>Otibanda Formation</td>
<td>Tpo</td>
<td>Up to 765 +</td>
<td>Lacustrine and fluviatile poorly consolidated sediments, mainly tuffaceous sandstone and siltstone, and conglomerate. Interbedded crystal tuff.</td>
<td>Unconformable on Edie Porphyry, Bulolo Agglomerate, and Owen Stanley Metamorphics</td>
<td>Contains vertebrate fossils (Plane, 1967). K-Ar determinations on tuff give age of about 3.5 m.y., the same as the Bulolo Agglomerate and the early phase of the Edie Porphyry. Formation was deposited in two lakes</td>
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<tr>
<td>Bulolo Agglomerate</td>
<td>Tpg</td>
<td>Not known, 300 +</td>
<td>Massive dacite and andesite agglomerate with minor tuff bands. Rare obsidian flows.</td>
<td>Contact with underlying units not seen, but undoubtedly unconformable on Morobe Granodiorite</td>
<td>K-Ar determinations on biotite, hornblende, and plagioclase give age of about 3.5 m.y. Derived from several centres of eruption, one known between Wau and Bulolo and another probably downstream of Bulolo</td>
<td></td>
<td></td>
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<tr>
<td>Namie Breccia</td>
<td>Tpv</td>
<td>Not known</td>
<td>Volcanic breccia of angular fragments of schist, and dacite and andesite porphyry in black fine-grained hydrothermally altered matrix.</td>
<td>Occurs as pipes up to 1.5 km across intruding Owen Stanley Metamorphics. Rare dyke-like apophyses up to 1 m wide intrude Metamorphics</td>
<td>Erupted at about the same time as Bulolo Agglomerate. Is host rock for gold mined at Upper Ridges Mine. Contains veins and stringers of manganocalcite, rhodochrosite, quartz, auriferous pyrite, sphalerite, marmatite, galeana, and free gold</td>
<td></td>
<td></td>
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<tr>
<td>Edie Porphyry</td>
<td>Tpp</td>
<td>Biotite and hornblende andesite and dacite, porphyry stocks and dykes.</td>
<td>Intrudes Owen Stanley Metamorphics. Fragments constitute large part of Bulolo Agglomerate and Namie Breccia.</td>
<td>Several phases of porphyry intrusion represented; one antedates Bulolo Agglomerate, and K-Ar determinations give age of 3.5 m.y. Many intrusions, particularly in upper Edie Cr, are younger and apparently were the main gold mineralizers</td>
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<tr>
<td></td>
<td>Babwaf</td>
<td>Tpb</td>
<td>700 +</td>
<td>Thickly bedded polymict conglomerate, and minor interbedded lithic sandstone (commonly micaceous), silty calcareous mudstone, and brecciated conglomeratic coral limestone</td>
<td>Unconformable on Langimar Beds</td>
<td>The only Foraminifera are unrestricted Miocene to Pliocene, but formation is thought to be Pliocene</td>
<td></td>
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<tr>
<td></td>
<td>Conglomerate</td>
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<td></td>
</tr>
<tr>
<td>UPPER</td>
<td>Tg Stage</td>
<td>Tmu</td>
<td>400 to 2000</td>
<td>Blue-grey marl, mudstone and siltstone with interbeds of argillaceous sandstone, pebble conglomerate, and coral and algal limestone towards base. Conglomerate of probable fluvial origin predominates to E</td>
<td>Unconformable on middle Miocene shelf and trough facies</td>
<td>Abundant Foraminifera in the mudstone belong to the Tg stage (Muruan Stage of APC, 1961). Basal beds probably upper Tt</td>
<td></td>
</tr>
<tr>
<td>MIocene</td>
<td>Unnamed Unit</td>
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<td>Age</td>
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<tr>
<td>HOLOCENE</td>
<td></td>
<td>Qha</td>
<td></td>
<td>Unconsolidated fluvial sediments; gravel, sand, and silt along major rivers; silty mud, carbonaceous mud, and sand forming coastal plains in S</td>
<td>Unconformable</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Qhw</td>
<td></td>
<td>Dacite lava, agglomerate and crystal tuff near Upper Ridges Mine, Wau</td>
<td>Unconformable</td>
<td>Derived from Koranga volcano, near Wau, which still shows remnants of its crater form</td>
<td></td>
</tr>
<tr>
<td>PLEISTOCENE TO HOLOCENE</td>
<td></td>
<td>Qvy</td>
<td></td>
<td>Dacite and andesite lava crystal tuff, agglomerate, and obsidian of Mt Yelia volcano</td>
<td>Unconformable</td>
<td>Recent volcanic activity at Mt Yelia apparent from well preserved craters</td>
<td></td>
</tr>
<tr>
<td>PLEISTOCENE?</td>
<td></td>
<td>Qp</td>
<td></td>
<td>Coarse unsorted angular conglomerate torrentially deposited near Wau; unconsolidated gravel, sand, and silt forming uplifted flood plains near E margin of Sheet area</td>
<td>Unconformable</td>
<td>Regarded as Pleistocene, but tectonism is so active that they could be Holocene</td>
<td></td>
</tr>
</tbody>
</table>
were laid down in two contrasting sedimentary environments. In the west, deep-water sediments were deposited in an elongate north-trending sedimentary basin, the Aure Trough (Fig. 3), while shallow-water sediments were accumulating along the eastern margin.

Granodiorite batholiths intruding the Owen Stanley Metamorphics have been dated isotopically as 12 to 14.5 m.y. old.

Upper Miocene and Pliocene/Pleistocene sediments fringe the earlier sediments to the south, and occur farther north mainly as synclinal remnants. Intermediate volcanic activity and faulting in the late Pliocene formed several large lakes along the Bulolo and Watut Rivers, in which thick lacustrine sediments were deposited, and preceded recent acidic volcanic activity at Mount Yelia and Wau. Intermediate porphyry intrusions which accompanied Pliocene volcanism introduced most of the gold produced from the Morobe Goldfield.

**Mesozoic to Lower Tertiary**

**Papuan Ultramafic Belt**

Ultramafic rocks near the eastern margin of the Sheet area are part of the Papuan Ultramafic Belt which forms the northern flank of the Owen Stanley Range to the southeast (Davies, 1971). The ultramafic rocks are faulted against the Owen Stanley Metamorphics along the Owen Stanley Fault, and it is generally accepted that they are part of upfaulted oceanic mantle (Thompson & Fisher, 1965; Davies, 1971).

**Owen Stanley Metamorphics**

The low-grade metamorphic rocks in the east were named Kaindi Metamorphics by Dow & Davies (1954). On the scale of mapping to date it has not proved possible to distinguish the Kaindi Metamorphics from the Owen Stanley Metamorphics (called Owen Stanley Series by E. R. Stanley, 1923). The metamorphic rocks of the Wau Sheet area are therefore referred to as Owen Stanley Metamorphics.

The Owen Stanley Metamorphics are predominantly low grade (see Stratigraphic Table), but fault wedges of higher grade are found in places. South of the Sheet area, evidence of a second metamorphic phase, probably retrograde, has been observed in the Owen Stanley Metamorphics (Macnab, 1969); here porphyroblasts of albite, unstrained quartz, and large flakes of muscovite cut across the foliation.

Less metamorphosed argillite and interbedded indurated greywacke, grit, and conglomerate have been mapped in places along the western margin of the Owen Stanley Metamorphics in the Sheet area. The argillite is commonly dark to very dark, with interbedded lenses of limestone and calcareous lithic grit, and is locally micaceous. The conglomerate is made up mainly of rock fragments of dark shale, slate, argillite, quartz, chert, and minor intermediate to basic igneous rocks. In the upper Indiwa River and along the lower Olipai River, distinctive red radiolarian sandstone and siltstone are interbedded with minor conglomerate bands.

The change from the higher-grade to lower-grade metamorphics occurs gradually over a zone 8 to 16 km wide, except where they are in fault contact. The structure of the lower-grade rocks is not known, so no estimate can be made of their thickness.
Age of the Owen Stanley Metamorphics. Fossils in the Owen Stanley Metamorphics have been found in situ at several localities in the Snake River area (Glæssner, 1949) and in river boulders at several localities in the southeast, e.g., in the lower reaches of the Etoa and Biaru Rivers, and near the heads of the Indiwa and Buiawim Rivers. Glæssner suggested an Aptian to Cenomanian age for the Snake River assemblage, and Skwarko (1960) assigned the same age to the Buiawim River fossils. A Cretaceous age can therefore be confidently assigned at least to part of the sediments making up the Owen Stanley Metamorphics.

The Mesozoic was a time of almost continuous deposition in the Central Highlands to the northeast, and there is no evidence to suggest that this was not also true in the Wau Sheet area; therefore much of the Owen Stanley Metamorphics could consist of Mesozoic sediments.

On the other hand, recent investigations southeast of the Sheet area (Macnab, 1969) have shown that the Upper Cretaceous to lower Miocene (Lower Te stage) Auga Beds have undergone low-grade metamorphism and in many places are indistinguishable from the Owen Stanley Metamorphics. In the Wau Sheet area there is a strong possibility that the lower-grade metamorphics on the western flank of the Owen Stanley Metamorphic Belt (Fig. 4) are the metamorphosed equivalent of the Upper Oligocene Omaura Greywacke (see below).

Age of Metamorphism. The regional metamorphism is generally regarded as having been associated with the emplacement of the Papuan Ultramafic Belt in late Cretaceous or early Tertiary time, but the evidence of retrograde metamorphism, and folding of foliation which was accompanied in places by development of a second cleavage, indicates that at least two stages of deformation and metamorphism have occurred.

The main metamorphism undoubtedly occurred after the Cretaceous, and an unequivocal upper limit is given by unconformably overlying volcanics and sediments of middle Miocene (lower Tf stage) age in the centre of the Sheet area. Also, the coarser sediments of the Omaura Greywacke show that their provenance during the late Oligocene was largely metamorphic. Thus the main metamorphism probably occurred some time between the end of the Cretaceous and the late Oligocene.

A considerable amount of indirect evidence points to a subsequent metamorphic event in the early Miocene (i.e. post-lower Te stage):

(a) As mentioned above, the less metamorphosed rocks are probably the metamorphosed equivalent of the upper Oligocene (lower Te stage) Omaura Greywacke;

(b) 160 km southeast of the Sheet area the Auga Beds of late Cretaceous to early Miocene age (lower Te stage) are indistinguishable from the Owen Stanley Metamorphics (Macnab, 1969).

Additional supporting evidence is provided by unpublished geochronological work on the Owen Stanley Metamorphics 4 km west of Wau (by Page in 1972). A sample of strongly cleaved kink-folded phyllite from Mount Kaindi gave an isotopic age of 21.0 ± 4.0 m.y. by the Rb-Sr method. The Model One Statistical Fit of the Rb-Sr isochron argues strongly against any updating by thermal effects of later intrusions to explain the result, and the results indicate an early Miocene metamorphic event after the lower Te stage, but before the upper Te stage.

It is also possible that the Owen Stanley Metamorphics could include older rocks such as correlatives of the probable Upper Triassic Goroka and Bena-Bena
Formations (McMillan & Malone, 1960) or of the pre-Permian Omung Metamorphics (Rickwood, 1955), which crop out 150 km farther north.

Fig. 4. Structural sketch map of Wau.
Eocene

Within a fault zone along the lower Tauri River, outcrops of siliceous marl and cherty argillite have been correlated with the Port Moresby Beds of Eocene age (APC, 1961). Farther north, along the headwaters of the Tauri River, several limestone lenses within a complexly folded and faulted zone of Omaura Greywacke contain Eocene Foraminifera (Terpstra, 1968), but the fauna could be derived, and the rocks may be younger than Eocene. Eocene limestone sequences farther northwest indicate a regional change from siliceous rocks and chert in the south to a limestone facies in the north, so the limestone may well be of Eocene age, and the rocks have therefore been mapped separately (Te on map).

It is also possible that the thick marble lenses in the Owen Stanley Metamorphics, which overlie beds containing Cretaceous fossils, are Eocene.

In the extreme south, siliceous rocks which crop out at Hell's Gate and along the lower reaches of the Tauri River are also probably Eocene.

Upper Oligocene to upper Miocene

Shelf Facies

Upper Oligocene to upper Miocene sediments deposited within the Kapau Fault Zone and farther east contrast strongly with the Aure Beds deposited contemporaneously in the Aure Trough: they are mostly shelf sediments and have been mapped as Omaura Greywacke, Langimar Beds, and an unnamed unit (Tms) (Figs 3 and 4).

Omaura Greywacke

After the Owen Stanley Metamorphics were metamorphosed, a sequence of clastics and minor highly altered basic volcanics, correlated with the Omaura Greywacke to the northwest (Dow & Plane, 1965), was laid down along the eastern margin of the northerly trending Aure Trough. The massive basic volcanics decrease towards the south, where they occur interbedded with coarse-grained volcanically derived sediments.

Lenses of calcarenite up to 150 m thick are common; they are recrystallized and grade locally into a brecciated conglomeratic reef limestone. Lower Te stage Foraminifera and derived Eocene fauna are found in the limestone, which is locally associated with massive bedded pebble and boulder conglomerate consisting mainly of quartz, shale, slate, schist, and rare dioritic fragments, and locally volcanic components.

The rocks grade westward into sediments more typical of a sedimentary trough, consisting of a thick sequence of predominantly dark grey to blue-grey shale, siltstone, and minor mudstone, commonly with coarser feldspar fragments. The rocks are locally calcareous and micaceous. Volcanically derived greywacke, locally grading into a pebble conglomerate, is fairly common, and the sequence contains lenses of fine to coarse calcarenite up to 15 m thick.

The Omaura Greywacke is equivalent in age to the lower part of the deep-water sediments laid down in the Aure Trough to the west (see Geosynclinal Facies below).

The less metamorphosed rocks of the Owen Stanley Metamorphics are very similar to the Omaura Greywacke and could be its equivalent. The only alternative
explanation of the distribution of the Omaura Greywacke west of the Kapau Fault Zone, and its absence to the east, is to postulate a fault with downthrow to the west of about 3000 to 4000 m, which is now concealed by younger sediments. In this case all the Omaura Greywacke would have had to be eroded before the deposition of the Langimar Beds, which is most unlikely considering the short time available.

**Langimar Beds**

Lower Tf stage sediments and basal volcanics occur as a north-trending belt of rocks near the middle of the Sheet area. They unconformably overlie the Owen Stanley Metamorphics in the east and the Omaura Greywacke in the west.

The basal volcanics consist mainly of basalt and andesite flows. A partly porphyritic andesitic welded tuff commonly forms the top of the volcanic sequence. The basalt is very similar to that of the Omaura Greywacke, but much less altered.

Towards the east, massive conglomerate consisting almost exclusively of volcanic clasts overlies the volcanic sequence generally unconformably, but to the north it rests directly on older rocks.

The sedimentary sequence overlying the conglomerate consists of thin to medium-bedded red, grey, and black silty mudstone, and siltstone, interbedded with thick to massive, grey and dark grey lithic sandstone, grit, and pebble and boulder conglomerate. The lithic sandstone is commonly calcareous, and lenses of white to cream dense calcarenite, locally conglomeratic and coralline, are found throughout the sequence.

Farther south, along the Kapau River, the rocks consist mainly of calcareous sediments including a locally developed bioherm up to 700 m thick, informally called the Kapau limestone (Stanley, 1960).

The calcareous facies changes both to the west and northeast. In the northeast conglomeratic rocks were laid down with massive dark greywacke, lithic sandstone, marl, mudstone, siltstone, and lenses of mainly detrital limestone. Towards the west a more neritic facies of thick to medium-bedded marl, dark siltstone, greywacke, grit, and pebble and cobble conglomerate with lenses of coral limestone, predominates.

In the extreme south, structural complexities make it difficult to measure the thickness of the sediments, but they appear to be at least 500 m thick. Towards the north the thickness increases greatly, reaching an estimated maximum of about 3600 m; here the rocks were deposited in a north-trending synclinal depression flanking the metamorphic landmass.

**Unnamed Unit**

Upper Miocene (upper Tf stage) sediments (mapped as Tms) conformably overlying the Langimar Beds in the central south are a typical shelf carbonate facies sequence. In the west the unit consists of 400 m of massive biohermal limestone overlain by 400 m of marl and mudstone. In the east the sediments grade through 400 m of interbedded marl, thin-bedded limestone, siltstone, sandstone, conglomerate, and some tuffaceous conglomerate, into a thinner, dominantly conglomeratic, sequence which lenses out against the Owen Stanley Metamorphics. The conglomerate is made up of granodiorite, slate, and other metamorphic rock fragments.
**Aure Beds**

Marine sediments ranging from lower Te to upper Tf stage were deposited in deep water in the Aure Trough while shelf sediments were being laid down to the east. They occupy most of the western half of the Sheet area, but because of strong folding, lack of diagnostic Foraminifera, lateral impersistence of marker beds, and the monotonous character of the generally unfossiliferous strata, they have been mapped as one unit, the Aure Beds (Aure Group of APC, 1961).

The sediments consist typically of fine argillaceous greywacke and siltstone with minor beds of marl and argillaceous limestone, and bands of tuffaceous greywacke and pebble conglomerate up to 100 m thick. The coarser fraction is essentially uniform throughout the sequence and consists of very poorly sorted angular grains of remarkably fresh plagioclase and hornblende (in parts also with pyroxene) and fragments of diorite, andesite, and metamorphic and sedimentary rocks.

A greater variety in the sediments is present towards the top of the sequence (middle Miocene, lower Tf stage) where pebble and boulder conglomerate, commonly volcanic, becomes common.

**Morobe Granodiorite**

The Morobe Granodiorite (Fisher, 1944) crops out in the northeast as two main batholiths (each exceeding 600 km²) in the Kuper and Ekuti Ranges, and as a number of smaller bodies. Biotite-hornblende granodiorite, in some cases with amphibole-rimmed relict clinopyroxene grains, makes up most of the batholith, but adamellite is common, and differentiates of monzonite, diorite, hornblendite, and pegmatite are developed at the margins.

The Morobe Granodiorite intrudes the Owen Stanley Metamorphics, and is overlain unconformably by the Pliocene Otibanda Formation.

K-Ar and Rb-Sr ages have been measured on the Morobe Granodiorite (Page, 1971; Appendix 1). The small granodiorite masses in the Watut River area were emplaced 14 to 14.5 m.y. ago (mid-Miocene), and the main masses (Ekuti and Kuper Ranges) give slightly younger ages of about 12 to 13 m.y. The field relations, petrographic character, and age of the Morobe Granodiorite are similar to those of several other large intrusive masses throughout the New Guinea highlands, where major igneous activity took place in the middle Miocene.

The intrusion of the Morobe Granodiorite was accompanied by widespread gold mineralization, which supplied a substantial portion of the alluvial gold mined in the region.

**Upper Miocene**

**Unnamed Unit**

Upper Miocene shallow-water sediments flanking the Lakekamu Embayment (Tmu) rest with marked unconformity on both the deep-water and shelf sediments of the middle Miocene. The bottom half of the sequence consists of grey-blue marl, mudstone, and siltstone, with thin interbeds of limestone and small lenses of intraformational conglomerate in the west, but conglomerate is the major rock type in the east.
The upper sediments are massive light blue-grey mudstone, with interbedded argillaceous sandstone, pebble conglomerate, and limestone commonly developed in the lower part. In places a similar but coarser sequence with coralline and algal limestone is developed. The topmost part of the succession commonly comprises interbedded silty and sandy mudstone.

Most of the sequence has been dated as Tg stage (Muruun Stage of APC, 1961), but the basal units are probably uppermost middle Miocene (upper Tf stage).

**Pliocene**

*Babwaf Conglomerate*

A sequence of massive polymictic conglomerate consisting mainly of metamorphic and granodiorite fragments forms cliffs up to 250 m high in the northern part of the Sheet area and has been correlated with the Babwaf Conglomerate of Dow (1967).

In the Sheet area the formation is at least 700 m thick and photo-interpretation suggests at least one stratigraphic break within the sequence. Foraminifera indicate a Miocene or Pliocene age and the conglomerate was probably laid down at the same time as the Pliocene? conglomerate of the Markham valley to the north (Ouba Series of Gray, 1930).

The late Pliocene was a time of uplift, accompanied by acid to intermediate volcanism. In the northeast the intermontane basins of the Bulolo and Watut valleys were formed by faulting, and were filled mainly by the products of the volcanism, the Bulolo Agglomerate and the Otibanda Formation.

In the south the Lakekamu Embayment was formed by downwarping and received volcanic detritus from active volcanoes along the main range southeast of the Sheet area.

**Edie Porphyry**

High-level intrusions of andesite and dacite porphyry into the Owen Stanley Metamorphics and Morobe Granodiorite in the eastern half of the Sheet area are here called Edie Porphyry. They were considered to be late Tertiary by Fisher (1944, 1945), who recognized two, and possibly three, phases of intrusion (lower Edie Porphyry, upper Edie Porphyry, and unclassified Porphyry); these have not been differentiated on the map because of the small scale.

The porphyry occurs as irregular hypabyssal stocks and dykes consisting mainly of plagioclase, quartz, biotite, and hornblende phenocrysts in a devitrified, originally glassy groundmass that is commonly highly altered to epidote, calcite, and opaque minerals. Pyrite is a common accessory mineral. The porphyry bodies in upper Edie Creek and the later dykes in the Wau area are extremely sericitized and locally silicified and pyritized.

The earlier intrusive phase (lower Edie Porphyry of Fisher) antedates the Bulolo Agglomerate, and samples of the porphyry bodies have been dated by the K-Ar method (Page & McDougall, 1972; Appendix I). The results on both biotite and plagioclase do not show any discernible age difference between the individual porphyry bodies. The resultant pooled age of 3.8 ± 0.3 m.y. indicates a mid-Pliocene age for the older phase of the Edie Porphyry.
The younger phase is generally more highly altered than the older, and was the main gold mineralizer of the Morobe Goldfield. It is undoubtedly the younger, because it intrudes the Namie Breccia, which postdates the older phase. One sample of a rhyolitic porphyry in lower Edie Creek gave biotite and plagioclase ages of about 2.4 m.y., indicating a considerable time interval between the two porphyry intrusions.

Namie Breccia

Volcanic breccia consisting of fragments of schist and porphyry in a black fine-grained matrix occurs as oval bodies up to 1.5 km across in the Upper Ridges Mine area immediately west of Wau. The breccia is the host rock for most of the primary gold mineralization in the Wau area. It is generally uniform in grain size and composition and in some places underground, particularly in the lower levels, it intrudes the Owen Stanley Metamorphics. The bodies are pipe-like and are probably diatremes, because in the upper levels of the mine they are vaguely bedded and their clasts are roughly sorted, probably by action within the throat of the volcano.

Bulolo Agglomerate

Massive dacite and andesite agglomerate exposed along the Bulolo River valley between Wau and the Watut River junction is probably the extrusive equivalent of the Edie Porphyry. The rock fragments are generally angular and are composed mainly of porphyry, but granodiorite, phyllite, and sericite schist, derived from the underlying rocks, are common in places. The matrix is a crystal tuff composed of quartz plagioclase, biotite, and hornblende, with some sphene and pyroxene.

The agglomerate blocked the Bulolo River between Wau and Bulolo, forming a lake in the upper Bulolo valley in which gravels of the Otibanda Formation around Wau were laid down. The unconformable contact between the Bulolo Agglomerate and pebble and cobble conglomerate can be seen a few metres off the main road at the mouth of Koranga Creek.

K-Ar isotopic age determinations on biotite, hornblende, and plagioclase from two agglomerate samples north of Bulolo suggest a maximum age of about 3.5 m.y., an age so similar to that of the lower Edie Porphyry that the close relation between the two units is confirmed.

Otibanda Formation

The Otibanda Formation (Plane, 1967) was deposited in a small lake in the upper Bulolo valley near Wau, and a much more extensive lake in the lower Bulolo and Watut valleys. The Wau lake was formed by the Bulolo Agglomerate damming the Bulolo River, and the larger lake was dammed by upfaulting along the Sunshine Fault in the extreme north of the Sheet area. The sediments in the two lakes differ because of the different provenances.

The lower lake was downstream of the main volcanoes, and hence is composed dominantly of volcanic clasts in a tuffaceous matrix. The sediments are regularly bedded, attesting to a dominantly lacustrine environment; intercalated thin tuff beds throughout the section show that sporadic volcanic activity continued during deposition.

The upper lake, being upstream of the main volcanics, was less affected by the volcanism, and consequently many of the clasts are schist and granodiorite from the Owen Stanley Metamorphics and Morobe Granodiorite. The sediments
are of a more fluvial character and are mainly river gravels. At Koranga Mine the conglomerate contained rich gold and was worked on a large scale by Koranga Gold Sluicing Co. Ltd until 1962. The gold was derived from the upper Edie Creek area (Fisher, 1945), and the Koranga Mine almost certainly marks the place where the ancestral Edie Creek debouched into the Wau lake. The area now backs onto the fault scarp which forms the unbroken face of Mount Kaindi, so considerable lateral and vertical movement has taken place on the fault since the lake was formed.

The formation varies considerably in thickness; it is at least 765 m thick at Koranga Mine, and at least 486 m at Sunshine gold workings near the Bulolo River/Snake River junction, but in neither place was a complete section measured.

The formation is notable for its vertebrate fossils (Plane, 1967), which include extinct marsupials, rodents, and reptiles. K-Ar determinations suggested that the age of the formation was 5.7 to 7.6 m.y. (Everden et al., 1964), but recent work (Page & McDougall, 1972) has demonstrated that this figure could be too high. Several samples of tuff from the Otibanda Formation gave ages of 3 to 4 m.y., about the same as the Edie Porphyry and the Bulolo Agglomerate.

**Unnamed Unit**

Marine and terrestrial Pliocene sediments (mapped as Tp) flank the Lakekamu Embayment in the south. In the east they consist of conglomerate and coarse sandstone made up almost entirely of volcanic detritus derived mainly from acidic and intermediate volcanoes which were active along the main range. Tuff and agglomerate are intercalated near the base of the succession.

To the west the sediments thicken markedly, are entirely marine, and are finer and partly calcareous, reflecting the increased distance from the source of the detritus.

**Quaternary**

The earth movements of the Pliocene continued throughout the Quaternary, but sedimentation was restricted to further infilling of the intermontane basins and the Lakekamu Embayment. Volcanism was restricted to Mount Yelia volcano in the northwest and to a small vent near Wau.

**Sediments**

Along the western edge of the Sheet area, unconsolidated fluvial sediments form flood plains uplifted as much as 150 m above sea level. They are regarded as Pleistocene, though in view of the active tectonism in the region they may be younger.

In the Wau valley, alluvial fans from the upfaulted Mount Kaindi area have partly covered the Otibanda Formation. They are composed of poorly sorted coarse conglomerate, and are thought to be Pleistocene.

Unconsolidated gravels along the major rivers and unconsolidated fluvial sediments forming the southern coastal plains are Holocene.

**Volcanics**

Acidic and intermediate volcanics were erupted in the Holocene from Mount Yelia volcano, and acidic volcanics from Koranga volcano.
Recently formed lava domes and craters are conspicuous in the summit area of Mount Yelia volcano, and with cold solfataric activity in the main crater attest to a very recent eruptive history (Branch, 1967). Unsubstantiated reports tell of an eruption within the last 30 years.

Little is known of the geology of Mount Yelia, but the lava domes are composed of augite-lamprobolite dacite, and andesite; dacitic ash, ashflow tuff, agglomerate, and obsidian have also been noted. The volcano is very similar to Mount Lamington, which erupted in 1951 with great loss of life, and Mount Yelia could be the focus for a similar cataclysmic eruption in the future.

Koranga volcano near Wau is about 1.5 km west-northwest of the airstrip, and is composed of intensely hydrothermally altered lava and agglomerate. Most of the rocks are so highly altered that their original composition cannot be determined, but glassy dacite is prominent among the less altered rocks.

Burke Creek, the easternmost tributary of Namie Creek, rises in a swampy basin-shaped area which is skirted by the Wau/Upper Ridges Mine road and is probably an explosive crater. If so, the eruption could have occurred within the last 30 000 years. The throat of the volcano penetrates the conglomerate beds of the Otibando Formation and was exposed by the sluicing operations at Koranga, but the rocks were so completely hydrothermally altered to clay minerals that a large slip which began at the end of 1967 filled the headrace and was the major factor in the eventual closure of the mine. Since then several million cubic metres of unstable clay has slumped into the old workings and movement still continues.

In May 1967, high-temperature solfataras started at the head of the slip, and it was thought that they could have presaged renewed volcanic activity. Though the temperature was very high (600° to 700°C) and the gas was composed of sulphur dioxide, the solfataras gave off little gas and eventually ceased in August 1967. It is thought that they were caused by some oxidation phenomenon, possibly the oxidation of pyrite which is common in the highly altered volcanics.

STRUCTURE

The Wau Sheet area has undergone four periods of deformation (Fig. 4): the first in the early Tertiary when the Owen Stanley Metamorphics were formed; the second in the early Miocene when the Omaura Greywacke was tightly folded; the third at the end of the middle Miocene; and the fourth which started in the Pliocene and continues to the present. The resultant structures form the basis for the three major structural units into which the area has been divided: (a) Owen Stanley Metamorphic Belt, (b) Auren Fold Belt, and (c) Lakekamu Embayment (Fig. 4).

Owen Stanley Metamorphic Belt

The Owen Stanley Metamorphic Belt is composed almost entirely of metamorphic and plutonic rocks formed during orogenies in the early Tertiary. The Belt has resisted later stress, behaving as a fairly competent block.

Detailed mapping in several areas of the Owen Stanley Metamorphics (Smit, 1964a, b) has failed to elucidate the structure because the strong axial plane cleavage developed during metamorphism in the upper Eocene or lower Oligocene has generally obliterated the bedding. Transposed bedding at the head of the Bulolo
River (Dow & Davies, 1964, p. 12) shows that folding is locally intense in the less competent rocks, but photo-interpretation suggests that the limestone and associated coarse clastics of Cretaceous to probable Eocene age have formed a competent unit which has been folded into broad simple folds several kilometres across. This can be seen in the lower Biaru River, where the rocks have been folded into a broad northwest-trending syncline, and in the Korpera-Eloa divide, which appears to be composed of cliff-forming sediments dipping consistently at a moderate angle to the southeast.

A second phase of deformation in the early Miocene folded the axial plane cleavage. In the headwaters of the Bulolo and Buiawim Rivers the cleavage is folded along north-trending axes, but elsewhere no consistent trend can be distinguished. Though the evidence is scanty, it seems likely that the less metamorphosed rocks on the western edge of the Belt are composed of lower Te stage sediments (Omaura Greywacke), which have been affected by only the second deformation.

Since the early Miocene, the Metamorphic Belt has resisted further stress. During earth movements at the end of the middle Miocene the Langimar Beds were broadly folded into the Müai Syncline; and in the Pliocene the Babwaf Conglomerate was folded and the Bulolo Intermontane Basin was formed by faulting.

**Aure Fold Belt**

West of the Owen Stanley Metamorphic Belt the lower Tertiary rocks are tightly folded along axes trending northeast to north. The fold axes are extraordinarily regular and many extend unbroken across the Sheet area. The folds are asymmetrical, the western limbs of the anticlines being the steeper; these limbs are in places overturned and are commonly broken by long parallel faults. The dip of the faults in the Sheet area is not known, but faults revealed by offshore seismic surveys to the south have been interpreted as thrust-faults dipping shallowly to the east.

The structures in the Aure Fold Belt are the result of two periods of deformation, the first in the early Miocene (i.e. between the lower and upper Te stages) and the second at the end of the middle Miocene (between the upper Tf and Tg stages). The effects of the first deformation cannot now be distinguished over most of the Sheet area because of the intensity of the later folding, but can be seen north of the Sheet area (Dow & Plane, 1965). It was probably the first deformation that produced the second cleavage in the Owen Stanley Metamorphics.

The second deformation affected sediments as young as upper Tf stage and produced the long parallel folds characteristic of the Aure Fold Belt. It made no discernible impression on the Owen Stanley Metamorphic Belt, which had become stabilized by this time.

In the southern half of the Sheet area the folds plunge gently to the south as a result of recent downwarping discussed below.

**Lakekamu Embayment**

The upper Tf stage sediments are overlain with marked unconformity by upper Miocene (Tg stage) and Pliocene sediments which were deposited in a downwarp in the Lakekamu Embayment. The downwarping continues to the
present day, as shown by the large swamps in the lower reaches of the Kunimaipa and Lakekamu River's.

On the western margin of the Sheet area and farther west the Pliocene folding was more intense, and upper Miocene rocks are folded along north-trending axes.

Faulting

Faulting has generally been subordinate to folding, but some major faults or fault zones have had a profound effect on the structure.

By far the largest is the Owen Stanley Fault, which impinges on the eastern margin of the Sheet area. It marks a fundamental break where a segment of oceanic crust and mantle has been upfaulted against the Owen Stanley Metamorphic Belt, exposing the ultramafic mantle (Thompson & Fisher, 1965; Davies, 1971). Vertical movement on the fault has obviously been great, and it is regarded by Davies (1971) as predominantly a thrust-fault. However, strike-slip movement of several kilometres (east block north) has been postulated for the fault in the Wau Sheet area during the Quaternary (Dow & Davies, 1964), and it is probable that horizontal displacement has been comparable to vertical displacement.

The Sunshine Fault is a major fault which curves across the Sheet area in the northeastern quarter. It is a scissor-fault with the western side upfaulted in the north and downfaulted in the south. It was active in the Pliocene, when it dammed the Watut River to form the Otibanda lake, and later when it displaced the Otibanda Formation by at least 700 m.

The western margin of the Owen Stanley Metamorphic Belt is delineated by the Kapau Fault Zone, a complex system of faults forming the western margin of the Muiai Syncline. Though most of the faults have a marked physiographic expression, the complexity of the faulting and the absence of marker beds in the affected rocks prevents measurements of their displacement. The dip of the faults is not known, but the marked curvature of many fault traces indicates that they could be thrust-faults. The Kapau Fault Zone displaces middle Miocene (lower Tf stage) sediments, but may also have been active earlier in the Miocene. Movement had virtually ceased by the upper Miocene, as the Tg stage sediments are not displaced where they cross the fault zone.

ECONOMIC GEOLOGY

Very substantial quantities of gold and silver have been produced from the Morobe Goldfield in the northeast, and there is some likelihood that economic base-metal deposits are associated with the intrusive rocks in the eastern half of the Sheet area. Though gas and oil shows are known at many localities to the east and south, extensive exploration has shown that the petroleum potential of the Sheet area is poor.

Gold and Silver

Gold and alloyed silver have been produced from both alluvial and lode deposits; by far the most come from the alluvial deposits of the Wau-Bulolo region (Table 5).

Gold was first discovered in the southeast, in the upper Waria River and its tributary the Ono River, in 1897, but the Morobe Goldfield was not discovered
until 1922, when W. 'Sharkeye' Park panned gold near the mouth of Koranga Creek. The field was gradually extended and worked for moderate returns until 1926, when a small prospecting party climbed around a 250-m obstructing waterfall in Edie Creek and discovered the phenomenally rich gravels of upper Edie Creek. The extensive alluvial flats of the Bulolo and upper Watut Rivers were later found to contain economic values, and in 1932 large-scale mining operations began, using bucket-line dredges. At this time the only ground access was by walking track, so all dredging machinery had to be transported by air, a pioneering achievement in air transport at that time (Idriess, 1933). At the peak, eight dredges were working simultaneously, but all dredging and most mechanized sluicing operations had ceased by 1966. Alluvial gold mining is now carried out almost exclusively by indigenous miners using ground-sluicing methods.

Lode mining began in 1932 in the upper Edie Creek area, but ceased in 1941; so most of the total mine production has come from the New Guinea Goldfields mines near Wau, where a modest open cut is still operated.

It is not possible to show all the occurrences of alluvial and lode gold in the Sheet area; indeed, gold can be panned from almost all the streams in the Bulolo and upper Watut watershed, and a great number have been worked for widely variable returns.

The main areas of production in the Morobe Goldfield are: Edie Creek; Koranga Creek; Little Wau Creek; the Bulolo River from Big Wau Creek downstream; the Watut River and the lower parts of some of its tributaries from Otibanda downstream; the Black Cat/Bitoi River area over the divide northeast of Wau; and Hidden Valley Creek near the head of the Watut River.

Outside the Bulolo-Watut watershed, most streams draining areas of Owen Stanley Metamorphics intruded by acid and intermediate igneous rocks contain traces of gold; some have been worked for small returns and have been shown on the map. The most important was near the mouth of the Eloa River (near Bulldog), where a small dredge worked for several years and produced over 34 900 oz gold up to 1932.

### TABLE 5. GOLD PRODUCTION FROM THE WAU 1:250,000 SHEET AREA

<table>
<thead>
<tr>
<th>Years</th>
<th>Lode Mining oz</th>
<th>Dredging oz</th>
<th>Alluvial Mining oz</th>
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<td>Before 1932</td>
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<td>1 929 592</td>
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<td>508 905</td>
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<td>818 717</td>
<td>261 172</td>
<td>37 599 678</td>
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<td>July 1965-June 1968</td>
<td>44 445</td>
<td>517</td>
<td>38 788</td>
<td>2 847 500</td>
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<tr>
<td>Total to June 1968</td>
<td>406 659</td>
<td>2 017 268</td>
<td>897 649</td>
<td>77 807 302</td>
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</table>

*Origin of the Gold.* All the gold in the Sheet area is attributed to the igneous activity which began with the intrusion of the middle Miocene Morobe Granodiorite. Even the latest manifestations of this activity, the recent dacitic volcanics at Koranga, contain traces of gold, as shown by a trial percussion-drill hole put down in the volcanics in 1959 (W. Bloomfield, driller, pers. comm. 1959).
The gold introduced by the Morobe Granodiorite is of high fineness, ranging from 860 fine (860 parts per thousand gold, 140 parts per thousand silver) to 930 fine, and has been found in small quartz stringers intruding Owen Stanley Metamorphics in the Bitoi River area. As no economic lode which could be attributed to the Morobe Granodiorite has been found in the Sheet area, it is assumed that all the gold occurs in similar small mineralized veins.

Though widespread, the gold mineralization of the Morobe Granodiorite was not rich, and has proved economic only where conditions are favourable for alluvial concentration.

By far the greatest proportion of the gold from the Wau-Bulolo region was introduced by the various phases of the Edie Porphyry, the main phase being the highly altered late-stage stocks and dykes. Some of the alluvial gold has been traced to its primary source, but in almost every case it proved to be carried in quartz or quartz/manganese oxide veins up to about 5 cm thick and up to about 2 m long and deep. However, most were extremely rich and commonly contained as much gold as quartz.

A few lodes were large enough to be mined economically; in the upper Edie Creek area the largest were the Edie Creek, Enterprise, and Day Dawn Mines.

By far the largest lodes occurred near Wau at the Upper Ridges Mine in the Namie Breccia. The primary lodes were irregular in size and richness and were composed mainly of manganocalcite, subsidiary quartz and pyrite, and minor sphalerite and galena. The gold occurred free, but was very finely divided.

On weathering, the gold was concentrated in the oxidized lodes which took the form of a manganese oxide wad in which very rich, coarsely crystalline gold was found in places. The present open-cut mine is working a stockwork of auriferous manganese-quartz stringers in oxidized Namie Breccia.

The gold introduced by the Edie Porphyry is of much lower fineness than that of the Morobe Granodiorite, and ranges from a moderate 750 fine to the very low value of 530 fine (Fisher, 1945).

Though all the porphyritic andesite in the Sheet area has been mapped as Edie Porphyry, there is little doubt that the main gold mineralizers were late-stage stocks and dykes. These occur mainly in upper Edie Creek but are also known in the Upper Ridges Mine, where the main mineralization postdates the Namie Breccia which contains abundant porphyry fragments.

Despite the phenomenal richness of upper Edie Creek the output of the Morobe Goldfield would have been very much smaller but for an unusually favourable set of circumstances:

(a) All streams draining the major gold-bearing porphyry bodies eventually make their way into either the Watut River or its major tributary, the Bulolo River. Thus instead of being dispersed into several drainage basins, almost all the gold was confined to one river system.

(b) While the gold-bearing rocks were being eroded, all the streams drained into the two lakes in which the sediments of the Oti banda Formation were being deposited. Thus instead of being carried away down the lower Watut River, the gold collected in the lake beds. However, the lake beds
do not contain enough gold to warrant mining, with the notable exception of the deltaic beds of Koranga near Wau, the rich gold of which was apparently supplied by the ancestral Edie Creek.

(c) Subsequent downcutting of the lake beds by the Watut River was unusually slow because the base level of erosion was controlled by an upfaulted block of the Owen Stanley Metamorphics, which proved very resistant to erosion. Consequently, the Otabanda lake beds were reworked over a long period by the Watut River, and the gold was concentrated into economic values in the present-day alluvial flood plains. Remnants of older river levels containing economic values were found as flanking terraces up to 30 m above present river levels, but by far the greatest quantity of gold was won by working the modern stream gravels.

(d) A large proportion of the gold shed into Edie Creek during the Holocene was carried through the Bulolo River gorge, because of the high gradient of both Edie Creek and the Bulolo River. Near Bulolo township the Bulolo River has a low gradient caused by an extensive area of resistant agglomerate, and most of the gold was therefore trapped in the recent river gravels from which the bulk of the gold won by dredges was obtained.

Petroleum

The southwestern half of the Sheet area has been the focus of considerable exploration in the search for petroleum. Gas seepages, in most cases accompanied by oil impregnation of nearby rocks, have been described (APC, 1961) at several localities in the southwest, where they are associated with outcrops of middle Miocene sediments, generally along faulted crests of anticlinal structures. South of the Sheet area, between Kerema and the mouth of the Tauri River, several gas seepages occur in folded Pliocene sediments.

No drilling has been done in the Wau Sheet area, but to the west shallow holes (deepest 539 m) were drilled near Upoia between 1911 and 1919 by the British New Guinea Development Company. The upper Miocene sediments were drilled and some showings of light oil were encountered.

The New Guinea Oil Company Ltd drilled seven scout holes and a deeper hole to 462 m at Hohoro near the coast 72 km west of Kerema, between 1923 and 1926, during which showings of oil and gas were reported.

After World War II the Australasian Petroleum Company Pty Ltd drilled four deep holes west of the Sheet area to test the Miocene succession: Hohoro No. 1 (1439 m), Hororo No. 2 (3244 m), Upoia No. 1 (1633 m), and Karawa No. 1 (3848 m). Small shows of oil and gas were found, but all holes were abandoned. Drill-stem tests indicated very low effective permeability in most of the strata encountered.

There is no reason to believe that the Miocene and Pliocene sediments in the Wau Sheet area are any more favourable for the accumulation of oil than in the surrounding area and, as they are tightly folded and complexly faulted, the prospects of finding commercial quantities of oil in the Sheet area are considered remote.
Copper

The geological setting of the eastern half of the Sheet area, consisting of upper Tertiary high-level stocks of intermediate porphyry intruding greenschist facies metamorphics, offers some prospect of finding porphyry copper deposits. The most obvious target area, the Wau/upper Edie Creek region, has been broadly sampled geochemically (Horne, 1968) with disappointing results, but the rest of the basement rocks of the Sheet area remain virtually unexplored.

Nickel

The Papuan Ultramafic Belt around Lake Trist has a very moderate relief on which a deep weathering profile 8 to 10 m thick has developed, and the area has been tested for lateritic nickel deposits, first by Bulolo Gold Dredging Company in 1957 (Campbell, 1958), and later in 1961-1962 by the Wau Resident Staff, who drilled 14 scout holes in an area 3 km long by 2 km wide northeast of Lake Trist. Though some moderate nickel values were encountered in some auger holes the overall grade is low, averaging 0.52 percent nickel after omitting the top 2 m in each hole (extracted from unpublished Monthly Reports to BMR, Canberra). The results indicated that the deposit could not be economically mined in such a remote area.

Mercury

Cinnabar was reported in alluvium worked for gold before World War II in Kau Creek, a tributary of the Ono River, but neither the gold nor the cinnabar has been traced to its source.

Limestone

Recrystallized limestone from a large lens about 6 km southeast of Wau township has been calcined and used in the recovery of gold, and small quantities have been trucked to Lae for industrial purposes, but no information about the purity is available.

A large recrystallized limestone lens in the Snake River near the northern margin of the Sheet area is suitable for quarrying and appears to be of high purity. The present access road up the Snake River could be readily upgraded if a greater industrial demand should develop.
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Footnote:
Most of the unpublished reports listed are held at the office of the Geological Survey of Papua New Guinea, Department of Lands, Surveys and Mines, Port Moresby.
# APPENDIX I

**ISOTOPIC AGE DETERMINATIONS, WAU 1:250 000 SHEET AREA**

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<th>Formation</th>
<th>Sample</th>
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* 1. Evernden et al. (1964)
  2. M. D. Plane (pers. comm.)
  3. Page (1971)
  4. Page & McDougall (1972)
  5. R. W. Page (pers. comm.)
## APPENDIX II

**VERTEBRATE FOSSILS, WAU 1:250 000 SHEET AREA**

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(See Plane, 1967, for details)