COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS

RECORDS:

1965/10

MINERAL DEPOSITS OF NEW GUINEA AND PAPUA AND THEIR TECTONIC SETTING

by

J.E. Thompson & N.H. Fisher

MINERAL DEPOSITS OF NEW GUINEA AND PAPUA AND THEIR TECTONIC SETTING

by

J.E. Thompson & N.H. Fisher

Record 1965/10

CONTENTS

MINERAL DEPOSITS OF NEW GUINEA AND PAPUA AND THEIR TECTONIC SETTING

ILLUSTRATIONS

MINERAL DEPOSITS OF NEW GUINEA AND PAPUA, AND THEIR TECTONIC SETTING

SUMMARY

Known mineral deposits in New Guinea and Papua are mainly gold lodes, with some copper, and are associated with intrusions of (1) granodiorite, (2) basic and ultrabasic rocks, (3) late Tertiary porphyries and andesites.

Nine principal structural units are distinguished:

1. Oriomo Continental Spur: South-Western Papua and Cape York; continental basement overlain by undeformed shallow-water sediments.

2. The Western Papuan Shelf: epicontinental zone in which Miocene (mainly) limestone overlies granitic basement between the Oriomo Continental Spur and the Aure Trough.

3. The Aure Tectonic Zone: a complex belt of compressional folding and high-angled reverse strike-faulting.

4. The Central Highlands Orogenic Belt: a zone containing a great variety of formations including pre-Permian metamorphic and igneous rocks, and numerous later granodiorites, porphyries and volcanics. It has been orogenically emergent since middle Miocene time.

5. The Owen Stanley Metamorphic Belt: consisting mainly of metamorphosed sediments of Cretaceous or earlier age, and granitic intrusives. It contains most of the important mineral deposits.

6. Papuan Ophiolite Province: an oceanic province occupied by basic and ultrabasic plutonic rocks, submarine lavas, claystone, calcilutite and chert.

7. The Northern New Guinea Arc: including that part of the mainland north of the Ramu-Markham fault system and most of New Britain. Mio-Pliocene clastic sediments, limestone and volcanics overlie basement of igneous and metasedimentary rocks; gabbro and other intrusives are common. A line of volcanoes marks the northern edge.

8. The Cape Vogel Basin: a thick Mio-Pliocene succession overlies basic submarine lavas. Recent volcanoes occur in the north-western part.

9. The Solomon Chain: consisting of a string of large islands which are nearly all fault-bounded wedges of pre-Miocene meta-volcanics, intruded by diorites, porphyries and basic to ultrabasic rocks, on and around which Miocene limestone, clastic sediments, tuffs and lavas were deposited.

Woodlark Island is a deeply eroded Lower Miocene volcanic complex, which does not obviously belong to any of the other structural units.

On the basis of the distribution of pre-Miocene plutonic rocks, four metallogenic provinces or regimes can be approximately defined.

1. Pre-Mesozoic continental metallogenic province, with a little high fineness gold near granite contacts but no important lode deposits.

2. Oceanic metallogenic province, including the areas of basic and ultra-basic rocks and their characteristic mineral associations.

3. Papua-New Guinea synorogenic metal province, which contains the principal gold-fields, characterised by a history of repeated granodioritic magmatic activity.

4. Solomon synorogenic metal province (including New Britain), differing from (3) in the less acid composition of the older plutonic rocks and the close association of copper and gold.

Known hydrothermal gold, copper, lead and zinc mineralisation occurs principally within orogenic zones emergent since pre-Miocene time and characterised by andesitic vulcanism and granodioritic to dioritic intrusives. The thick lower Miocene to Recent sedimentary accumulations are virtually unmineralised.

The present New Guinea morphology is largely the result of late Tertiary to Recent tectonism. A theory is presented relating the distribution of geotectonic units to north-easterly migration of geosynclinal orogenic axes.

TABLE 1.

DATA ON MAIN MINERAL DEPOSITS THAT HAVE BEEN WORKED IN NEW GUINEA AND PAPUA

Name of Lode and Reference	District	Length of main ore-shoot (feet)	Depth	Thickness	Strike degrees	Dip	Lode-Type	Main Gangue	Other Minerals	Country Rock
Day Dawn South (Fisher 1935)	Edie Creek	260	150	3	145	40-55 NE	Fissure, partly chloritoid schist-porphyry contact	Quartz and manganese minerals, some calcite.	Tetrahedrite galena Pyrite, sphalerite, stephanite (?)	Chloritoid schist of Kaindi Metamorphics and quartz porphyry
Edie No. 1 (Noakes 1941)	"	1100	350	4	135	65 SW	Fissure	Quartz and manganese minerals, calcitic in parts	Pyrite, manganite, rhodocrosite	Biotite porphyry
Edie No. 2 Noakes 1941)	"	1600	450	5	90-115	65 S	Fissure	Quartz and manganese minerals	Pyrite, hematite	Chloritoid schist and phyllite (Kaindi Metamorphics).
Edie No. 5 (Noakes 1941)	"	250	150	4	90-115	80N	Fissure	Quartz and manganese minerals	Pyrite, hematite	" "
Karuka (Noakes 1941)	"	900	250		130	45 S	Fissure	Quartz and manganese minerals	Pyrite, hematite	" "
Enterprise (Fisher 1940)	"	800	300	6	105	45 SW	Fault fissure downthrown to SW	Ferruginous quartz with manganese	Pyrite, cinnabar	Chloritoid schist, phyllite, agglomerate, volcanic breccia, porphyry.
Day Dawn (Fisher 1939a)	"	600	250	4	115-155	40-80 SW	Fissure zone, partly phyllite-porphyry contact	Quartz stringers, brecciated phyllite, manganese	Pyrite, sulpharsenides and sulphantimonides of silver, mangano-calcite, rhodocrosite, native silver	Phyllite and quartz-biotite porphyry.
Upper Ridges (Fisher 1938c)	Wau	700	350	15	Variable NW	40 SW	Fissure and replacement	Calcite, rhodocrosite, quartz	Manganite, pyrite, galena, sphalerite, chalcopyrite, pyrrhotite	Volcanic breccia and porphyry.
Andersons Creek (Fisher 1938b)	Wau	132	100	12	135	55 SW	Fault fissure partly on contact	Calcite, manganese minerals	Pyrite, manganite, limonite.	Phyllite (Kaindi Metamorphics) and volcanic breccia
Laloki (Fisher 1941)	* Astrolabe	450	160 (vert.)	90 (max.)	ENE & E	35-60°N	Massive sulphide lens	Iron sulphides	Chalcopyrite, sphalerite, galena, marcasite, magnetite, arsenopyrite	Sheared shale and 'grit'.
Umuna (de Keyser 1961)	Misima	4000	600	15	155	Steep W	Fault fissure shear zone	Fault breccia with quartz pug and gangue of mineralized schist and porphyry	Pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, covellite, chalcocite.	Schist mainly, and porphyry (andesite)
Kulumadau (Trail, 1961) T.P.N.G. Mines Dept. Annual Reports (1901-1918)	Woodlark	700	575	6	170	80 E	Shear zone	Carbonated volcanics and pug	Pyrite, galena, calcite, quartz, sphalerite, copper minerals and manganese	Basaltic andesite
Kupei (Fisher 1936)	Bougainville Island	230	150	100 (max)	N-NW	Steep	Stock work of quartz veinlets in porphyry	Quartz	Bornite, chalcopyrite, pyrite, galena, sphalerite, magnetite	Acidic feldspar, hornblende porphyry.
Pumkuna Fisher 1936 Thompson 1962)	"	230+	?	2	140	40-60 NE	Fissure	Quartz	Chalcopyrite, bornite, molybdenite, pyrite, covellite, chalcocite, magnetite	Feldspar hornblende porphyry
Mt. Kaindi (Fisher 1938a)	Mt. Kaindi	90	50	6	90-150	25NE	Curve fissure	Brecciated phyllite with quartz veins	Manganese minerals, pyrite.	Phyllite and porphyry.

* Mined for copper; other deposits mined for gold.

MINERAL DEPOSITS OF NEW GUINEA AND PAPUA, AND THEIR TECTONIC SETTING

J.E. Thompson & N.H. Fisher

I. INTRODUCTION

The main aims of this paper are to review in a general way the distribution and nature of the known deposits of economic minerals in the Territory of Papua and New Guinea and relate their occurrence to regional structure and history of igneous activity. The ore deposits that have been exploited were worked mainly, or exclusively, for gold and it is not possible in this paper to describe them all, especially as reports on many of them have not been published. Accordingly, the most important data on the various known deposits are set out in summary form in Table I. Figure I is a generalised version of the geology of Eastern New Guinea. Knowledge of orebodies other than gold is scanty, for although it can be said that most of the streams in the area have been prospected for gold, comparatively little systematic exploration for other metals has been done; such exploration in New Guinea is both difficult and expensive because of the terrain, climate, weathering and vegetation.

From the standpoint of igneous associations, known mineralization falls into three main categories:

1. that associated with the earlier granite or granodiorite intrusives.

2. that associated with the basic and ultrabasic intrusives of the Papuan Basic Belt, and similar basic provinces, and

3. that associated with late Tertiary porphyries and andesites.

II. IGNEOUS ASSOCIATIONS OF THE MAIN MINERAL DEPOSITS

Mineralization associated with granodiorites

No exploitable lodes have so far been found associated with the granodiorites. Known mineralization is of two types (a) silicified contact zones containing pyrite and small quantities of other minerals, and carrying generally less than 4 dwt gold to the ton, as in the Goroka Formation adjacent to the Bismarck Granodiorite, north-west of* Goroka (McMillan & Malone, 1960). (b) small gold-bearing quartz stringers distributed over a considerable area of the country rock adjacent to the contact, as in the Upper Bitoi - Black Cat area near Wau where a concentration of such veinlets in metamorphics near the granodiorite, probably associated with an anticlinal structure in the metamorphics, was the source for the alluvial gold worked in these streams (Noakes, 1938).

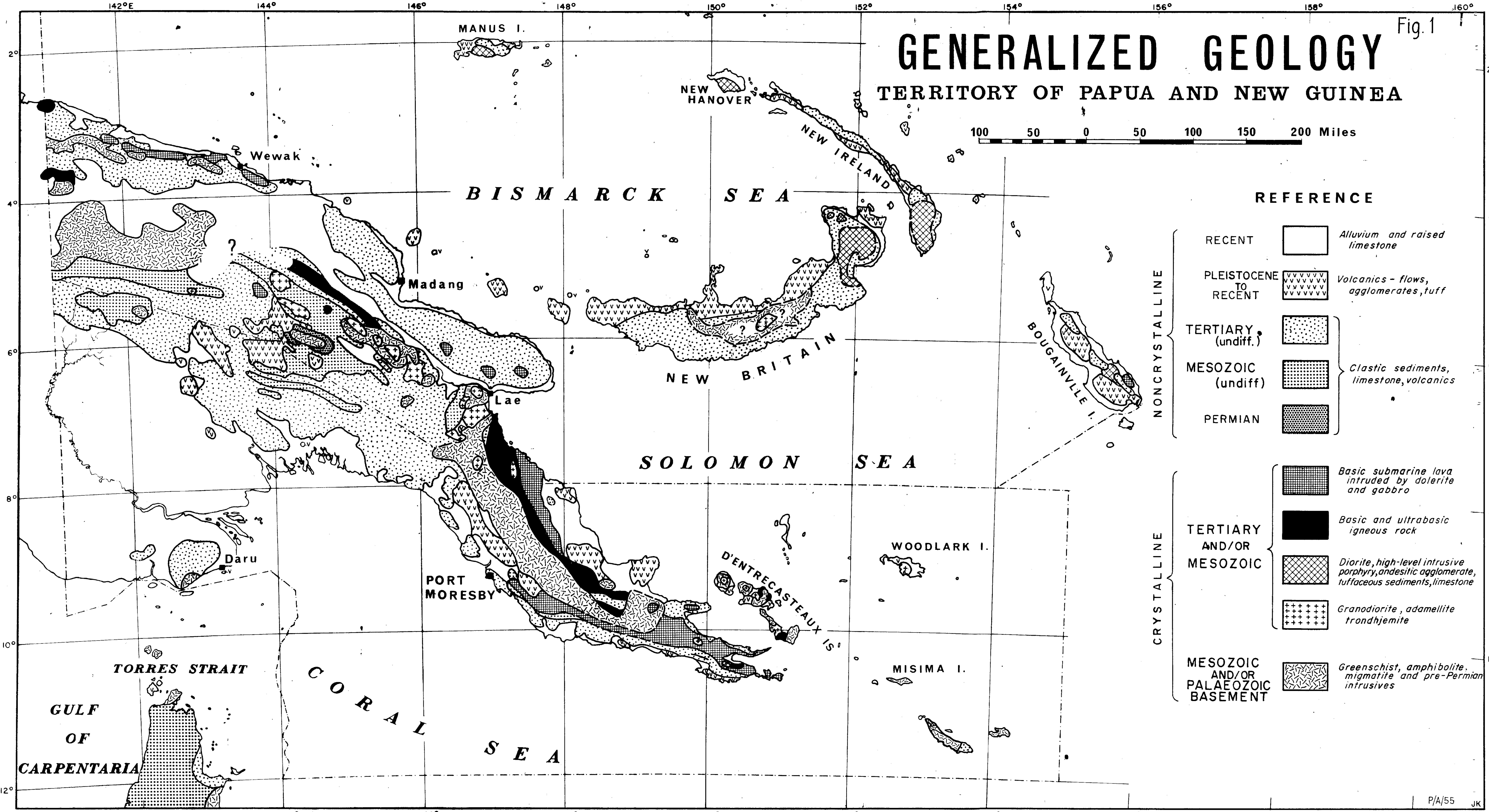
The granodiorites are intrusive into Cretaceous sediments in the Morobe district but are pre-Miocene, and in the Central Highlands range from pre-Permian - Kubor Granite near Mt. Hagen (Rickwood, 1955) - to Lower Jurassic (Dow & Dekker, 1964).

Mineralization associated with the basic intrusives

Mineralization associated with the basics and ultrabasics is naturally of a different type. Metals represented include gold, copper, nickel, cobalt, platinum, osmiridium and chromium. Gabbroic intrusives in the Port Moresby district (Astrolabe Mineral Field) have associated with them massive pyritic orebodies generally carrying a few percent of copper and a few pennyweights of gold per ton. Platinum and osmiridium have been found in the river alluvials in widely separated areas ranging from the Sepik to Milne Bay, but especially from the Gira and Yodda Goldfields and from the Milne Bay area (Nye and Fisher,1954). Chalcopyrite has been noted in the Oipo Gabbro of the Marum Basic Belt in the Bismarck Mountains (Dow & Dekker, 1964).

---

*For localities mentioned in the text see Figure 3.



Bureau of Mineral Resources, Geology and Geophysics December 1964

The most important area in this category is what is now called the Papuan Basic (or Ultrabasic) Belt, a 30-mile wide strip of country which extends south-easterly from Salamaua for about 220 miles to the Tufi district on the north coast of Papua. It contains ultramafic zones, consisting of peridotite, pyroxenite, serpentinite and actinolite schist, and feldspathic zones made up mainly of gabbro and norite, but including also trondhjemite, intruded by dolerite dykes. Dow and Davies (1964) deduced that the rocks of the Belt were emplaced some time between Upper Cretaceous and Lower Middle Tertiary; some gravity differentiation had taken place but "tectonic movements and stress during crystallization prevented the development of orderly layering and caused the intrusion of residual magma into the already-solidified parts of the pluton".

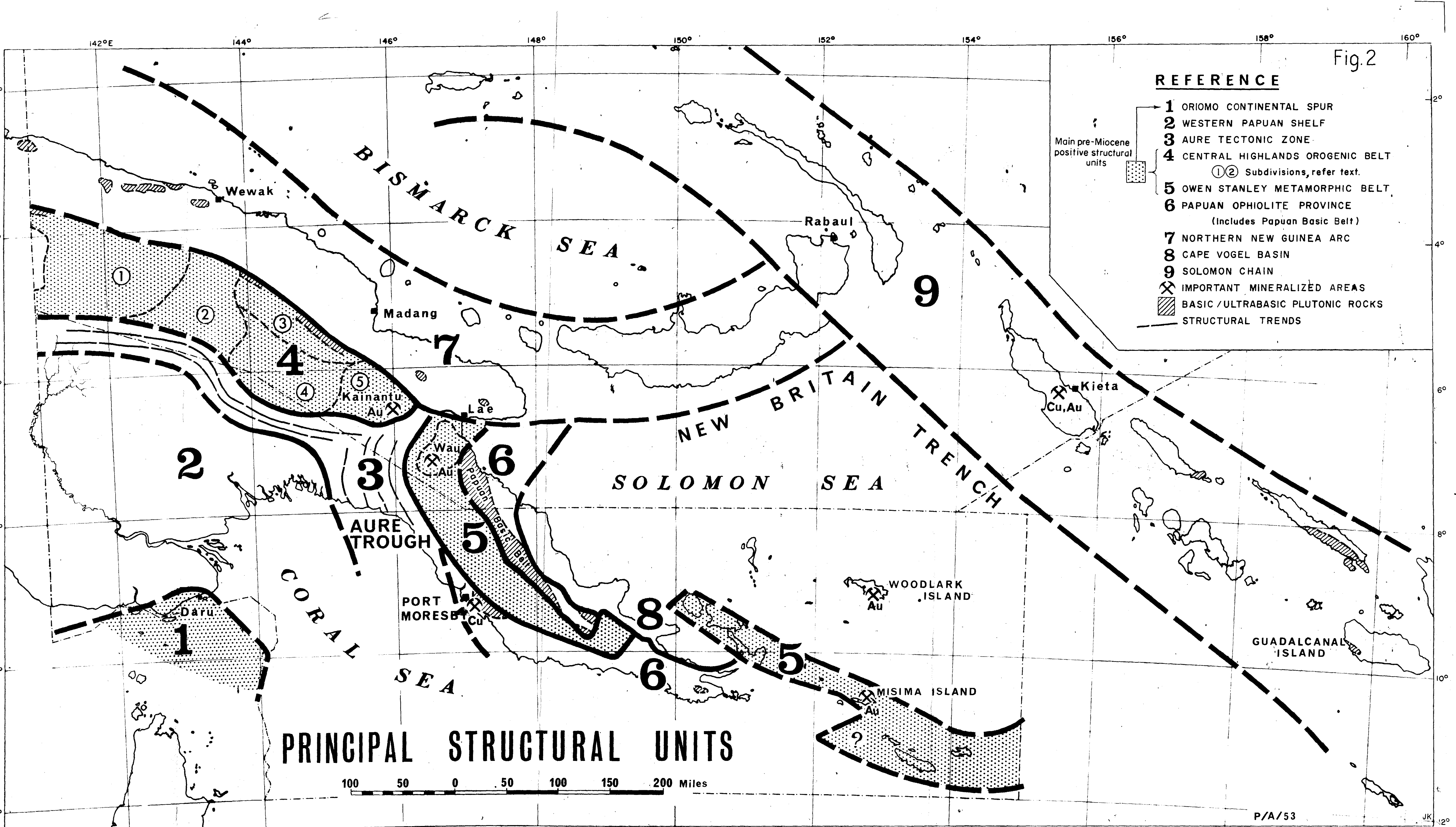
The only mineral worked within the Papuan Basic Belt so far is alluvial gold (with incidental platinum) but the gold is derived from the neighbourhood of acidic intrusives - porphyry and monzonite. The ultrabasic members of the Belt contain nickel - probably about 0.2 per cent in the peridotites - and the main mineral potential of the area is the possibility of occurrence of secondary concentrations of nickel in veins of nickel-magnesian silicate in the sub-surface weathered rock. Such prospecting as has been done suggests that the grade may be too low, particularly where access is so difficult. The terrain is unfavourable for the development of lateritic type concentrations of economic importance.

Late Tertiary mineralization

The principal lode formations that have been worked are the gold orebodies associated with the late Tertiary andesites and porphyries (Fisher 1939 a & b, 1945, De Keyser 1961, Trail 1962). These have many features in common. They are all epithermal type fissure veins; all contain quartz, pyrite and some manganese; calcite and rhodocrosite are commonly present; gold is of low fineness 560-750; silver content is high though in many orebodies difficult to recover; quartz porphyry, dacite or andesite occurs near the lodes, in many cases forming part of one wall (or both) of the lode or is found intruding the country rock within the mine workings; the strike of the lodes is parallel to the regional direction of tectonic movement; the vertical dimension of the lodes is small compared to the length; and all show strong evidence of secondary enrichment and redistribution of silver and gold, so that many of the lodes became too poor to work below the zone of oxidation. Some rich zones were found in the upper parts of the lodes but the grade generally worked was of the order of 6 to 10 dwts per ton.

Another type of mineralization that has contributed largely to the alluvial gold deposits, though generally uneconomic to work in situ, is the small rich quartz veinlets commonly carrying a high percentage of gold, such as those in the 'mudstone' adjacent to the Upper Edie porphyry that have obviously been the source of much of the gold of the Edie Creek rich alluvials and of the Bulolo River dredging flats. These have been found only occasionally in cleaning up the floor of alluvial workings and not enough is known of their general attitude to relate them to regional or even local structure. Those known are generally only about an inch or so in width and few if any have been traced for more than 100 feet. The principal minerals observed are quartz and gold, and some pyrite; in some areas magnetite and sphalerite have also been found with the gold in alluvial workings.

Rarely is there positive evidence of the age of these latest porphyry mineralisations, but what there is indicates a fairly late Tertiary age. At Edie Creek, the Enterprise lode occupies a fissure which displaces agglomerate and breccia, and the Golden Ridges orebody occurs in breccia, which contains porphyry fragments but is again intruded by the latest porphyries. These breccias and agglomerates are continuous with the agglomerate that forms the lower part of and is interbedded with the Otibanda lake beds, which have been regarded as Pleistocene because of their vertebrate fossil content. Recent age determinations from the lowest beds in this formation give an age of 7,000,000 years (R.A. Stirton; pers.comm.) suggesting that their deposition began in the Pliocene. Some of the Tertiary



PRINCIPAL STRUCTURAL UNITS

Bureau of Mineral Resources, Geology and Geophysics. November 1964 To accompany Record 1965/10 mineralisation predated these agglomerates; some is later.

On Misima the age of the porphyries which are thought to be associated with the mineralisation has not been established, but it is almost certainly Tertiary, and probably Miocene. On Woodlark the main mineralisation is in the Okiduso Volcanics of probable Miocene age.

On Bougainville the earliest sediments known are of Miocene age, but their relationship to the gold and copper-bearing 'porphyries' has not been established. In the Astrolabe district near Port Moresby the massive sulphide orebodies appear to be genetically related to gabbros which are known to intrude Oligocene rocks and are probably Lower Miocene in age.

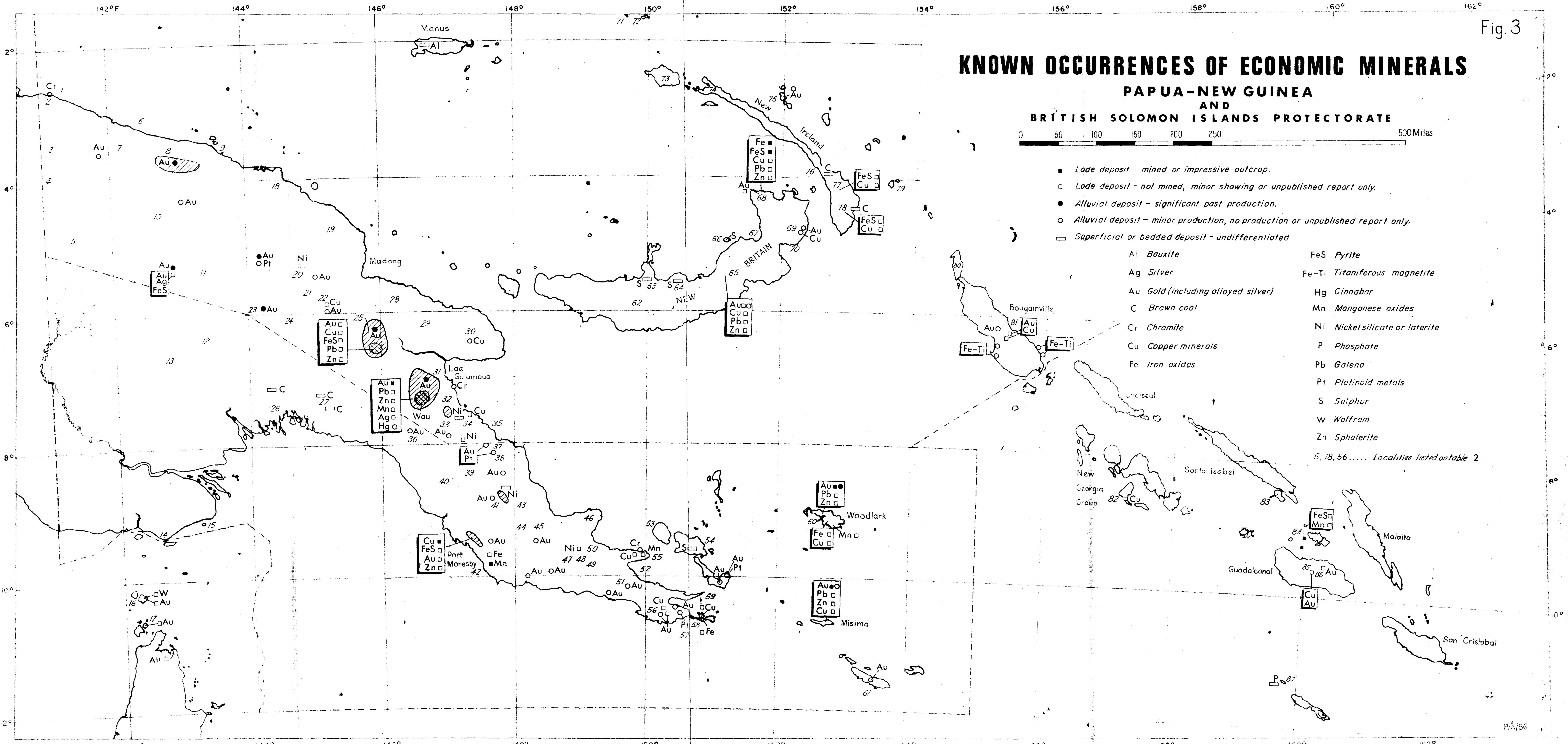
III. GEOTECTONIC SETTING

Eastern New Guinea and the islands of the Bismarck Archipelago and Solomon Chain are part of a zone of late Tertiary to Recent tectonism encircling the Pacific Ocean and now manifest by island arcs, mountain chains and contemporary volcanic and seismic activity. Stages in its evolution have been obscured by recurrent orogeny, erosion and strike-slip fault displacements of great magnitude, and the present day topography of the region is closely controlled by Quaternary to Recent faulting and the accumulation of andesitic volcanic products, but there is evidence that the area has been, ever since Lower Cretaceous times, an unstable zone of tectonic compensation between two differentially moving major crustal elements; the Australian Continent on the south-west and the 'Pacific Plate' to the north and north-east.

Oceanic and continental crust have different bulk mineralogical composition and, accordingly, different bulk density. The continental crustal material, characterised by granitic intrusions, is lighter than and buoyant on denser oceanic crust of basaltic composition. Because of their different densities these two types of crust can be expected to respond at different rates to radially or tangentially directed forces either from within the earth (e.g. convection) or from without (e.g. tidal).

Stresses built up between oceanic and continental crust may be compressional or tensional, with or without a rotational component, and the direction and magnitude of those stresses will change with time. Compression will, according to its intensity, be accommodated in a mobile zone by folding, reverse faulting or low-angled thrusting, and tension will be relieved by normal faulting or rifting. It is conceivable that faulting down to the basaltic layer or deeper at the edge of a continent may result in detachment of a fragment from the continental mass. Once detached such a fragment would seek its own isostatic equilibrium and more importantly be free to respond independently of its parent continental mass to forces subsequently applied. This concept of detached continental fragments or slivers has been likened to the much more easily comprehensible detachment of ice-bergs from ice sheets and their independent movement away from the parent sheet in response to marine currents and tides.

While large vertical displacements along faults can frequently be seen or demonstrated in the field, large transcurrent and low-angled-thrust displacements are rarely capable of demonstration except by very detailed mapping or by drilling. It is thus not surprising that few large lateral displacements (in New Guinea) have been recognised with confidence. If, as the configuration of structural elements in the south-west Pacific area strongly suggests, there has been differential lateral movement between the Pacific Plate and the Australian Continent, then large scale low-angled thrusting, strike-slip faulting, and dilatationary displacements are to be expected. No large-scale thrusts have been recognised at the surface in New Guinea but there is evidence of recent strike-slip displacement along major north-westerly striking faults such as the Owen Stanley Fault (Dow and Davies, 1964) and the Bismarck Fault (Dow and Dekker, 1964). The apparent left lateral fault displacement of segments of the Owen Stanley



Bureau of Mineral Resources Geology and Geophysics December 1964

To accompany Record 1965/10

TABLE 2.

LIST OF LOCALITIES MENTIONED IN THE TEXT; PLOTTED ON FIGURE 3 (OPPOSITE) IN NUMERICAL ORDER FROM NORTH-WEST TO SOUTH-EAST.

Adelbert Range	19	Hydrographer Range	45	Nakanai Range	65
Aikora River	37	Kainantu	25	New Hanover	73
Aird Hills	26	Kavieng	74	Oenake Mountains	2
Aitape	6	Kieta	81	Open Bay	67
Banks Island	16	Kokoda	41	Oura Oura	46
Bellona Island	87	Kua River	30	Prince Alexander Ra.	8
Betilonga	85	Kubor Range	24	Purari River	27
Bismarck Mountains5	20	Kulumudau	60	Rendova Island	82
Border Mountains	3	Lakekamu River	36	Rigo	42
Bowutu Mountains	34	Lake Kutubu	12	Saint Matthias Is.	72
Buka Island	80	Lake Trist	32	San Jorge Island	83
Burgers Mountains	11	Lolobau Island	66	Saruwaged Range	29
Cape Lambert	68	Mabaduan	14	Sepik-Ramu Delta	18
Cape Nelson	46	Mafulu	40	Sideia Island	58
Danlilian River	77	Magavara	51	Snake River	31
Daru Island	15	Mambare River	38	Sudest Island	61
Dowa Dowa	57	Marambu River	69	Tabar Island	75
East Cape	59	Matakan	76	Tapio	55
Feni Island	79	Morobe	35	Thurnwald Range	5
Fergusson Island	54	Mount Albert Edward	39	Torricelli Range	7
Finisterre Range	28	Mount Bosavi	13	Vanimo	1
Gira River	37	Mount Dayman	49	Waiowa	50
Gold Ridge	86	Mount Garbuna	63	Waria River Valley	33
Goodenough Bay	52	Mount Hagen	23	Weitin River Wewak	78 9
Goodenough Island	53	Mount Lamington	43	Whiteman Range	62
Goropu Mountains	48	Mount Pago	64	Wide Bay	70
Green River	4	Mount Wilhelm	21	Yanderra	22
Hanesavo Island	84	Musa River	44	[illegible]	
Horn Island	17	Musa Valley S.E.end	47		
Hunstein Range	10	Mussau Island	71		

Metamorphic Belt (Fig. 2) in eastern Papua and the apparent northward deflection of the Northern New Guinea Arc at its contact with the Solomon Chain suggest that at the present time there is a strong northerly drag operative between eastern Papua and the Solomon Chain.

The structure of New Guinea, and the South-west Pacific area in general, cannot be clearly identified with any stage of those of the concepts of structural evolution of an orthogeosyncline in which subsidence and the accumulating weight of sediment initiates a cycle which proceeds through a tectogene phase and culminates in an orogeny in the region of the axis of thickest depositon.

The structural development of this region has been dominated by lateral movement of the Pacific Plate relative to the Australian Continent; in late Tertiary to Recent time relative movements of the Pacific Plate appear to have been northerly. Transcurrent faulting and rifting consequent on these movements, recurrent vulcanism and isostatic adjustment between light continental , sialic , material supported on denser oceanic, basaltic, crust have provided extreme topographic relief and abundent sediment supply for the formation of thick, linear, eugeosynclinal accumulations such as in the Mio-Pliocene Aure Trough and Northern New Guinea Basin. These accumulations are now strongly deformed, particularly in their axial regions, not by tectogenesis, but by continuing movements in the crystalline basin framework and gravitational adjustments in the incompetent sedimentary pile.

IV. GENERALIZED STRUCTURE, STRATIGRAPHY, AND MINERALIZATION

Regional Subdivisions

For convenience of description the region can be divided into the nine principal structural units shown on Figure 2, namely:

1. Oriomo Continental Spur
2. Western Papuan Shelf
3. Aure Tectonic Zone
4. Central Highlands Orogenic Belt
5. Owen Stanley Metamorphic Belt
6. Papuan Ophiolite Province
7. Northern New Guinea Arc
8. Cape Vogel Basin
9. Solomon Chain

In most cases, these units are bounded by tectonic lineaments which are expressed topographically. Because of their distinctive tectonic histories each of the structural units can also be considered as a depositional province. However, some structural features which have determined the boundaries of these units are of late Tertiary to Recent age and transgress petrogenic and metallogenic provinces determined by pre-Tertiary igneous and metamorphic basement characteristics. Woodlark Island, which is discussed later as an area of gold and base-metal mineralization, is not included in any of the proposed structural units because of its isolation and limited exposure. It is discussed under a separate heading as are the principal oceanic areas which lie within the New Guinea mobile belt.

The structural and depositional characteristics of each of the structural units will be outlined briefly, commencing at the stable continental side of the region and progressing north-easterly to the unstable Pacific margin. After discussion of the structural units, four fundamental metallogenic provinces will be nominated, one related to pre-Mesozoic continental basement, another related to oceanic crustal basement, and two attributed to orogenic development, including anatectic magma generation, of pre-Tertiary orthogeosynclines. The distribution of these provinces is indicated on Figure 4, and the igneous, depositional and metallogenic histories of each are portrayed on the idealized sections in Figures 6 and 7.

1. Oriomo Continental Spur

The term "Oriomo Spur" has been applied (A.P.C., 1961) to a spur of granitic rocks which extends from Cape York beneath the Torres Strait to Mabaduan on the south coast of Papua, and then plunges northerly beneath Tertiary limestone and Mesozoic clastic sediments. The region here designated "Oriomo Continental Spur" includes the granite outcrop at Mabaduan and a small area around it where Miocene limestone lies directly on an erosional granite surface. The southern extension of the unit has been arbitrarily linked to the Great Barrier Reef on the east and, on the west, taken just south of the Papuan coastline to accord with aeromagnetic indications of shallow basement (Hartman, 1962).

From Lower Miocene to Upper Miocene time southerly transgressive bryozoal, algal and coral reefs grew and accumulated on the Papuan part of the region. They attained a maximum thickness of about 1500 feet at the northern extremity. These reefs also extended much farther north across a wide platform of epicontinental marine Cretaceous clastic sediments. It seems probable that marine Cretaceous sediments also extended south to Cape York but were stripped by erosion before deposition of the Miocene limestone. The Papuan part of the region emerged at the end of the Miocene and has since received only a thin veneer of Pliocene and Pleistocene terrestrial sediments and, in the vicinity of Daru Island, a spread of andesitic volcanic ejecta from a vent or vents not yet located.

No mineralization is known in the Papuan part of this unit. Specimens of wolfram at times brought by natives to Port Moresby from the Daru area have probably been acquired from known wolfram deposits on Banks Island in Torres Strait. Gold mineralization has been recorded from Horn Island. The wolfram and gold of these Torres Straits Islands is associated with granite which is probably of Permo-Carboniferous age. There is no evidence that the violent tectonic movements which took place throughout the greater part of New Guinea from Upper Miocene to Recent time had any serious effect on this region.

2. Western Papuan Shelf

This unit corresponds partly with the topographic province called the Fly-Digoel Depression by David, (1950) and earlier geologists, and is essentially the same as the Papuan part of Glaessner's (1950) structural Fly-Digoel Shelf. The name Western Papuan Shelf is used here to avoid confusion between the structural and topographic provinces.

The Western Papuan Shelf is strictly a structural unit and includes a large part, but not all, of the Miocene reef and shoal platform which was built up between emergent granitic basement of the Oriomo Continental Spur and the abrupt edge of the Aure Trough. The northern front of this Miocene reef platform extends into the adjoining tectonic unit.

The epicontinental character of this zone is borne out by its structural rigidity and by the presence of granite and granite-derived Jurassic quartzose sandstones at the bottom of several deep exploratory wells. The northern and north-north-eastern boundary of this unit is taken along a line where folding and faulting are of sufficient magnitude to expose pre-Tertiary rocks. To the north-east and east, where the Miocene shallow-water limestone is not severly folded and is transgressed by Pliocene to Recent clastic sedimentation, the margin of this unit is more arbitrary.

Over a large part of the area the Miocene limestone is exposed in karst topography or elsewhere is covered by a few hundred feet of Pliocene to Recent terrestrial sediments which in the Lower Fly River region are lateritized. However, in the southern foothill zone parallel to the main range in the Fly-Strickland drainage area, an elongate basin containing some 10,000 feet of coarse terrestrial clastic tuffaceous Plio-Pleistocene sediments has developed.

The Tertiary limestone ranges in thickness from about 1500 feet on the south to about 6000 feet in the north where Oligocene limestone is present. In the Omati Trough in the eastern part of the area about 9500 feet of Lower Miocene basinal limestone beneath 1400 feet of Middle Miocene shoal limestone, comprise an anomalously thick, but localized, development of Miocene limestone.

Structural deformation of the limestone platform within this province is gentle except along its northern margin where there are large robust folds such as the Cecilia and Iehi Anticlines. The 9000 feet volcanic mountain, Bosavi, to the north and the eroded volcanic neck at Aird Hills in the east attest Pleistocene vulcanism at the outer edge of this shelf.

The Miocene limestone lies with regional unconformity over a marine Cretaceous sequence of glauconitic sandstone and siltstone up to 4000 feet thick in the Morehead Basin, east of the Oriomo Continental Spur, and about 3000 feet thick in the A.P.C. Barikewa No. 1 well to the north. Conformably beneath the Cretaceous sequence are Jurassic mudstones and quartzose sandstones which are predominantly terrestrial in the south but become more marine ~~and~~ increase in thickness northwards. In the A.P.C. Barikewa No. 1 well, in the outer (north-eastern) part of the structural unit, about 8000 feet of marine Jurassic sediments and about 800 feet of pre-Jurassic, possibly Triassic, conglomeratic arkose and continental red beds were penetrated.

The mild deformation of the Miocene limestone sheet is probably related to irregularities of the unconformity surface on which it was deposited. Little is known of structure in the underlying Mesozoic succession, but no significant angular discordance with the Tertiary limestone has been observed. However, normal faulting and erosion in pre-Miocene time resulted in the loss by erosion of about 3000 feet of Cretaceous section from the southern, uplifted side of the Komewu Fault, a persistent feature which strikes north-westerly across the unit.

Basal Mesozoic sediments, known only from drilling, are coarse quartzose and ~~arkosic~~ continental sandstones which usually merge into a zone of weathered granite. A minimum K/Ar age of 236 million years (Permian) was obtained from a granite core from the bottom of the A.P.C. Aramia No. 1 well (Dr. J.R. Richards; pers. comm.); at Komewu No. 1, on the southern side of the Komewu Fault, weathered dacite was drilled at the base of the sedimentary section.

Lignitic coal beds have been encountered in the Jurassic succession, particularly towards its base, in most of the wells drilled, but they are too deep for exploitation. Lignites have also been noted in the thick Pliocene section on the southern foothills of the main range. Pliocene and Pleistocene sediments in the south-western part of the unit are lateritized but neither iron nor alumina enrichments of economic importance are known. It is possible that the Miocene shoal limestone may contain phosphatic beds, particularly where it adjoins deeps such as the Omati Trough. A small quantity of gas containing methane, carbon dioxide, and 1.7% helium was obtained from basal Mesozoic sediments in the A.P.C. Aramia No. 1 well. The helium content of this gas could be of commercial interest if large gas accumulations were located. It is not surprising that metallic mineralization has not been recorded in this tectonically passive region.

3. The Aure Tectonic Zone

This is a complex belt of compressional folding and high-angled reverse strike-faulting extending north-westerly from the eastern side of the Papuan Delta to the main range near the West Irian border. The unit has two distinct sets of tectonic trends which in a more critical treatment would be the basis of further subdivision. However, for the purpose of this paper it can be considered as a single fold belt.

In the south-east, the thick Mio-Pliocene clastic succession in the Aure Trough (A.P.C. 1061) is tightly folded and strike-faulted along axes which trend south-easterly near the coast and swing northerly inland (Fig. 1). A conflicting fold and fault belt exposing Mesozoic clastic sediments beneath Tertiary limestone extends west-north-westerly from the middle reaches of the Purari River on a broadly sinuous course to the Fly-Strickland headwaters. In the region of conflict of these two trends the structure is extremely complex and there may be some large-scale transcurrent fault displacements. The two distinct trends are probably attributable to independent orogenic or lateral movements in the Central Highlands to the north (Unit 4, Fig. 2) and the Owen Stanley Ranges to the north-east (Unit 5, Fig. 2).

The sedimentary succession in the eastern part of this tectonic zone has a probable aggregate thickness in excess of 55,000 feet, of which at least 45,000 feet is of Miocene and Pliocene age. Mesozoic sediments do not crop out in the Aure Trough but it seems likely that the Mesozoic succession known in the shelf province to the west would extend unconformably beneath the thick Mio-Pliocene sedimentary pile in the Aure Trough and increase in thickness probably to more than 10,000 feet.

Over a large part of the long, sinuous west-north-westerly trending part of the Zone, Cretaceous marine clastic sediments are exposed beneath Lower Miocene or, rarely, Eocene limestone. In the extreme north-west, in the upper reaches of the Strickland River, granite is exposed beneath Jurassic shale and quartzose sandstone; and, on the northern fall of the main range in the Sepik River headwaters, a Mesozoic marine section containing about 1600 feet of Cretaceous sandstone and shale and 9000 feet of Jurassic black micaceous shale has been recorded (A.P.C., 1961).

Despite the tight folding and faulting and the vast thickness of sediments involved, regional metamorphism is not evident in any of the sediments which crop out in this zone. However, Mesozoic sediments buried deeply beneath the thick Mio-Pliocene sedimentary pile in the Aure Trough may be metamorphosed.

Pleistocene basaltic and andesitic volcanic cones form high domal mountains, with typical deeply incised radial drainage, in the central and western part of this structural unit.

It is notable that Mesozoic and Tertiary non-extrusive igneous rocks are not known in this unit even though folding and faulting are intense and, over much of its length, the sedimentary sequence is deeply exposed. This lack of intrusive activity suggests that deformation is the product of vertical and lateral movements of the enclosing basement elements rather than inherent orogenic tendencies. This is probably why the unit is devoid of metallic mineralization. Beds of Pliocene brown coal up to 10 feet thick are known in the Lower Purari River area and Cretaceous sands containing up to 50% glauconite have been recorded (A.P.C., 1961) from near Lake Kutubu. These deposits are of little economic significance because of their remoteness and low grade.

4. The Central Highlands Orogenic Belt

The internal structure of this unit is exceedingly complex. However, from Middle Miocene time onward it has been orogenically emergent and supplied much of the clastic and volcanic detritus in the deep eugeosynclinal Northern New Guinea Basin to the north and contributed to a lesser degree to Mio-Pliocene clastic sedimentation in the Aure Trough to the south and south-east.

The unit contains a crystalline basement of pre-Permian metamorphics and medium-acid igneous rocks overlain by a thick, discontinuous, accumulation of Permian to Middle Miocene marine sediments and basic volcanics, and, after emergence, by localised Pliocene to Recent sub-serial andesitic to basic volcanic accumulations and lake deposits. Pre-Permian, (?) Triassic/Lower Jurassic and Cretaceous holocrystalline medium-acid igneous rocks are exposed in batholithic dimensions; Tertiary medium-acid intrusives are exposed at a higher emplacement level as dykes and sills of andesitic porphyries. Significant gold-pyrite mineralization is associated with Pliocene shallow intrusives of andesite porphyry and andesitic volcanic breccias near Kainantu at the eastern end of the Belt.

It seems that this region has, at least since Permian time, been a zone of recurrent intrusive activity, emergence and erosion along the northern edge of an epicontinental platform which itself was mostly emergent in Permian-Triassic, Upper Cretaceous to Eocene, and Upper Miocene to Recent times and at other times inundated by only shallow seas. The abundance of submarine volcanic deposits and greywackes in the fragmentary Triassic to Lower Miocene sedimentary record along the north-eastern part of this unit contrasts strongly with the record of quiet shelf sedimentation or emergence to the south. It is here suggested that until Lower Miocene time a contact zone between continental crust on the south and oceanic crust to the north passed along the northern side of this unit. It is noteworthy in this context that pre-Miocene clastic sediments have not been identified north of this unit or north of the Owen Stanley Metamorphic Belt adjoining on the south-east. A possible inference from this lack of pre-Miocene clastic sedimentation is that the region was oceanic and beyond the transportation limit for clastic sediments derived from the continent or from its marginal tectonic and volcanic zones.

The unit as delineated on Figure 2 is heterogeneous, both structurally and stratigraphically. It contains at least five subdivisions, details of which cannot be adequately described within the limited scope of this paper. The subdivisions are indicated numerically from west to east on Figure 2, and are discussed, briefly, in the same order.

(i) <u>Crystalline basement rocks of the Thurnwald and Hunstein Ranges</u> The geology of this area is very poorly known but from the accounts of prospectors and early explorers and from reconnaissance mapping around its margin by oil companies, it is believed to be a block of granodiorite with contacting schist and phyllite. Alluvial gold won by natives from streams north of Ambunti is shed from within this block but the locality and geological environment of the deposits are not known. To the south, a thick marine succession of Cretaceous and Jurassic sediments dip unconformably off this basement block; to the west it is flanked by Paleocene limestone and volcanics (Paterson and Perry, 1964). On the north, the crystalline rocks extend beneath the Sepik River alluvium and emerge in the Green River area where they are in probable fault contact with serpentinite which is overlain by Eocene limestone. This serpentinite may denote an extension of the zone of strike faulting in the Bismarck and Schrader Ranges farther east.

(ii) <u>A preserved embayment of broadly folded Miocene clastic sediments, shoal limestone, and volcanics unconformably on Cretaceous black marine shale covers a large area west of Wabag.</u> The Miocene sediments are exposed in mountains such as Burgers Mountain (Dekker & Faulks, 1964), and Cretaceous sediments are exposed in the valleys. The eastern part of this subdivision has been mapped by reconnaissance traverses (Dekker & Faulks, op. cit.). The remainder of the area is extremely rugged, only sparsely populated and difficult to approach from established administrative centres. The only mineralization known in the area is in the vicinity of Porgera where small quantities of alluvial gold have been won by a few Europeans and many native groups. Some of the gold is shed from stockworks of quartz with associated sphalerite, pyrite, galena and chalcopyrite in Cretaceous black shales near intrusive contacts with small dioritic intrusions. Gossanous lodes in this area have a high silver content.

(iii) A zone of W-N-W strike-faulting up to 40 miles wide on the northern flank of the Central Highlands, including the Schrader and Bismarck Ranges. In this zone Dow and Dekker (1964) have noted evidence for Recent right-lateral strike-slip displacement along some faults and it was suggested that large strike-slip displacements have taken place within this zone at various times back to the Jurassic. Major strike faults within this zone have deflected around the solid mountain-forming mass of the Bismarck Granodiorite and contacting metamorphic rocks of possible Palaeozoic age. Dow & Dekker (1964) consider that the Bismarck Granodiorite was emplaced during Upper Triassic or Lower Jurassic and accordingly they suggest it should not be correlated with the pre-Permian granodiorite in the core of the Kubor Anticline as was proposed by Rickwood (1955). The geological record in this region is so fragmentary that the timing, direction, and magnitude of strike fault displacements must remain obscure.

This imbricated zone is also characterised by large and small basic to ultrabasic intrusives and basic submarine extrusives which have intruded, extruded along fault zones or have been emplaced by faulting, in Lower to Middle Miocene time. The largest basic-ultrabasic intrusive mass, called the Marum Basic Belt by Dow and Dekker (1964), is about 50 miles long and up to 8 miles wide, aligned with the regional west-north-west strike, bounded on the south by the Simbai Fault and on the north by the fault-controlled Ramu Valley. The ultrabasic phase of this mass is a plug-like intrusive of serpentinized dunite and pyroxenite which occupies an area of approximately 100 square miles in the eastern part of the Belt.

The oldest rocks of this zone are schists and phyllites intruded and thermally metamorphosed by the Bismarck Granodiorite. The sedimentary sequence commences with fossiliferous Upper Triassic marine greywacke and coarse arkosic clastic sediments derived from a nearby acid volcanic terrain. These are the only Triassic rocks recorded in eastern New Guinea. Unconformably on the Triassic sediments is a thick repetitious succession of marine greywacke, siltstone, and basic submarine volcanics ranging in age from Lower Jurassic through to Upper Cretaceous and aggregating upward of 15,000 feet in thickness. Upper Cretaceous to Lower Miocene dark, contorted and regionally metamorphosed marine siltstone, probably in excess of 5,000 feet thick, conformably overlies the Mesozoic submarine lava and greywacke sequence.

Alluvial gold has been won from many streams within this zone; some streams which drain basic and ultrabasic rocks also contain alluvial platinum. Dow & Dekker (1964) are of the opinion that much of the alluvial gold is shed from the margins of Miocene gabbro and microdiorite intrusives and that some comes from the Bismarck Granodiorite and the coarse arkosic Triassic sediments.

At Yanderra, on the northern fall of Mount Wilhelm, copper mineralization has been recorded in the Bismarck Granodiorite in the vicinity of intrusive hornblende andesite porphyry. The copper occurs as chalcopyrite disseminated in granodiorite and in small calcareous veins. Streams draining this area carry a small amount of alluvial gold which has been worked by natives. The small surface showing of copper mineralization has not provided sufficient incentive for systematic prospecting or drilling. Minor chalcopyrite, and pyrrhotite mineralization was noted by Dow and Dekker (1964) in the Marum Basic Belt, but no significant lodes were located. They also drew attention to nickel enrichment in residual soils over dunite of the Marum Basic Belt. However, large areas of mature laterite over peridotite, such as might contain economic low-grade lateritic nickel deposits, cannot be expected in this rugged country.

(iv) This zone, centred on the Kubor Anticline (Rickwood, 1955) is characterised by large amplitude folds, and Pleistocene to sub-Recent andesitic and basaltic strato-volcanoes, tholoids, lava flows and apron deposits of pyroclastics and coalescing alluvial fans. The lack of basic and ultrabasic intrusives and the scarcity of post-Permian submarine basic lavas distinguish this zone from the adjoining strike fault zone north of the Bismarck Fault Zone. Pre-Permian granodiorite and unfossiliferous grey and green pyritic slate exposed in the core of the Kubor Anticline are overlain by an incomplete succession of marine sediments about 34,000 feet thick, commencing with Permian basic volcanics and limestone and including Upper Jurassic shale and limestone, Cretaceous tuff, greywacke and marl, Eocene and Oligocene limestone, and Lower to Middle Miocene greywacke and shale. South of the Kubor Anticline, folding decreases in amplitude, and dissected volcanic cones and their apron deposits mask the transition into the Aure Tectonic Zone.

There are no significant Mesozoic or Tertiary high-level intrusives within this zone and accordingly mineralization is sparse.

(v) <u>That part of the Central Highlands Orogenic Belt east of longitude 145°20'E</u> is characterised by the large number of medium to small intrusive bodies ranging in age from (?) Jurassic to Upper Tertiary and in composition from granodiorite to gabbro.

Nearly every stream within this area carries some alluvial gold and many have been worked by native groups for modest returns; some alluvial deposits have been exploited from time to time by Europeans but these have been barely economic. All igneous contact zones have probably contributed some gold to the alluvial deposits of the area. Dow and Plane (1963) consider that (?) Pliocene andesite porphyry and co-magmatic andesitic volcanics have been the main source of gold in the area. However, gabbro and dolerite of Miocene emplacement, and Upper Cretaceous and Jurassic granodiorites of batholithic dimensions all shed some gold. In Yonki Creek gold is associated with magnetite.

An eight-ton sample parcel of oxidised copper ore averaging about 8% copper has been taken from a small contact deposit between Miocene gabbro and limestone exposed in Yonki Creek. From the same area Dow & Plane (1963) recorded chalcopyrite and pyrite in small quartz veins in metamorphosed limestone. Native copper has been recovered with gold from alluvial deposits derived from (?) Pliocene andesitic volcanics near Aifunka, about six miles west-south-west of Kainantu, but no primary copper mineralization of interest has been located. A small lead/zinc lode occurs in a shear zone near the intrusive contact of granite and (?) Palaeozoic metasediments, about 2½ miles north-west of Kainantu. This lode was tested by drilling in 1958 (Davies, 1958) but has not been mined.

The oldest rocks in this area are phyllites, schists and gneisses at the eastern end of the Bismarck Range; these are intruded by granodiorite, diorite and gabbro. The absence in this zone of the thick Mesozoic succession exposed on the flanks of the Kubor Anticline can probably be attributed to regional easterly plunge, as in the Kubor Anticline. The same regional plunge direction is suspected in the eastern part of Bismarck Range where the top of the Bismarck Granodiorite is exposed in many places through windows in the (?) Palaeozoic metamorphic rocks and where there seems to have been an easterly progression of intrusive activity expressed by successively younger intrusives emplaced at successively higher levels.

The Central Highlands Orogenic Belt is an important structural element which emerged orogenically in late Tertiary time and has since shed clastic sediments to the north and south-east; from Upper Cretaceous to Upper Miocene time it was at the northern edge of a shallow, at times emergent, epicontinental platform, which supported algal, bryozoal and coral reef growths from Eocene to Middle Miocene time. Throughout Jurassic and Cretaceous time it was the site of thick marine clastic deposition, with considerable tuffaceous contributions from volcanic islands to the north, and accumulations of submarine basic lavas along its northern flank.

From at least Permian to Upper Triassic time the region was an emergent, possibly orogenic northern front of the Australian continent, and the pre-Permian metamorphics and granitic batholiths may be correlative with similar rocks in the Tasman Geosyncline.

The basic submarine lavas and the less common andesitic subaerial volcanics which recur throughout the Upper Triassic to Middle Miocene sedimentary succession on the northern flank of the Central Highland Orogenic Belt are the products of periodic vulcanism to the north, probably aligned along the zone of contact and tectonic conflict between continental crust and oceanic crust. At times volcanic island chains may have emerged and erosional detritus as well as primary volcanic products were shed into adjacent deeps.

The (?) transcurrent strike-faulting which dominates the northern part of this unit has been active from at least late Tertiary to Recent time and possibly commenced much earlier.

5. The Owen Stanley Metamorphic Belt

This structural unit is composed essentially of regionally metamorphosed greywacke sediments and limestone, and, locally, metamorphosed igneous rocks. At various places within the Belt, three grades of metamorphism have been noted.

The rocks of lowest metamorphic grade are indurated and slightly sheared Cretaceous greywacke and sericite schist in the north-western part of the Belt (Dow, 1961a) and occurring as boulders from near Lake Trist (Dow and Davies, 1964). Similar Cretaceous metasediments occur on the south-western margin near Mafulu (A.P.C. 1961).

Dow (op.cit.) observed that in the Snake River area the Cretaceous metasediments are markedly unconformable on a very thick contorted sequence of phyllite, schist and some marble. These are the dominant metamorphic rocks throughout the length of the Metamorphic Belt; fossils have not been found in them but they are generally considered of Palaeozoic age. However, there is no evidence that, in part, they have not been derived from Triassic, Jurassic, or even Lower Cretaceous sediments.

Still higher grade metamorphics represented by amphibolite, gneiss and migmatite derived from both sedimentary and igneous rocks occur in the mountainous country at the northern end of the unit south of Lae, on the D'Entrecasteaux Islands (Davies and Ives, in press), and on Misima Island (de Keyser, 1961).

Post-Cretaceous sediments have not been identified within the Belt, except for small accumulations of clastic sediments and raised reefs on Misima Island. Thus, since Cretaceous time the greater part of the unit has been either an emergent steep-sided linear island, peninsula, or submerged ridge beyond the limit, or above the level of terrestrially derived sediments. In either case, small fringing reefs or marginal small accumulations of clastic sediments, may have formed on the flanks or on the top of the crystalline mass but these would have been removed by erosion during regional late Tertiary uplift.

The Owen Stanley Metamorphic Belt has, since at least Middle Miocene time, played a similar role to the Central Highlands Orogenic Belt as an emergent source of clastic sediments, but petrologically and structurally it is somewhat different. It is not unreasonable to assume that these two crystalline units were joined until Upper Miocene or Pliocene time, as a spur of crystalline rocks plunging regionally to the south-east consistent with the plunge at the eastern end of the Bismarck Range and the Kubor Mountains. The present day structural discordance between these two units was recognised by Glaessner (1950) on the basis of local divergence of structural trends. It is further emphasised by a marked northerly swing of the faulted north-easterly margin of the Metamorphic Belt. The structural break between the two units is now occupied by Upper Miocene clastic sediments broadly folded on northerly axes. It is envisaged that throughout the Miocene, rapid orogenic uplift of the northern end of the Metamorphic Belt took place. This uplift seems to have been centred on the region of multiple medium-acid igneous activity corresponding to the Morobe Goldfield. The cause of the uplift may well have been a south-westerly directed pressure associated with fault emplacement of the Papuan Basic Belt or underthrusting of the Metamorphic Belt beneath the Papuan Basic Belt. The uplift culminated in transverse faulting across the spur of crystalline metamorphic rocks, and continuing similarly directed pressure from further lateral movements either of the Papuan Basic Belt or the Metamorphic Belt, or both, caused the northern end of the Metamorphic Belt to separate from the Central Highlands Orogenic Belt, assume its present arcuate shape, tightly fold and fault the sediments of the Aure Trough, and cause the northerly swing of the structural grain in the Aure Trough.

Like the Central Highlands Orogenic Belt, the northern margin of the mainland part of the Owen Stanley Metamorphic Belt is controlled by major strike fault lineaments along which both vertical and lateral movements have taken place in Pleistocene to Recent time. However, whereas the faulting of the northern part of the Central Highlands unit is complex and involves large blocks of plutonic acid igneous rocks, the northern margin of the Owen Stanley unit is defined by a single narrow fault zone, the Owen Stanley Fault, which can be traced as a distinct topographic break for over 200 miles. Recent transcurrent movements along the front of these two structural units, as expressed by displaced stream courses, are in opposite directions; in the fault complex of the Central Highlands right-lateral (anticlockwise) movement is indicated (Dow and Dekker, 1964) whereas at the northern end of the Owen Stanley Fault the most recent movement has been left-lateral (clockwise) (Dow and Davies, 1964).

The main compositional feature of the Owen Stanley Metamorphic Belt is the almost exclusive predominance of regionally metamorphosed sediments of the green-schist facies. Intrusive igneous rocks are neither as widespread nor as diverse as in the Central Highlands unit. Most of the intrusives are derivatives of granodioritic magma exposed at various levels of emplacement. There are three main igneous provinces known: (1) The Morobe Goldfields (Wau-Bulolo) area at the northern end of the Belt (Fisher, 1944) (2) The D'Entrecasteaux Islands, (Davies & Ives, in press), and (3) Misima Island (de Keyser 1961). Lesser granodiorite or andesite porphyry intrusives are known in the headwaters of the Waria River (Fisher, 1945), on the southern flank of the Musa Valley (Smith and Green, 1961) and on Sudest Island. Truly basic intrusives of batholithic dimensions have not been recorded but small lamprophyre dykes have been noted by Smith and Green (1961) and Stanley (1923a) in the headwaters of the Musa River. Except in the D'Entrecasteaux Islands, where the unit is fragmented by many transverse faults, there is no contemporary or recently extinct vulcanism within the Metamorphic Belt - the most recent vulcanism was in the Wau-Bulolo area where Plio-Pleistocene rhyolite and andesitic pyroclastics overlie unconsolidated lake beds. Large areas of Plio-Pleistocene andesitic to basaltic agglomerate and conglomerate which extend along the south-western flank of the unit from the Astrolabe Range near Port Moresby north-westwards to the Lakekamu River may have extruded from vents within the Metamorphic Belt, which have not been located. For the present, the authors prefer to relate these volcanics to faulting along the margin of the unit.

The few regional geological maps of Papua-New Guinea published to date have followed Stanley (1923a) in showing a median mountainous core of metamorphic rocks extending to the eastern tip of Papua. Unpublished reconnaissance observations by one of the authors (J.E.T.) have established that the mountains east of longitude 149°30'E, that is, east of Mount Dayman, are composed of fine-grained, uralitized and epidote-veined dolerites and basic submarine lavas, intruded by plutonic masses of gabbro and rarely diorite and granodiorite, and by dykes of undersaturated felspathoid porphyries. These observations are consistent with the suggestion by Smith and Green (1961) that the metamorphics of the Owen Stanley Range may have been displaced transcurrently to the north along a prominent fault across the eastern end of the Musa Valley, and with the idea expressed by Davies and Ives (in press) that the D'Entrecasteaux Islands are an offset extension of the Owen Stanley Range. Dislocation of fold axes in Pliocene sediments west of Cape

Vogel is suggestive of some left-lateral transcurrent displacement in the basement but evidence for the necessary total displacement of 65 miles is lacking. However, any evidence of pre-Pliocene transcurrent faulting in this region would be concealed beneath sediments of the Cape Vogel Basin.

The suggested easterly extension of the Owen Stanley Metamorphic Belt to include Misima and Sudest Island (see fig.2) is tenuously based on gross lithological characteristics of the islands and on major submarine topographic features.

Metamorphism has obscured bedding in most of the metasediments of the Metamorphic Belt but, in many places, structural attitudes are displayed by a superimposed lineation which may be parallel to bedding. This lineation, which can best be seen in high-altitude oblique air photos or on aerial reconnaissance, strikes with the regional north-westerly trend of the unit and is usually monoclinal, dipping moderately to the north; or broadly anticlinal. Large domal structures, flanked by faults and internally intruded by granodiorite, have been mapped on Goodenough (see fig.7) and Fergusson Islands, (Davies and Ives, in press). Similar doming occurs at Mt. Dayman and in the Gorupu Mountains at the eastern end of the unit on the mainland. Structure in the intensively intruded and mineralized areas around Wau and also on Misima Island is probably more complex and the relationships between structure, intrusion and mineralization are not clear.

The Morobe Goldfield, the most productive gold mining area in the Territory, occupies a large part of the northern end of the Owen Stanley Metamorphic Belt. Here, the most important lode gold deposits are associated with andesitic and quartz-felspar porphyries of probable late Tertiary age (Fisher, 1945). The gold occurs in:

(1) Quartz and manganocalcite fissure lodes in propylitized chloritic schist, phyllite, and andesitic volcanic breccia.

(2) Fine discontinuous stringers of free gold, in some places with quartz and manganese oxides, in volcanic breccia and propylitized chloritic schist and,

(3) Silicified and pyritized contact deposits along the chilled margins of intrusive porphyries.

Galena, marmatite and pyrite mineralization has been encountered in the lower levels of some mines and occurs at the surface near intrusive porphyry contacts with phyllite. Gold associated with the porphyries ranges in fineness from about 450 to about 600. This province of Tertiary gold mineralization is strikingly similar geologically and mineralogically to the gold mining area centred on Baguio in central Luzon. Gold has also been introduced into the Morobe Goldfields area by (?) Cretaceous granodiorite and several small gold-bearing quartz leaders have been located on granodiorite intrusive contacts. The gold from this source invariably has a fineness in excess of 750 and, while it probably contributes significantly to the alluvial gold deposits in the region, no promising lodes have been located. Insignificant amounts of cassiterite recovered from gold dredging operations in the Bulolo Valley undoubtedly come from disseminations in the large masses of granodiorite drained and not from lodes.

On Misima Island, gold mineralization is associated with dacitic and andesitic porphyries intrusive into greenschist metamorphics. The gold occurs in massive quartz lodes, and as ramifications of small quartz leaders in sheared and brecciated greenschist and porphyry close to intrusive porphyry contacts. Pyrite, galena, honey-coloured sphalerite and, more rarely chalcopyrite, occur in the lower levels of the now-abandoned mine on the largest known lode. De Keyser (1961) has suggested that the source of the gold on Misima Island may possibly have been the greenschist itself and that its concentration on and near porphyry contacts may be due merely to thermal effects accompanying intrusion. All previous geologists have assumed that the gold is of magmatic derivation. Gold mineralization is seemingly not associated with an older trondhjemite intrusive emplaced in metamorphics of higher grade than greenschist.

In the D'Entrecasteaux Islands, where the metamorphics are commonly of the alamandine-amphibolite facies and acid, shallow-emplacement porphyries are rare, (Davies and Ives, in press), there is little known gold or other metallic mineralization.

An important, obvious but often overlooked distinction between the Central Highlands Orogenic Belt and the Owen Stanley Metamorphic Belt lies in their respective present day geographic relationships to north-eastern Australia and inferred similar palaeogeographic relationships at least back to Lower Miocene times. The Central Highlands unit is linked to northern Australia by a broad epicontinental platform which was largely emergent back to the Upper Miocene; from Upper Miocene to Lower Miocene it was the site of limestone deposition and was again probably emergent throughout most of the early Tertiary and Upper Cretaceous time. On the other hand, the Owen Stanley Metamorphic Belt has seemingly been separated from north-eastern Australia throughout Quaternary and Tertiary time by deep sea which occupied the Aure Trough - Coral Sea structural depression. Early Tertiary cherts and dark shales indicative of a deep-water depositional environment, and tuffaceous, non-quartzose Cretaceous sediments and limestone on the south-western flank of the Owen Stanley Belt in the Port Moresby region suggest that, at least back to Cretaceous time, this unit was beyond the limit of continentally-derived sediments and separated from Australia by deep sea.

6. Papuan Ophiolite Province

'Ophiolite' is used here to denote an association of ultrabasic and basic plutonic rocks, basic submarine lavas, grey, red-brown and green siliceous claystone, inorganic calcilutite and bedded chert. This assemblage of oceanic igneous rocks and oceanfloor deposits typifies a tectonic zone where there has been no emergence and where there is no emergent continental mass nearby.

The term "ophiolite" or "ophiolitic suite" has been applied in some popular concepts of geosynclinal evolution to a petrological suite comprising ultrabasic and basic intrusives, basic submarine lavas and greenschist metasediments and meta-volcanics which are regarded as symptomatic of an early stage in the orogenic development of a geosyncline. No such implication is intended here; the term is used merely to include all intrusive, extrusive and sedimentary rocks derived from or deposited on oceanic crust away from the influence of clastic sedimentation from large land masses.

The strongly deformed Upper Cretaceous to early Tertiary sediments including chert, argillite, limestone, tuffaceous limestone and black tuffaceous shale which occur in the foothills zone between Port Moresby and Milne Bay are included in this structural unit.

Leucocratic gabbro, diorite, trondhjemite and, rarely, granodiorite intrude the more common dark basic rocks of the Province in the Bowutu Mountains (Dow and Davies, 1964) and in the Magavara and Milne Bay areas of eastern Papua.

The two parts of this unit (see Fig.2) are probably co-extensive beneath the folded late Tertiary sediments of the Cape Vogel Basin and the Pleistocene to Recent volcanic and coastal plain deposits between Morobe and Cape Vogel. It is also possible that the basic igneous rocks and associated Miocene submarine lavas and deep-water sediments in the northern part of the Central Highlands Orogenic Belt were part of the Ophiolite Province before large-scale late Tertiary faulting took place along the Markham-Ramu Valley.

Geological investigations within this unit have been directed particularly towards the ultrabasic rocks of the Papuan Basic Belt (Thompson, 1957, 1958, 1962a; Davies, 1959; Smith and Green, 1961; Dow and Davies, 1964) because of the prospects of "lateritic" or "silicate" nickel deposits. The remainder of the region is very poorly known, except in the vicinity of

Port Moresby where copper mineralization has attracted attention. Scattered observations by one of the authors (J.E.T.) at many points around the eastern Papuan coastline and adjoining islands, and on two reconnaissance traverses across the mountains, have confirmed the persistence of ophiolitic lithologies but have provided very little information on structure. The thick massive dolerite and basalt sequence which forms the bulk of the unit is generally poorly exposed and rarely shows structural attitude. The topography suggests broad folding or slight tilting rather than tight folding or imbrication.

Many of the basic igneous rocks show alteration effects which may be attributable to mild regional stress, contact thermal effects by leucocratic intrusives, or to the interaction of warm submarine basic lavas and sea water. Dyke swarms of undersaturated felspathoid porphyries intrude a thick succession of submarine basalts in the hinterland south of Cape Vogel.

The economic minerals known or expected in this province are, in probable order of importance, : Copper-bearing sulphides and their oxidation products, nickel magnesian silicates and nickel-enriched residual soil, gold, platinoid metals, chromite, asbestos, and manganese oxides of marine sedimentary origin. Nickeliferous sulphide deposits have not been recorded but may occur in association with noritic and gabbroic intrusives. The region has not been widely prospected for base-metal deposits and little systematic geological mapping has been done.

The best known mineral deposits are the cupriferous sulphide deposits in early Tertiary dark shale intruded by gabbro near Port Moresby (Fisher, 1941). Small, but rich, superficial enrichments of copper carbonates and oxides were extracted by individual miners and small syndicates from many gossans within this area between about 1900 and 1914. Since 1914 many attempts have been made to mine and treat copper-bearing sulphide ore from this area but none has been successful. The primary sulphide ore usually contains from 2 to 5% copper, mostly as chalcopyrite, associated with pyrite, marcasite, sphalerite and magnetite. Gold averaging from 1 to 3 pennyweights per ton in the primary ore is locally enriched to more than ½ oz. per ton in the oxidised zone. The most impressive mineralized outcrops in the Port Moresby area have now been drilled but no single orebody sufficiently large to warrant mining has been proved. It is, of course, possible that larger orebodies may not be exposed; these could possibly be located by geophysical or geochemical means. The association of this copper mineralization with dark shale and the absence of mineralization within the gabbro permit the possibility of a syngenetic sedimentary origin.

Traces of copper carbonates occur in dolerite on Sideia Island near Samarai and near an intrusive contact of gabbro and meta-volcanics at Oura Oura in the Milne Bay area. Several minor occurrences of copper-iron sulphides associated with basic and ultrabasic rocks of the northern part of the Papuan Basic Belt reported by Dow and Davies (1964) have not been seriously investigated.

Nickel is concentrated by chemical weathering processes into the lower half of residual soil profiles on serpentinized dunite and harzburgite in the Papuan Basic Belt. Large quantities of these nickel-enriched, ferruginous, soils are known near Kokoda and Lake Trist but nickel values exceed 1% only at the very base of the soil profiles; the average grade of the deposits is well below the present economic limit. Supergene nickel magnesian silicates (garnierite) have been seen at several places in weathered ultramafic rocks of the Papuan Basic Belt but no large deposits are known. Nickel sulphide mineralization is to be expected in association with gabbroic and noritic intrusives in the Ophiolite Province, but to date only traces have been recorded (Thompson, 1962a).

Massive chromite, a common primary segregation from ultramafic magma, has not yet been found in the ultrabasic rocks of the Papuan Basic Belt, but dispersed accessory chromite, in association with magnetite, is a common constituent in "black sands" of rivers and beaches in the vicinity of the ultrabasic rocks.

Alluvial gold is not nearly as widespread in the Ophiolite Province as in the Central Highlands or Owen Stanley structural units. The principal gold-bearing streams in the Province are the Waria, Gira, Aikora and Mambare Rivers which originate in the Owen Stanley Range and flow across the Papuan Basic Belt to the north-east coast of Papua. Much of their gold is derived from granodiorite and andesite porphyry intrusives in the Owen Stanley Metamorphic Belt. Some lesser streams wholly within the Papuan Basic Belt in the Bowutu Mountains carry small quantities of alluvial gold derived from intermediate and acid differentiates or intrusives within the basic complex. Alluvial gold has also been won from the Magavara River, which heads in an area where granodiorite is intrusive into a dolerite and basalt sequence. Small quantities of gold have been won from pyritic shears and small quartz-pyrite lodes in olivine gabbro intruded by granodiorite at Oura Oura near Milne Bay. Some alluvial gold was won from this area during the period 1910-1916, and small smounts of alluvial gold have been won since from small streams draining a basic-ultrabasic complex on the southern arm of Milne Bay.

Osmiridium and platinum which occur with alluvial gold in the Waria, Gira, Aikora and Mambare Rivers are undoubtedly shed from dissemin-ations within the serpentinized peridotite of the Papuan Basic Belt. In 1932, there was a minor rush to alluvial platinum deposits in the headwaters of the Dowa Dowa River which drains north into Milne Bay, but within a few years the area was abandoned. The platinum of this deposit, which occurs without gold, was won from a short stretch in the upper reaches of the Dowa Dowa River where moderately dipping bedded Lower Miocene sediments form natural riffles across the stream bed. The very localized occurrence of this platinum is not thought to imply a concentration in nearby peridotite but rather it reflects the almost ideal stream conditions for entrapment of heavy minerals at this particular locality.

Parts of the sedimentary succession in the Ophiolite Province represent favourable environments for manganese oxide deposits of marine sedimentary origin such as those that are being deposited with siliceous oozes and clay on the present sea floor far removed from, or protected from, vigorous clastic sedimentation. Manganese deposits in Eocene chert and argillite of the Port Moresby- Rigo area are of such origin but have been remobilised by subsequent folding and supergene processes. A discontinuous layer of large, irregularly shaped, siliceous,manganese oxide nodules beneath Lower Miocene limestone and on basic igneous rocks near Tapio on Cape Vogel is probably a sea floor deposit on basic volcanic rocks of the Ophiolite Province.

A quick study of the strand characteristics around the mainland of eastern New Guinea reveals that large sections of the coastline showing evidence of Recent submergence fall within the Ophiolite Province. Further, vertical displacement on the Owen Stanley Fault and the few erosional remnants of a mature landscape on the crest of the Owen Stanley Range, indicate Pleisto-cene to Recent uplift of the Owen Stanley Metamorphic Belt relative to the Ophiolite Province. The only portion of the coastline in the Ophiolite Province where Quaternary emergence is in evidence lies between Cape Vogel and East Cape, south of the D'Entrecasteaux Islands which may be a dis-placed part of the Owen Stanley Metamorphic Belt.

The full structural implications of Quaternary differential vertical movements are not clear, but they do serve to distinguish the Ophiolite Province of oceanic basaltic affinity from the Owen Stanley Meta-morphic Belt and the Central Highlands Orogenic Belt of a more continental character; the Ophiolite Province being recessive relative to sea level (or less emergent relative to a crustal datum) while both the Owen Stanley and Central Highlands units were positive structural elements throughout Cainozoic time. Clear evidence of Pleistocene glaciation on the highest parts such as Mt. Wilhelm and Mt. Albert Edward demonstrate that these were high areas during the Pleistocene.

7. The Northern New Guinea Arc

This unit is bounded on the south by a major structural lineament which is expressed topographically by the Markham and Ramu Valleys and the New Britain Trench south of New Britain. The chain of volcanic islands extending from the mouth of the Sepik River to the Gazelle Peninsula at the eastern end of New Britain forms the northern boundary. The unit is terminated abruptly in the east by a north-westerly trending lineament across New Britain between Wide Bay and Open Bay.

On Figure 2, the unit is shown extending west of the Sepik-Ramu delta to include the mountains between the Sepik Valley and the north coast. The volcanic line to the north, and the prominent fault lineament to the south, used to define the unit over most of its length, are not conspicuous east of the Sepik-Ramu delta. In a more detailed structural analysis a fair case could be made for the termination of the Northern New Guinea Arc at the lower Sepik delta but, for the purposes of this paper, it has been extended to include all the country north of the Sepik River. This part of the unit includes a chain of slightly "en echelon" mountains ranging from 2000 to 5000 feet above sea-level. In the cores of these mountains, crystalline rocks are exposed either in fault contact with, or overlain by, the thick Mio-Pliocene clastic sedimentary succession of the Northern New Guinea Basin (Reynolds et al., 1963). At many places, Eocene shoal limestone lies unconformably between the crystalline basement and the Mio-Pliocene clastic sediments. Granitic and metamorphic basement is exposed in the Prince Alexander and Torricelli Mountains. Basic to ultrabasic igneous rocks crop out as basement in the Border Mountains and Oenake Mountains in the west and are faulted against mio-Pliocene sediments in tectonically complex zones on the northern flank of the Torricelli and Prince Alexander Ranges. No thermal effects or mineralization have been recorded in sediments contacting either the acid or basic rocks of this region. It seems that the floor of the Northern New Guinea Basin west of the Sepik-Ramu delta was composed of granodiorite and regionally metamorphosed sediments on the south and a fault complex of basic to ultrabasic rocks to the north. Late Tertiary to Recent reactivation of the faults in the basic to ultrabasic basement has produced tight folding and thrusting of the overlying Mio-Pliocene clastic sediments.

No mineral lodes are known in this region but there has been no systematic prospecting for metals other than gold. Alluvial gold has been won from several streams eroding basal conglomerates overlying granitic and metamorphic basement in the Prince Alexander Mountains. This alluvial gold ranges in fineness from 837 to 931 suggestive of a genetic association with the granitic basement (Fisher, 1937,1945). Beach sands between Vanimo and the West Irian border contain an appreciable amount of chromite derived from the ultrabasic rocks exposed beneath Tertiary limestone and clastic sediments in the coastal ranges (Thompson, 1962 (a)). Baker (1952) noted microscopic amounts of dispersed sulphides, including chalcopyrite, in a random collection of basic and ultrabasic rocks from the northern flank of the Torricelli Range between Aitape and Wewak.

The mainland part of the Northern New Guinea Arc east of the Sepik delta includes, from west to east, the Adelbert Range (6,500 ft. a.s.l.), the Finisterre Range (13,500 ft. a.s.l.) and the Saruwaged Range (13,500 ft. a.s.l.), which are composed of a broadly folded, faulted and recently uplifted thick succession of Tertiary clastic sediments, volcanics and limestone.

The Mio-Pliocene sediments and pyroclastics of the Adelbert Range cannot be correlated confidently with the sedimentary succession of comparable age west of the Sepik Delta. Crystalline basement has not been recorded in the Adelbert Range but small areas of Eocene limestone, which elsewhere within the unit lies directly on basement, are known. The Adelbert Range is separated from the much higher and more spectacularly rugged Finisterre Range by a topographic depression, suggestive of a basement fault, which trends west-north-west through Astrolabe Bay and is co-extensive with the straight, strongly emergent, coastline flanking the Finisterre Range.

The Finisterre and Saruwaged Ranges are composed of a very rapidly deposited thick accumulation of Miocene clastic sediments, basaltic volcanics, and limestone, the basal part of which has been intruded by gabbro, particularly on Huon Peninsula. This succession has been broadly folded, extensively faulted and elevated along marginal, steeply dipping, fault zones, represented by the Markham-Ramu Valley system on the south and the relatively straight coastline to the north. Upper Miocene limestones cap the Saruwaged Range at elevations exceeding 10,000 feet above sea level. Coastal terraces at many levels, steep stream gradients, V-shaped valley profiles, mass erosion by landslips, and seismic activity all indicate that this area is one of the most tectonically unstable regions in Papua-New Guinea at the present time. There is no recorded evidence of Tertiary acid synorogenic intrusives, gabbroic and doleritic intrusives into greywacke and limestone low in the sedimentary succession have been reported by Siedner (1958) in tributaries of the Leron River on the southern fall of the Finisterre Range, by Noakes and Gardner (1959) north of Lae, and by Horne (pers. comm.) in the headwaters of the Kua River in the mountains of the Huon Peninsula. Green copper staining on gabbro boulders in tributaries of the Leron River was noted by Siedner (op. cit) and an unusual occurrence of finely disseminated native copper in gabbroic rocks from the Kua River was mentioned by Horne. Gold has not been reported from the area and no promising showings of other metals are known. The possibility of economic copper mineralization associated with basic intrusives in the Finisterre and Saruwaged Ranges should not be overlooked.

New Britain, excluding the Gazelle Peninsula, forms the eastern part of the Northern New Guinea Arc. It is clearly bounded on the north by a zone of Recent vulcanism and on the south and south-east by a submarine trench. The geology of this area is poorly known and most of the information used here has been extracted from an account of the regional geology of the island by Noakes (1942), based on a few reconnaissance traverses and many scattered observations. No systematic regional geological mapping has been done. Metasediments and granodiorite of unknown age are exposed in the Nakanai and Whiteman Ranges. These basement rocks are overlain by andesitic volcanic agglomerate and breccia of probable early Tertiary age which are intruded by basic and acid dykes and sills. Flanking and capping both the crystalline basement rocks and the pyroclastics is a Middle to Upper Miocene limestone succession which has been elevated and deeply eroded to form rugged high-level karst topography. A gently folded Plio-Pleistocene paralic sequence of sandstone, sandy marl and limestone, which forms low country west of the Whiteman Range, appears to lie unconformably on the Miocene limestone succession and is itself overlain unconformably by Recent volcanic debris. Clastic sediments, limestones and volcanics of probable Pliocene age occur also near Wide Bay. The thickness of the Tertiary sedimentary succession on New Britain has not been measured or estimated. However, the moderate dips and the exposure of crystalline basement in the mountainous core suggest that Tertiary sedimentation on New Britain was much less vigorous than on the mainland part of this structural unit. This is consistent with the predominance of Tertiary sediments of shallow-water facies on New Britain and the absence of the thick dark shale deep-water sequences which dominate the Finisterre-Saruwaged sedimentary succession and are present to a lesser degree farther west.

Traces only of alluvial gold have been found in streams which drain the igneous rocks of the Nakanai Range. Copper and silver-lead minerals have also been recorded from the central part of this range, but it is not known whether they are associated with granodiorite intrusives into pre-Tertiary metamorphic rocks or with porphyries intrusive into the volcanic agglomerate and breccia. Thin beds of brown coal have been noted in the late Tertiary clastic sediments of New Britain and small deposits of sulphur of volcanic origin occur in solfataric areas of active and recently extinct volcanoes at Mt. Pago and Mt. Garbuna in the central part of the northern volcanic belt and on Lolobau Island at its north-eastern extremity (Fisher, 1942b).

Central and western New Britain differs from the remainder of the Northern New Guinea Arc in that basic to ultrabasic intrusives are not known. Further, it has acid to intermediate porphyries intrusive into (?) early Tertiary volcanic agglomerate and breccia which are not a feature of the mainland parts of the unit. As far as can be ascertained from the only available account of the geology of the Nakanai and Whiteman Ranges (Noakes, 1942), the granodiorite and, more particularly, the acid porphyries, intrusive into volcanic agglomerate and breccia, would seem to warrant closer attention as possible mineralizing intrusives. Mineralized areas of importance could well have remained undetected in such a heavily forested and sparsely populated area where visual prospecting methods are of limited value only. Reconnaissance geochemical prospecting may be the only means of determining whether significant base-metal mineralization is present in this area.

8. The Cape Vogel Basin

The name Cape Vogel Basin was used by Paterson and Kicinski (1956) to refer to a structurally and topographically depressed coastal zone extending from Morobe to East Cape, passing between the D'Entrecasteaux Islands and the mainland and extending an unknown distance to sea north-west of the D'Entrecasteaux Islands. This may be a valid regional structural unit and is used as such in this paper, but when used in a stratigraphic sense the Cape Vogel Basin cannot be justifiably extended beyond the thick Miocene and Pliocene sedimentary pile exposed on Cape Vogel and the southern shore of Goodenough Bay (A.P.O.C., 1930). North-west from Cape Vogel, unconsolidated coastal plain deposits and Pleistocene to Recent, dominantly andesitic, volcanics mask any possible extension of the Mio-Pliocene sedimentary succession exposed on Cape Vogel.

Copper, manganese and chrome mineralization were reported by E.R. Stanley (1916) on Cape Vogel. The manganese and chrome localities have been visited by one of the authors (J.E.T.) but the copper occurrence has not been relocated. The manganese occurs as nodular masses of manganese oxides seen only as "float" in streams draining to the north coast of Cape Vogel. The manganese nodules appear to be shedding from the unconformity surface between Lower Miocene limestone and underlying basic volcanic rocks. This unconformity surface is also marked by a layer of pebbles and boulders of multicoloured jasper. These manganese and siliceous deposits may be former sea bottom precipitates. The chrome reported by Stanley occurs as small crystals of chrome spinel disseminated in basic igneous rocks and forms a significant fraction of the heavy minerals in alluvial and beach sand deposits in the area.

Crystalline basement beneath the 13,000 ft. thick Mio-Pliocene succession of clastic sediments on Cape Vogel is composed of basic submarine lavas. Plio-Pleistocene basic shallow intrusives and extrusives on Cape Vogel have indurated and silicified contacting Upper Miocene sediments but have not mineralized them to any significant extent. The copper mineralization reported by Stanley (1916) may have come from such a contact zone.

North-west from Cape Vogel this structural unit includes many centres of Pleistocene to Recent vulcanism, some of which have coalesced to form large mountain blocks such as Cape Nelson and the Hydrographer Range; others form isolated peaks or hills rising above the coastal plain. This vulcanism is dominantly andesitic, but basaltic and dacitic phases have been noted. The two most recently active volcanoes in this province, namely Waiowa (Gorupu) (Baker, 1946) and Mt. Lamington (Taylor, 1958), ejected fragments of ultramafic rocks which were presumably stripped from the walls of the conduit during the passage of andesitic magma through the ultramafic part of the Papuan Basic Belt in the adjoining Ophiolite Province (Fig.6b). The magma chambers for these andesitic volcanoes probably lie below the basic and ultrabasic rocks of the Ophiolite Province which in this region may have been thrust over metasediments of the adjoining Owen Stanley structural unit.

9. The Solomon Chain

This unit contains eight large elongated island masses aligned north-westerly within a zone about 1200 miles long and 150 miles wide, marginal to the Pacific Ocean. It is limited on the south-west by a lineament expressed over most of its length as a steep marine escarpment and terminated to the south-east at about 162°30'E longitude by a north-easterly aligned deep. The north-western limit of the unit is not marked by known submarine features but for the purpose of this discussion the unit has been extended to include Manus Island.

Most of the large islands of the Chain, except Malaita, are fault-bounded wedges of pre-Miocene metavolcanics intruded by diorite masses, medium-acid porphyries and basic to ultramafic plutonic rocks on and around which Miocene limestone, clastic sediments, tuffs and basic submarine lavas were deposited. The Miocene sediments are extensively faulted and moderately folded along axes parallel to the north-westerly trend of the unit. Large masses and slices of basic and ultrabasic igneous rocks have been intruded or otherwise emplaced along major fault zones on the islands of San Cristobal, Guadalcanal, Santa Isabel, San Jorge and Choiseul, and pyroxenite pebbles have been noted in streams draining to the Bougainville coast south-east of Kieta.

The greater part of the unit falls within the British Solomon Islands Protectorate. Most of the information on geology and mineral occurrences in this part of the unit has been taken from reports of the Geological Survey of the British Solomon Islands (Grover, 1955, 1960), Grover, Pudsey-Dawson and Thompson, 1958) and from papers by Stanton (1961) and Coleman (1962). Many mineral occurrences have been located in the B.S.I.P. part of the Chain; some have been tested by drilling and costeaning but, thus far, none have been successfully developed.

The principal known occurrences of economic minerals are as follows:

1. Gold at Gold Ridge on central Guadalcanal in epithermal manganiferous and pyritic quartz veinlets in andesitic volcanic breccia intruded by diorite and medium-acid porphyry dykes.

2. Pyrite-chalcopyrite-gold mineralization near Betilonga and also in the headwaters of the Sutakiki River on central Guadalcanal. This mineralization occurs in shear zones and siliceous lodes in andesitic agglomerate intruded by diorite.

3. Nickel-enrichments in soil, traces of nickel magnesian silicates (garnierite), disseminated chromite and traces of chrysotile asbestos in the principal areas of ultramafic rocks on several islands.

4. A manganese oxide deposit on Hanesavo Island at the north-western end of the Florida Group. This deposit contains about 10,000 tons with a manganese content of approximately 46% (Phipps, 1960). The manganese oxide is associated with submarine basic lavas, chocolate coloured manganiferous clay and chert; it may be of sedimentary origin.

5. A pyrite body approximately 70 ft. long, 20 ft. wide and of unknown depth on Hanesavo Island in the same geological environment as the manganese oxide deposit just described. Some covellite was reported in the pyrite body (Pudsey-Dawson, 1960) but no copper assays are available.

6. Native copper disseminated through dolerite on Rendova Island over an area 350 ft. long and 150 ft. wide. Two samples yielded 0.50% and 0.10% copper on assay (Grover, 1955).

7. Phosphate deposits on Bellona Island estimated to contain 700,000 tons of phosphate with an average grade of 30.3% P_2O_5 and 4,500,000 tons with an average grade of 22.3% P_2O_5 (White and Warin, 1964).

The north-western part of the Solomon Chain within the Territory of Papua and New Guinea incorporates Bougainville, New Ireland, the Gazelle Peninsula of northern New Britain, and the chain of eroded, extinct volcanic islands north-east of New Ireland, extending from northern Bougainville through Tabar to Mussau Island. The submarine lineaments which define the Solomon Chain on the north-east and south-west do not clearly extend as far west as Manus Island; however, the geology, geographic position and orientation of this island permit its inclusion with the Solomon Chain in this broad structural appraisal. Major faulting which determines the boundaries and, to a large extent, the internal structure of this unit is expressed topographically by (1) the isthmus separating Gazelle Peninsula from the rest of New Britain, (2) the eastern arm of the New Britain Trench, (3) a distinct lineament striking north-westerly through the southern bulge of New Ireland and probably also determining the straight south-western shoreline farther north, (4) the chain of volcanic islands parallel to the north-east coast of New Ireland.

The principal known centres of metallic mineralization in the northern part of the Solomon Chain are in central Bougainville and in the north-western corner of Gazelle Peninsula. In both places the mineralization is associated with diorite, microgranodiorite and medium-acid porphyries either intrusive into or overlain by complex andesitic volcanic piles.

At Kupei, near Kieta on Bougainville, gold occurs in a closely spaced network of quartz stringers in quartz porphyry which contains disseminated bornite and chalcopyrite (Fisher, 1936). Many of the auriferous quartz veins contain a median band of chalcopyrite or bornite, indicating that at least some of the copper mineralization was younger than the quartz. In 1936, Fisher estimated reserves of about 37400 tons of gold ore at Kupei containing between 8 and 10 dwts per ton; the extent of the copper mineralization was not investigated. The boundaries of the mineralized porphyry were not mapped but Fisher noted that the porphyry was probably a large mass and that it had intruded a thick pile of coarse andesitic agglomerate similar in composition. Gold and copper mineralization in the same geological encironment also occurs at Pumkuna about three miles south-south-west of Kupei (Fisher 1936, Thompson 1962b). The mineralogy of these deposits is typical of mesothermal deposition, whereas the association with young pyroclastics suggests an epithermal environment. This apparent anomaly may be explained by a local low geothermal gradient because of volcanic heat or it may indicate mineralization at considerable depth and subsequent emergence and erosion before the present eruptive phase. Small quantities of alluvial gold have been won from streams in other areas in central Bougainville which have not been examined geologically.

Lenses of magnetite-hematite in skarn near Cape Lambert in the north-western part of the Gazelle Peninsula have been investigated by costeaning and diamond drilling (Gardner, 1957). The estimated iron ore reserves in these deposits are a probable 81,000 tons and a further possible 53,000 tons. The iron ore has been emplaced in limestone largely metasomatized to skarn, which is apparently interbedded in a complex pile of andesitic to basaltic flows and pyroclastics intruded and thermally metamorphosed by diorite. Pyrite mineralization also occurs in close association with the magnetite and, at one locality, minor copper mineralization in metasomatized limestone has been recorded. Minor gold mineralization in quartz-pyrite veins in diorite, (Fisher, 1942a) and lead and zinc mineralization (Noakes, 1942) occurs nearby.

The mountainous interior of the Gazelle Peninsula has not been mapped geologically nor has it attracted prospectors. Noakes (1942) considered that this rugged area and the Nakanai and Whiteman Ranges of central New Britain were composed of "slate and phyllite" intruded by granitic rocks and overlian by andesitic agglomerate and breccia. He compared the metamorphic rocks of New Britain with metasediments of the Morobe goldfields and the Prince Alexander Range on the New Guinea mainland and suggested derivation from similar sediments by comparable metamorphic processes. This suggestion was not supported by any petrological data. Rocks in the Cape Lambert area which superficially look like regionally metamorphosed clastic sediments were seen in thin section to be basaltic and andesitic tuffs thermally altered by dioritic intrusives (Dallwitz in Gardner, 1959).

It is tentatively suggested here that the mountainous core of the Gazelle Peninsula, may be a deeply exposed accumulation of pre-Miocene volcanics, tuffaceous sediments, and limestone either intruded by or deposited on diorite and granodiorite. It is also possible that some of the "slate and phyllite" reported by Noakes in the Nakanai and Whiteman Ranges of Central New Britain is thermally metamorphosed tuffaceous sediment.

A very small quantity of alluvial gold in a headwater tributary of the Marambu River in the eastern part of the Gazelle Peninsula is shed from an abundantly pyritic gabbro nearby (Edwards, 1951), and alluvial native copper is derived from basalt in the same area. These occurrences are of little economic significance.

The geology of New Ireland is not well known. Stanley (1923b) discussed some of the main geological features of the island on the basis of information contained in German literature and records referring to observations made during German occupancy before 1914. It is from this reference and from passing unpublished observations and impressions by the authors during short visits and flights over the island that the brief geological account which follows has been compiled.

Physiographically and geologically, New Hanover may be regarded as a north-western extension of New Ireland from which it is separated by shallow seaways and small basalt islands. Thus, New Ireland consists of a straight isthmus, mountainous in places, some 200 miles long and up to 10 miles wide connecting two terminal bulges which contain deeply dissected mountainous cores of intermediate to basic plutonic, hypabyssal and extrusive igneous rocks. This "dumb-bell" configuration may illustrate an important morphological feature of the Solomon Chain which will be discussed later.

The south-western terminal bulge is similar in size, degree of dissection and broad geology to the mountainous core of the Gazelle Peninsula. It consists of a pre-Eocene intermediate to basic igneous complex comprising both intrusive and volcanic rocks. Early Tertiary limestone overlies the complex on the south and south-west, and Mio-Pliocene limestone and marine and terrestrial clastic sediments flank the mountains, except along the western side. The mountain block of the south-western bulge is split medianly by a large north-westerly striking fault which conspicuously controls the principal drainages.

A large part of the narrow isthmus is covered by raised late Tertiary and Quaternary limestone capping and flanking accumulations of basalt. Late Tertiary clastic sediments containing brown coal occur on the west coast near Natakan (Noakes, 1939). The islands between Kavieng and New Hanover are composed of deeply weathered basalt.

New Hanover which forms the north-western terminal bulge of the New Ireland "dumb-bell" has a single, deeply dissected mountain range which rises steeply from the south coast but has a long gently sloping northern flank of deeply dissected alluvial fans. The geology of the main range is not known, but boulders in the dissected alluvial fans are dominantly basalt with some andesite and leucocratic basic to intermediate plutonic rocks.

No economic mineral deposits are known on either New Ireland or New Hanover but the areas have not been prospected extensively. Sub-bauxitic soils containing widely dispersed small gibbsitic accretions occur on deeply weathered surfaces of the dissected alluvial fans on the northern slopes of New Hanover, but deposits of commercial-grade bauxite are not known (Thompson, 1961a). Small magnetite sand concentrations which occur on many of the beaches of Southern New Ireland have not been seriously considered as economic deposits. In a recent examination, Best (pers. comm.) recorded the presence of pyrite-chalcopyrite mineralization in sheared andesite in the Danlilian River draining to the west coast and the Weitin River draining to the south-east coast.

The chain of small but high volcanic islands which lie along a north-westerly line between Mussau and Buka Island marks the Pacific side of the northern part of the Solomon Islands Chain. These islands are of interest in the context of metallic mineralization because of the presence of alluvial gold on Tabar Island. No lodes have been discovered. The island is an eroded volcanic complex but its petrological characteristics are not known. The only available petrological data relating to these islands refers to Feni Island, east of southern New Ireland, where grey or greenish basaltic lavas have been noted (Fisher, 1957) and to Mussau Island at the north-western end of the group where White and Warin (1964) recognized basalts and tuffs.

The geology of Manus Island as known from reconnaissance investigations by Thompson (1952) and Owen (1954) is broadly comparable with that of the Gazelle Peninsula and the terminal bulges of New Ireland. It has a mountainous, deeply dissected nucleus of diorite, flanked on the north and east by Middle Miocene limestone, which is in turn overlain by Upper Miocene and Pliocene gently folded clastic tuffaceous sediments and basaltic volcanics. The western third of the island is composed of basaltic and dacitic interbedded flows and tuffs which dip gently northwards to form a gentle northerly slope, deeply dissected by north-flowing consequent streams. Residual soils on narrow flat-topped interfluves in this terrain are bauxitic and small deposits of high-grade bauxite are formed on a finely vesicular black dacite flow in the volcanic succession. The age of these volcanics is not known but the juvenile dissection suggests that they may be Pleistocene or sub-Recent. The igneous rocks of the mountainous core can only be dated as older than the Middle Miocene limestone which flanks them. They may represent a deeply eroded Lower Miocene, or older, centre of andesitic vulcanism. No metallic mineralization of economic significance is known on Manus Island but many of the diorite and andesite boulders in streams draining from the igneous mountains are abundantly pyritic.

As in other major linear structural units within the New Guinea mobile belt, internal differences in composition and structure along the length of the Solomon Chain are such that further subdivision would be necessary in a more detailed structural analysis of the region. For the purpose of this paper, however, it is sufficient to note that the south-eastern part of the Chain (the B.S.I.P.), the central part (Bougainville Island) and the north-western part (the Gazelle Peninsula, New Ireland and Manus Island) have distinguishing morphological and geological features which reflect different degrees of late Tertiary to Recent tectonism.

In the south-eastern part of the Chain, intense late Tertiary to Recent tectonism, particularly the independent vertical displacement of individual strike-fault slices, is indicated by (1) the presence of ultramafic rocks on many islands; (2) the thick (6000 ft. approx.) Mio-Pliocene carbonate and clastic marine sedimentary succession (Rickwood in Uni. of Syd., 1957) on Malaita Island; and (3) the widespread exposure of pre-Miocene diorite on Guadalcanal Island.

The geological history of Bougainville Island in the central part of the Chain has been dominated by recurrent explosive andesitic vulcanism since Lower Miocene time. In southern Bougainville, this vulcanism was centred over dioritic rocks and coarse andesitic pyroclastics similar to the pre-Miocene igneous rocks on Guadalcanal Island. Neither thick accumulations of Tertiary marine clastic sediments nor large areas of ultramafic rocks have been recorded from this part of the Chain. The age of the intrusives which introduced the copper-gold mineralization on Bougainville Island is not known.

The western part of the Solomon Chain, comprising New Ireland, the Gazelle Peninsula, New Hanover and Manus Island, is characterized by pre-Miocene dioritic plutonic centres now exposed as deeply eroded mountain blocks such as the igneous cores of Manus Island, New Hanover, southern New Ireland and the Gazelle Peninsula, which have been covered or flanked by Tertiary andesitic pyroclastics, shallow-water limestones and clastic sediments. On southern New Ireland, and the Gazelle Peninsula, part of the clastic succession contains brown coal beds suggestive of coastal plain deposition. Between these centres of dioritic intrusion and explosive andesitic vulcanism are linear zones of basalt extrusion which rarely, if ever, built up above sea-level. Such zones of basalt extrusion may, however, be incorporated in fault slices and elevated above sea level but they do not form blocky mountains like the centres of more acid magmatic activity. The"dumb-bell" shape of New Ireland is attributed to nuclei of dioritic intrusives separated by lower and narrower zones of basaltic vulcanism.

The relationship of the plutonic rocks of the Solomon Chain and New Britain to the volcanic agglomerates and breccias overlying them is a problem pertinent to the understanding of the copper-gold mineralization on Bougainville and Guadalcanal. The simplest explanation, viz. young diorite intrusive into an older volcanic complex is difficult to substantiate, because such intrusion would imply very high-level, but anomalously slow, crystallization of magma within a mountainous pile of coarse pyroclastics. Further, the mineralization on Bougainville and Guadalcanal, more mesothermal than epithermal in type, is suggestive of deep emplacement. The following sequence of magmatic events is tentatively suggested for the Bougainville and Guadalcanal centres of medium-acid plutonism and vulcanism.

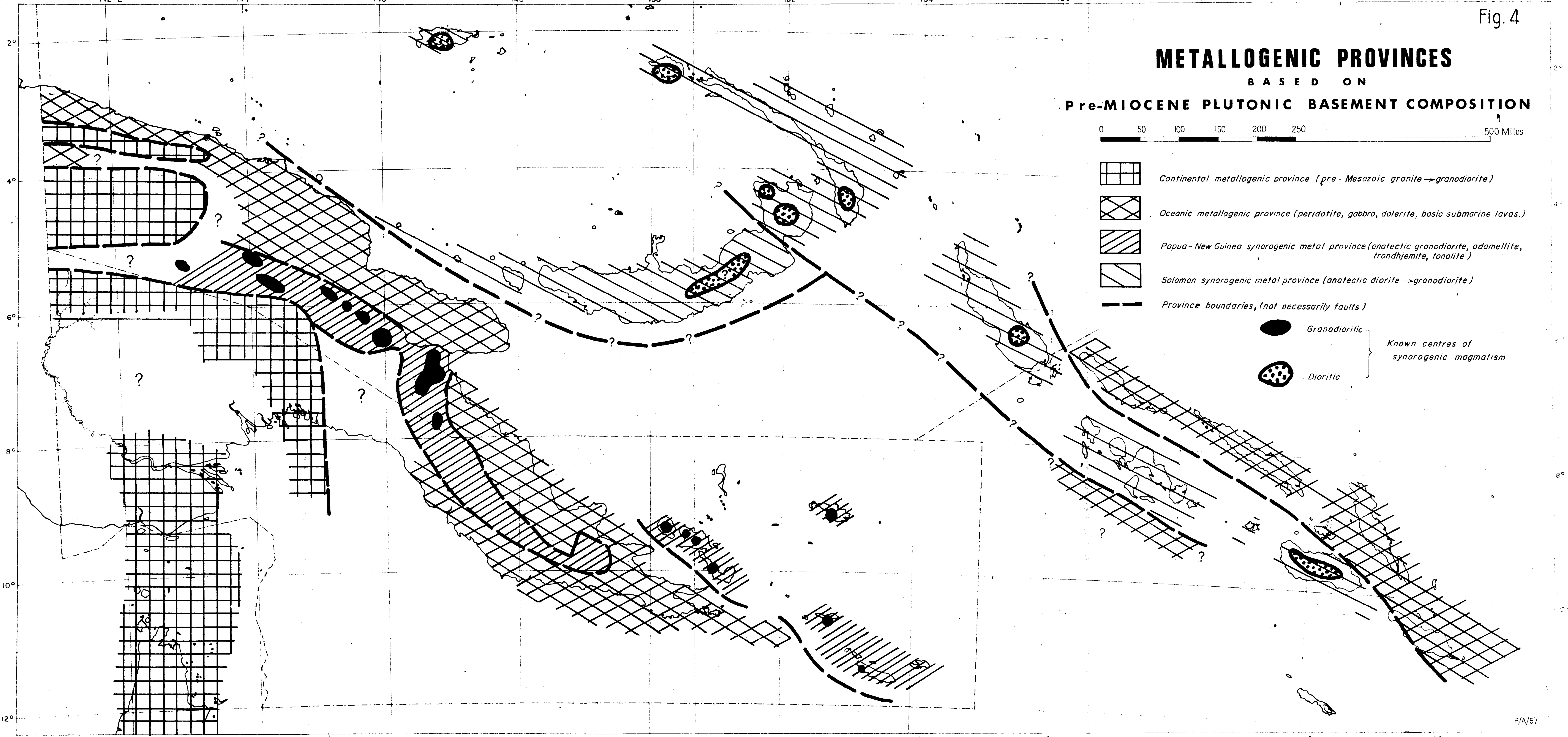
1. Anatectic generation of dioritic magma from metasediments.
2. Intrusion and crystallization of diorite plutons in metasedimentary host formations at depth.
3. Uplift and removal of host metasediments by erosion.
4. Explosive andesitic vulcanism around the margins of the pluton and along fault zones within it.
5. High-level emplacement of porphyry dykes and sills with the introduction of copper-gold mineralization during or immediately after the explosive phase of vulcanism - at least while the basal part of the volcanic agglomerate pile was still warm (to account for the mesothermal mineralization).
6. Erosion and deposition of flanking limestone and clastic sediments.
7. On Bougainville Island - renewed explosive andesitic vulcanism.

Further investigation of this problem both in the field and by absolute dating methods would seem to be justified because the copper-gold mineralization within this province has many features in common with many porphyry-copper deposits of central and south America and the Philippine Islands.

10. Woodlark Island

This isolated island, about 170 miles north-east of the eastern tip of Papua, is of importance in this review because of the widespread gold, silver, lead, zinc, copper, iron and manganese mineralization which occurs within an area of approximately 50 square miles. Alluvial gold mining flourished during the period 1895 to 1914 and nearly every small creek draining west from the Okiduse Range was worked for gold. Good returns were obtained by individual miners and many small gold lodes were uncovered. Attempts to mine these lodes below the high water-table in this region were generally unsuccessful and only the Kulumadau lode was developed underground. At the surface this lode is a pyritic blue pug occupying a shear zone in an andesitic volcanic breccia; it was from 18 to 20 inches wide, traced laterally for 700 ft. and mined on seven levels to 575 ft. (approx.) The grade at the 400 ft. level was about 14 dwts per ton over a width of 6 ft. (Trail, 1961) and the ore contained sphalerite, galena, pyrite and chalcopyrite with quartz and calcite (Edwards, 1954). Recorded production from this mine between 1901 and 1918, when the mine closed, was 76,200 ounces of

Fig. 4



Bureau of Mineral Resources, Geology & Geophysics Dec. 1964

To accompany Record 1965/10

gold from about 128,000 tons of ore. Other lodes in the area with similar mineralogy yielded good returns of gold from enriched oxidised zones but attempts to mine them at depth were not successful.

Trail (1961) considered that Woodlark Island was a deeply eroded Lower Miocene volcanic complex in which several eruptive phases, exposed at different erosional levels, are represented. In bulk composition the vulcanism was essentially andesitic but within the eroded volcanic pile both granitic and gabbroic intrusives have been exposed. Small cupriferous magnetite skarn bodies in a sequence of indurated tuffaceous sediments on Suloga Peninsula were attributed by Trail to metamorphism and metasomatism of limestone beds by intrusive gabbro. The known magnetite bodies in this area contain about 500,000 tons of high-grade magnetite above sea level (Thompson, 1960). Interesting geochemical copper anomalies were obtained from soils over areas of skarn rocks on Suloga Peninsula (Trail, 1961) but subsequent shallow drilling failed to intersect any copper lodes.

Because of its isolation, Woodlark Island cannot be fitted into the structural scheme developed thus far. However, this highly mineralized area has many features in common with the mineralized area near Cape Lambert on the Gazelle Peninsula and compares in some aspects with the mineralized areas of Guadalcanal. Outlying islands such as Manus, New Hanover, St. Matthias Group, and others, built around deeply eroded volcanic complexes, have had a geological history similar to Woodlark Island but no mineralization has been recorded from them.

11. The Coral, Bismarck and Solomon Seas

These expanses of sea conceal large parts of the mobile belt under discussion and this review would not be complete without at least an acknowledgement of their existence as critical gaps in our knowledge. Investigations of the physical properties of the crust below these seas by regional gravity, seismic and possibly heat-flow studies must be undertaken before a comprehensive tectonic analysis of the New Guinea mobile belt can be made.

V. METALLOGENIC PROVINCES (Figures 4, 5 & 6)

The structural units discussed in the preceding section are not clear-cut petrogenic or metallogenic provinces. Their boundaries and distinguishing features are, for the most part, expressions of Pliocene to Recent tectonics related to differential movements, both lateral and vertical, of the Pacific oceanic crustal plate on one side of the mobile belt and the Australian continental crust on the other. The plutonic and hypabyssal intrusives which introduced most of the metallic mineralization within the New Guinea mobile belt are generally older than and not causally connected with the latter-day tectonic regime which determined the structural units. Some epithermal gold mineralization, of Pliocene or younger age, can be attributed to reactivation of underlying older magmatic centres.

The thick accumulations of marine sediments of Miocene and younger age which occupy the Papuan Basin, the Northern New Guinea Basin, the Cape Vogel Basin and smaller sedimentary basins within the Solomon Chain and on New Britain have not been mineralized to any significant extent.

As a basis for establishing regional metallogenic provinces it is necessary to consider the distribution of pre-Miocene plutonic rocks. These can be classified firstly into two categories, thus:

1. Intermediate to acid plutonic rocks ranging from diorite through granodiorite to granite (differentiation products and hybrid igneous rocks outside these petrological limits may occur, locally, within this category).

2. Basic and ultrabasic plutonic rocks ranging in composition from gabbro to peridotite.

The pre-Miocene intermediate to acid plutonic intrusives can be further subdivided, on petrological grounds and regional structural and stratigraphic considerations, into three groups comprising:

1. Pre-Permian "continental" granite and granodiorite intrusive into schists and phyllites of Palaeozoic or older age or overlain by unmetamorphosed sediments of Permian to Eocene age.
2. Synorogenic granodiorite, tonalite, adamellite and related types intrusive into slightly metamorphosed Mesozoic sediments, older schist, phyllite and amphibolite. (Small batholiths and stocks of adamellite and trondhjemite within a basic to ultrabasic igneous environment in the northern part of the Papuan Basic Belt and near Milne Bay may also be members of this group.)
3. Pre-Miocene synorogenic diorite and granodiorite in the Solomon Chain and New Britain. A lower limit for the age of this group has not been established.

This coarse four-fold (one basic and three acidic) subdivision of pre-Miocene plutonic rock types provides a primary metallogenic classification which is meaningful in terms both of plutonic crustal elements and the igneous products of the orogenic development of Palaeozoic and possibly Mesozoic orthogeosynclines within the New Guinea mobile belt.

The continental crust is represented by the pre-Permian granite and granodiorite intrusive into Palaeozoic metasediments. The oceanic crust is represented by the basic to ultrabasic rock types, with their cover of basic submarine lavas and deep-water marine sediments.

The two groups of pre-Miocene medium-acid synorogenic plutonic rocks are distributed in linear zones: the granodioritic group is contained within the eastern half of the Central Highlands Orogenic Belt and the Owen Stanley Metamorphic Belt; the dioritic group falls within the Solomon Chain. The medium-acid plutonic rocks of central New Britain are classified tentatively with the diorites of the Solomon Chain from regional considerations (Fig.4). However, further work may show that they are more closely allied with granodiorites of the New Guinea mainland, as implied on the generalized geological map (Fig.1).

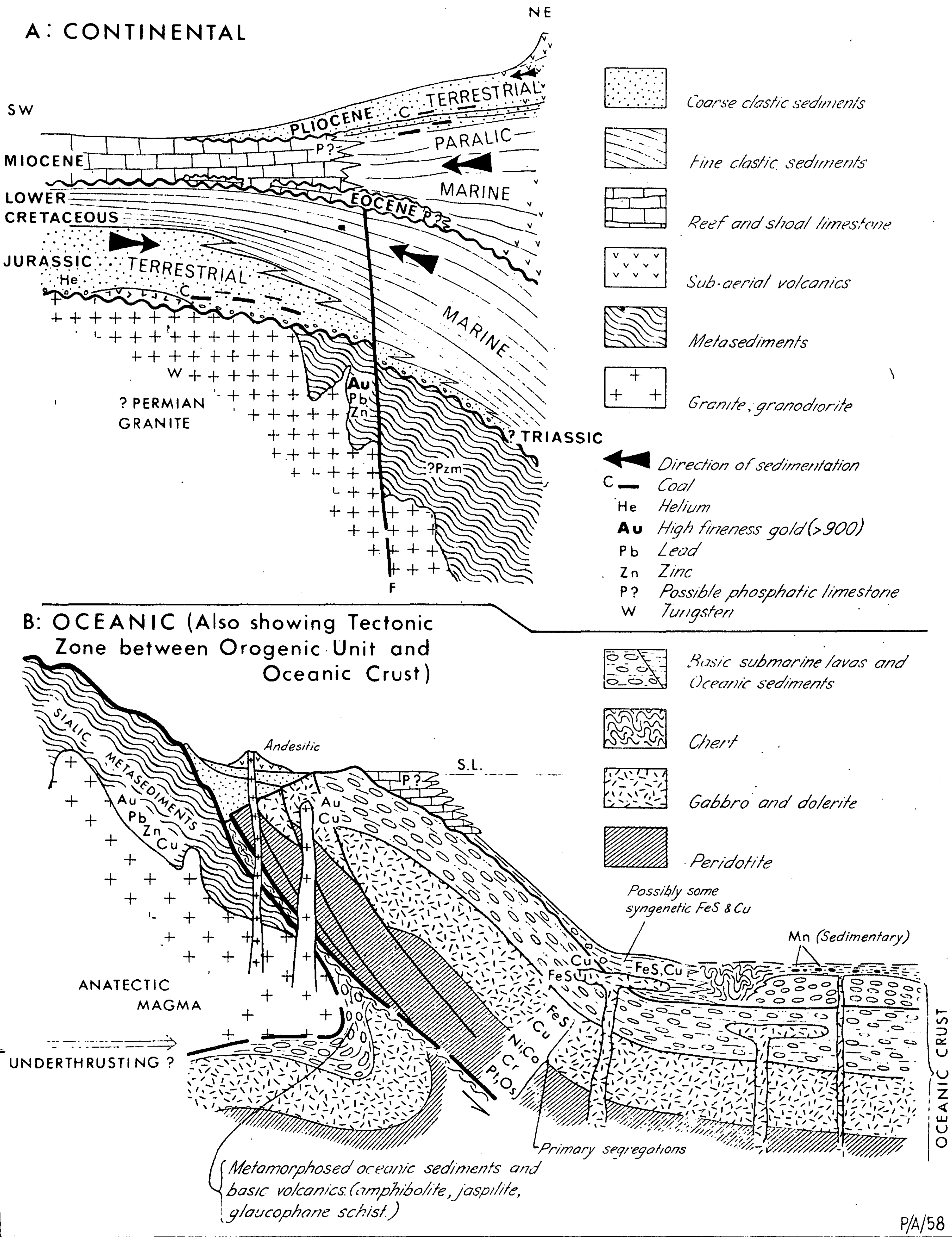
The granodioritic plutons of the gold-producing areas near Kainantu and Wau and in the D'Entrecasteaux Islands and the Louisiade Archipelago may have been derived by anatexis from Palaeozoic geosynclinal sediments, and likewise, the dioritic plutons of the Solomon Chain and the granodiorites of central New Britain may have been derived from pre-Miocene, possibly Mesozoic, geosynclinal sediments. The concept of an anatectic origin for these two groups of medium-acid plutonic rock types stems principally from the seeming inadequacy of other explanations which would depend on some process of differentiation of basic oceanic crust or subcrustal material to produce large volumes of medium-acid magma.

The regional distribution of the suggested major metallogenic provinces is indicated diagrammatically on Figure 4. The boundaries between these provinces are vague. Over most of the region, the province boundaries are either concealed by Miocene to Recent sedimentary cover, or late Tertiary and Quaternary tectonics have caused apparent or actual overlapping. Tectonic mixing of the provinces is most common at the boundaries of the two orogenic provinces and the oceanic province where tectonic activity has been intense. Some anomalous occurrences of medium-acid plutonic rocks in a basic or ultrabasic igneous environment, as in the northern part of the Papuan Basic Belt, may be explained by the thrusting of basic to ultrabasic oceanic crust over Palaeozoic metasediments from which anatectic magmas have been generated subsequently. Andesitic volcanoes which occur at the surface of the basic oceanic province, such as Mt. Lamington, Cape Nelson and Waiowa (Gorupu) in north-eastern Papua, may have been derived through a superficial thrust slice of basic igneous rocks from magma chambers developed in metasediments of more sialic composition. The presence of peridotite boulders in the ejecta from the Mt. Lamington (Taylor, 1958) and Waiowa volcanoes (Baker, 1946) lends some support to this idea.

FIG.5

IDEALIZED CROSS SECTIONS THROUGH PRIMARY METAL PROVINCES

(Not to scale)



P/A/58

Both metallogenic provinces related to synorogenic intrusives could probably be further sub-divided on the following bases:

1. Petrological, mineralogical and geochemical characteristics of different centres of magma generation.

2. Petrological and mineralogical characteristics related to level of emplacement or level of exposure of individual intrusive bodies.

3. Age of intrusive emplacement as established by absolute dating methods.

Information currently available on these aspects is too sparse and imprecise to warrant any attempt to subdivide the basic four-fold classification shown on Figure 4.

The mineralization characteristics of the four proposed metallogenic provinces which at this stage seem distinctive, cannot be presented very convincingly because this analysis has, of necessity, been moulded around information available from many varied sources and not from any specifically designed investigation. However, features of mineralization thought to be distinctive of each province will be discussed briefly. Mineralization in the primary continental and oceanic provinces which probably pre-date the New Guinea mobile belt are considered firstly. The two synorogenic geosynclines within the mobile belt, are discussed later.

1. Pre-Mesozoic Continental Metallogenic Province (granite and granodiorite) (Fig. 5a)

No important lode deposits can be definitely attributed to this province. That part of the province in the western half of the Central Highlands Orogenic Belt, including the Thurnwald and Hunstein Ranges, has not been closely prospected. Gold with a fineness in excess of 900 such as that derived from basal conglomerates on granitic basement in the Prince Alexander Range (Fisher, 1945) may be characteristic of this province. The fineness of gold in Torres Straits islands, also within this province, is not known. Lead-zinc sulphide mineralization in (?) Palaeozoic metamorphics at Efontera near Kainantu, if genetically related to pre-Permian intrusives (McMillan and Malone, 1960), would be included in this province. Wolfram, which occurs on Torres Straits islands, has not been recorded in New Guinea.

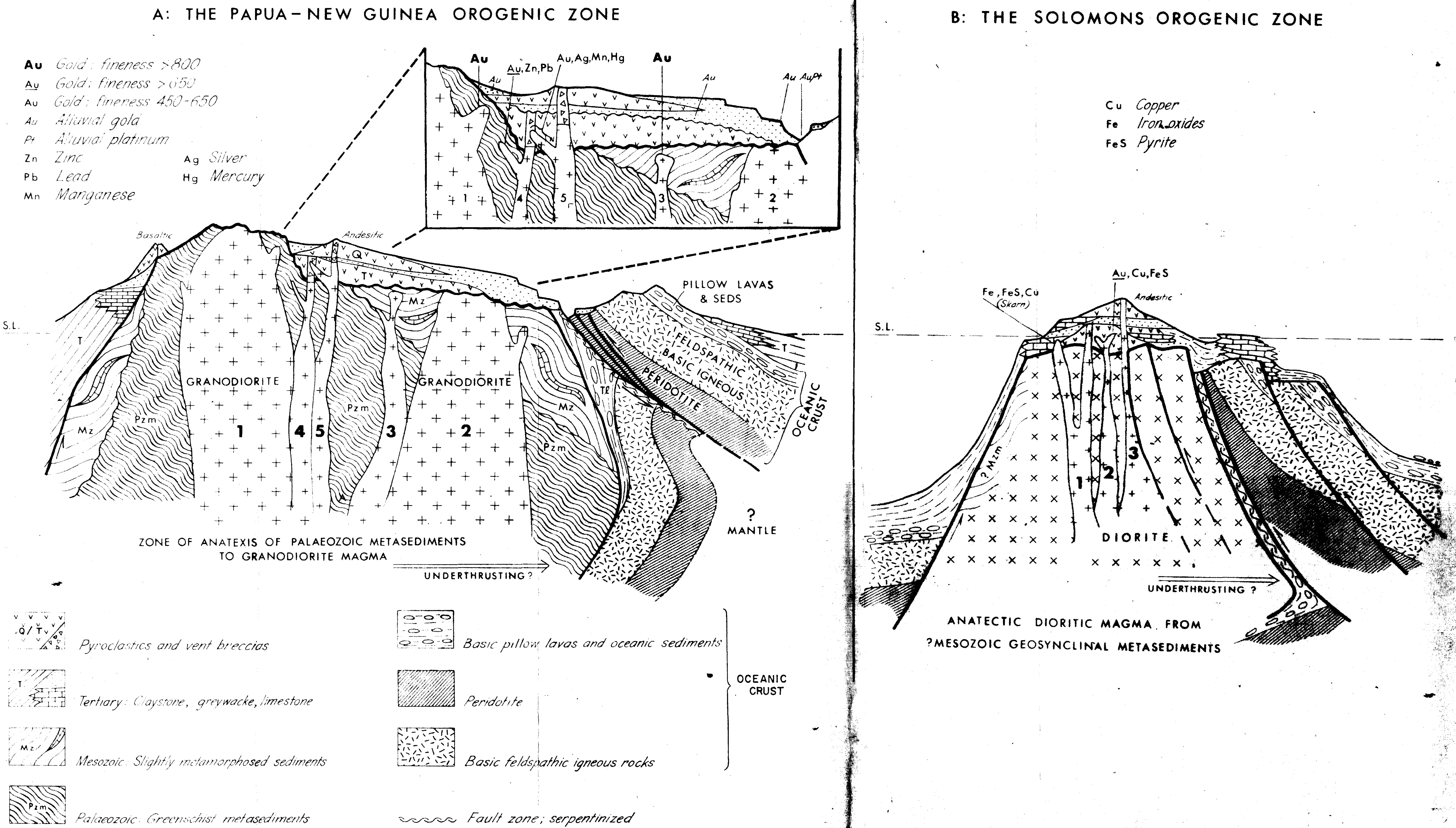
2. Oceanic Metallogenic Province (peridotite, gabbro, dolerite, submarine basic lavas) (Fig. 5b)

Dispersed primary nickel, cobalt, chromium and platinoid metals exclusively characterize the peridotites of this province. These metals are virtually absent from the continental granites and the synorogenic granodiorite and diorite suites.

The nickel and cobalt traces which are intimately bonded in the crystal lattices of olivine and pyroxene minerals are released when the peridotites are decomposed by humid tropical weathering. Once released into the residual ferruginous soils these metals may be flushed away or concentrated into zones low in the soil profile; some nickel may also be deposited as garnierite in fractures in the underlying rocks. The chromium occurs as disseminated small chrome spinel crystals and more rarely as massive chromite lenses. Massive chromite specimens, reputedly from serpentinite lenses in the northern part of the Central Highlands Orogenic Belt, have been sighted but their precise locality is not known. Chrome spinel is concentrated in many small beach deposits on the north coast of the New Guinea mainland, particularly between Vanimo and the West Irian border, south-east of Salamaua and on the north coast of Cape Vogel. No lodes containing the platinoid metals are known, but either platinum or osmiridium, or both, have been recovered from most alluvial gold deposits in streams which traverse ultramafic rocks. The platinoid metals are probably sparsely disseminated throughout the ultramafic rocks.

FIG. 6

IDEALIZED CROSS SECTIONS THROUGH SYNOROGENIC METAL PROVINCES
(Not to scale)



Chalcopyrite and native copper in minor quantities have been reported in association with gabbroic intrusives at several localities within this province. The cupriferous sulphide mineralization associated with gabbro intrusive into early Tertiary dark shale in the Astrolabe Mineral Field near Port Moresby is generally attributed to the gabbro. However, it is possible that some of the metal content of this deposit may be of syngenetic sedimentary origin, having been concentrated in dark marine clays uncontaminated by coarse terrigenous clastic sediments.

Both alluvial and lode gold has been recorded from within the oceanic metallogenic province. In the northern part of the Papuan Basic Belt (Dow and Davies, 1964) gold appears to be genetically associated with intrusives of adamellite composition which may be either differentiates of basic magma of the oceanic province or intruded from magma reservoirs in underlying sialic metasediments. Gold mineralization has not been recorded in the non-feldspathic, ultramafic rocks of the oceanic province.

Veinlets of chrysotile asbestos in serpentinite have been noted at several localities, but no concentrations of commercial grade asbestos are known.

Lead and silver mineralization is not known in this province and zinc sulphides have been recorded at one locality only, in association with the copper-bearing sulphide orebodies near Port Moresby. The absence of lead and silver may be a distinguishing feature of the province.

Manganese oxide deposits near Port Moresby, on Cape Vogel, and possibly also those of Hanesavo Island in the Solomon Chain, were deposited on the deep sea floor in an environment not subjected to vigorous clastic sedimentation, which also favoured the accumulation of siliceous oozes and chocolate coloured manganiferous clays. In the cases cited, penecontemporaneous submarine extrusion of basic lavas occurred nearby. The oceanic province, by virtue of its higher density and its inability to generate light density anatectic magma at depth, has no inherent orogenic motivation. It therefore remained at deep sea levels for longer periods than the more sialic elements and accordingly was more likely to accumulate manganese oxides and other deep-sea precipitates. Exhalations from the basic submarine lavas or soluble manganese compounds draining off adjoining terrain of ultramafic rocks may have some genetic connections with the manganese deposits. The margins of the oceanic province have become emergent because of contact with the orogenic sialic elements; either by compression against them or by underthrusting, in which case isostatic adjustment or intrusion of anatectic magma generated in the underthrust sial may result in emergence of the oceanic crust.

Dark shales which accumulate slowly on the ocean floor away from orogenic land may be favourable hosts of sedimentary syngenetic mineralization. Such sediments are not uncommon in early Tertiary successions in many parts of the oceanic province.

3. <u>Papua-New Guinea Synorogenic Metal Province (Fig. 6a)</u>

The principal goldfields in Papua-New Guinea, namely Kainantu, Wau-Bulolo, Misima Island and Woodlark Island, lie within this province. Many streams which drain other parts of the province carry alluvial gold but few lodes have been located; in some cases alluvial gold outside the main goldfields has not yet been identified with any known intrusives.

The most striking feature of the main gold-bearing areas is their polycyclic granodioritic magmatic history, commencing in the Central Highlands in early Mesozoic time, and in the Wau-Bulolo area in Upper Cretaceous or early Tertiary time. The intrusives of this early phase of activity are now exposed as large batholiths in metasediments of the greenschist facies. A late Tertiary (Mio-Pliocene) phase of magmatic activity in both the Central Highlands and the Wau-Bulolo area is expressed by the many medium-acid porphyries, differing slightly in age and composition, emplaced near the margins of the earlier granodiorites with which they are probably cogenetic. In both of the areas, andesitic volcanic breccias and rhyolitic flows represent a Plio-Pleistocene phase of magmatic reactivation and, in some instances, still younger high-level porphyries have intruded these volcanics. Most of the gold lodes exploited in the Wau-Edie Creek area were introduced into fractures in schist and phyllite or, in the case of the youngest intrusives, into andesitic agglomerate and breccia. The lodes associated with the youngest intrusives are distinctly epithermal, being characterized by a manganocalcite or drusy quartz gangue, gold of low fineness (450-650 approx.), a high content of silver not combined with gold, and only partly filled fractures. Such lodes are readily oxidised within the range of percolating groundwaters to manganese wad usually enriched in gold. In some places, small but richly gold-bearing quartz veinlets, or gold alone, has permeated volcanic breccia as in the Upper Ridges area near Wau, or hydrothermally altered schist as at Edie Creek. Selective surface mining or ground-sluicing of such deposits has been highly profitable but economic exploitation below the surface by adit or shaft mining would not be possible. Open-cast mining of this type of deposit on a low-grade large-tonnage basis could possibly be economic but the high cost of an adequate sampling programme could probably only be justified by a rise in the price of gold. The manganocalcite-quartz-gold lodes associated with the youngest intrusives become more quartzose and pyritic in depth and in the deeper levels (400-600 ft. below the surface), the ore is distinctly pyritic, commonly contains galena and marmatite, and the gold content drops. Cinnabar, which is found in alluvial concentrates in the Edie Creek area, may come partly from disseminations in (?) Pleistocene volcanic agglomerate, but is a prominent constituent also of the Enterprise orebody at the western end of the Edie Creek line of lodes.

In the Kainantu area, the lodes associated with Mio-Pliocene intrusives are quartzose, and pyritic, fissure fillings and contact deposits. An unusual type of epithermal gold deposit at Aifunka is associated with a skarn bed in a (?) Pliocene andesitic to rhyolitic volcanic succession; pyrite and minor chalcopyrite occur in the volcanic sequence, and alluvial native copper has been reported in gold-bearing alluvials nearby.

The older porphyries have introduced gold into schists and phyllites in the Wau area as silicified contact deposits and fissure fillings characterised by pyrite, and marmatite and, rarely, galena. Gold and pyrite occurs in the chilled margins of these intrusives as well as in the contacting metasediments. Mio-Pliocene medium-acid sills and dykes in the Kainantu area have also introduced gold and pyrite as silicified contact deposits. At Mt. Victor, near Kainantu, a gold-enriched limonitic quartzose orebody on a contact between Pliocene andesite porphyry and (?) Cretaceous granodiorite gives way at shallow depth to a massive pyritic body with low gold values (Dow, 1961 (b)).

In both the Wau-Bulolo and Kainantu areas, much gold has been shed into alluvial deposits from the silicified margins of the early granodiorite batholithic masses but no significant lodes have been located in these contact zones. Gold from these older intrusives usually has a fineness in excess of 800 (Fisher, 1945).

Gold mineralization on Misima Island occurs principally in quartzose fissure and shear fillings in greenschist near intrusive felspar porphyry of probable early Tertiary age. Gold also occurs along porphyry contact zones and in sheared and brecciated zones within the porphyries. Pyrite, galena, honey-coloured sphalerite and minor chalcopyrite occur at the surface in the Quartz Mountain area and in the lower levels of the Umuna Lode (de Keyser, 1961). The common gangue mineral is quartz, but calcite and barite also occur. The fineness of the gold on Misima Island is not precisely known.

The mineralization on Misima Island has less associated manganese and silver than mineralization in the Wau area, but sulphides of iron, lead, zinc and copper are more abundant. Also, the zinc sulphide on Misima Island is light-coloured while that at Wau is black, iron-rich, marmatite. Miocene pyroclastics on Misima Island were deposited after the intrusion of the mineralizing porphyries and, as far as is known, volcanic agglomerates or breccias did not serve as hosts for mineralization, as at Wau and Kainantu. These factors suggest that the porphyries on Misima Island were more deeply emplaced or are more deeply exposed than the mineralizing (?) Plio-Pleistocene porphyries in the Wau area.

In general, the gold mineralization on Woodlark may be compared, in mineralogy, level of emplacement and time of emplacement, with the Miocene to Pleistocene mineralization in the Wau area. Very few precise data are available on the mineralogy and gold fineness of the many known lodes on Woodlark Island. However, such information as is available suggests that sulphide mineralization is more widespread than in the Wau area and gold fineness is higher than that of gold associated with the youngest porphyries of Wau. Andesitic pyroclastics are the favoured host rocks for mineralization on Woodlark Island, and pre-Miocene metasediments are lacking. The iron-copper mineralization at Suloga Point on Woodlark Island is in a metasomatised limestone bed within a volcanic pile invaded by gabbro, and is in no way related to the widespread gold mineralization on the island which Trail (1961) has attributed to dykes of porphyry invading Upper Miocene or Pliocene pyroclastics.

The mineralization of the Papua-New Guinea synorogenic province is characterized by epithermal deposition of gold, silver, manganese, lead, zinc and rarely copper. The parent granodioritic magma of the intrusives and mineralization of this province has been sporadically active from Jurassic to (?) Pleistocene time. It is suggested that this magma was, and possibly still is being, generated by the anatexis of Palaeozoic orthogeosynclinal sediments.

4. <u>Solomon Synorogenic Metal Province (Fig. 6b)</u>

This province includes that large part of the Solomon Chain with dioritic plutonic basement overlain by pre-Miocene andesitic agglomerate and breccia. It excludes the islands on the north-eastern, Pacific, side of the British Solomon Islands Protectorate characterized by basic and ultrabasic plutonic rocks, basic metavolcanics (amphibolite), basic submarine lavas and thick sequences of Mio-Pliocene limestone and clastic sediments. These islands are included in the oceanic metallogenic province previously described.

From the meagre information available, central and western New Britain is more closely allied petrogenetically and in Tertiary depositional history, if not metallogenically, to the dioritic and andesitic part of the Solomon Chain than to the mainland part of the Northern New Guinea Arc with which it appears to have structural continuity at the present time. It may, in fact, constitute a separate structural and petrogenic/metallogenic province but the available information is too sketchy to propose this with any confidence.

It was suggested earlier that the magmatic centres which supplied the dioritic plutonic rocks and Miocene to Recent andesitic pyroclastics of this province were of anatectic derivation from sediments of possible Mesozoic age. This concept is difficult to substantiate because of the general deficiency of outcropping metasediments within the structural Solomon Chain. Those recorded are mostly amphibolitic and are associated with the ultrabasic and basic rocks of the oceanic province; they are probably metamorphosed basic tuffs and tuffaceous sediments. However, it does seem certain that orogeny over a large part of the Solomon Chain is related to both periodic generation of dioritic magma and to faulting due to physical contact between differentially moving sialic crustal material and the oceanic "Pacific Plate".

This province may be compared in a general way with the mainland orogenic province and both can be contrasted strongly, petrologically and mineralogically, with the oceanic province. The Solomons metallogenic province differs from the mainland orogenic metal province in two main features, namely:

1. Composition of plutonic basement rocks. The oldest plutonic rocks in the Solomon province are dioritic; those of the mainland orogenic province are granodioritic. However, the younger mineralizing hypabyssal intrusives on Bougainville are quartz porphyries, at least as acid as most of the mineralizing porphyries on the mainland, if not more so. The difference in average composition of the plutonic basement rocks could be attributed to the more basic composition of sediments (basaltic tuffs and greywacke) from which the Solomons diorites were derived, or alternatively it may be indicative of the generation of magma by some process other than anatexis of sediments, viz. differentiation of oceanic crustal or sub-crustal material.

2. The close association of copper and gold on Bougainville and Guadalcanal has no known counterpart in the mainland orogenic province. This may be a compositional feature related to the more basic dioritic magmatic environment or it may reflect deeper emplacement or even a regional rise in crustal temperature, and near-surface fluid magma chambers.

Known mineralization in the Solomons orogenic province is biassed heavily towards copper. Lead, zinc, silver are not common and calcite and manganocalcite as gangue minerals are not known. Most of the known copper-gold lodes on Bougainville and Guadalcanal are not clearly defined fracture fillings but rather fine stockworks or intergranular disseminations. This type of deposition offers some encouragement that porphyry-type copper deposits may be present; search for these could be more actively pursued. Such search should include all areas known or suspected to contain pre-Miocene diorite and andesitic pyroclastics intruded by Miocene or younger quartz porphyries; this would include Guadalcanal, Bougainville, the Gazelle Peninsula, southern New Ireland, New Hanover and Manus Island. The pre-Miocene intrusives and extrusives in central New Britain, about which little is known, may also warrant investigation for disseminated copper mineralization. Likewise, the New Georgia Group of islands, between Bougainville and Guadalcanal, seemingly lying within the Solomons orogenic province, warrant at least reconnaissance geochemical prospecting for copper. The native copper in association with gabbro on Rendova Island in the New Georgia Group (Grover, 1955) seems to be more closely related to mineralization of the oceanic type than with that of orogenic units, and may be indicative of oceanic crustal basement on the south-western flank of the British Solomon Islands Protectorate part of Solomons orogenic province.

The thick, widespread, loosely compacted apron deposits of the contemporary andesitic volcanic complexes on Bougainville contain a very large amount of dispersed titaniferous magnetite and ilmenite which is readily concentrated and transported to coastal plain deposits by the deeply entrenched, swiftly flowing, consequent drainage system (Thompson, 1961). Further concentration is being effected by the vigorous wave action and long-shore currents which characterize the Bougainville coastline.

VI. GENERAL DISCUSSION AND CONCLUSIONS

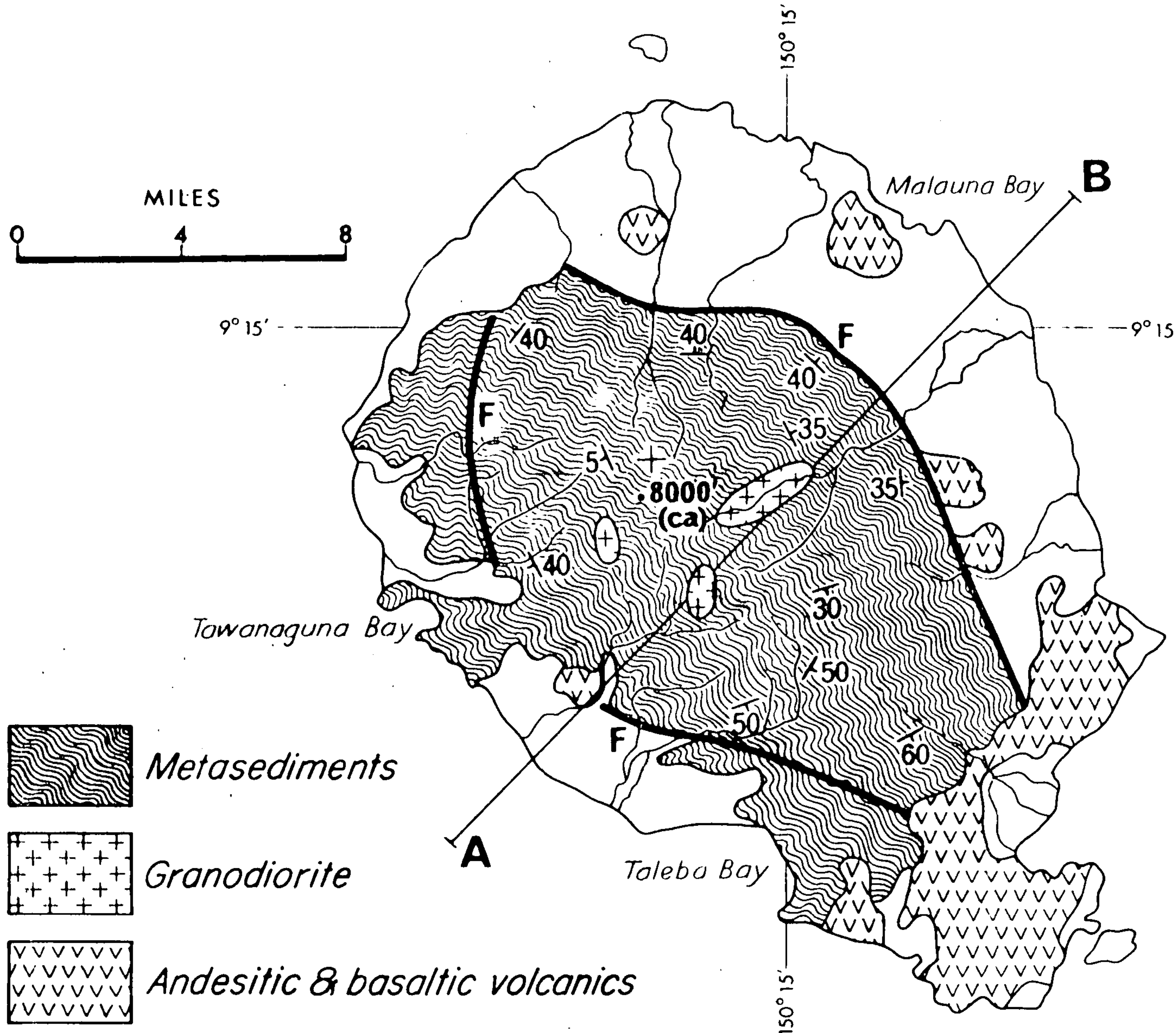
The following general inferences can be made from the material presented in the earlier sections:

1. Metallic mineralization is virtually absent from the exposed parts of the thick Lower Miocene to Recent accumulations of marine clastic sediments and the few, mostly basic, igneous rocks intrusive into them.

2. Known hydrothermal gold, lead, zinc and copper mineralization occurs principally within orogenic zones initiated in pre-Miocene time and persistent as essentially emergent regions characterized superficially by andesitic vulcanism and internally by granodioritic to dioritic plutonism. Within these zones, synorogenic intrusive activity has been located above centres of anatectic magma generation from which magma has risen periodically from

Fig. 7

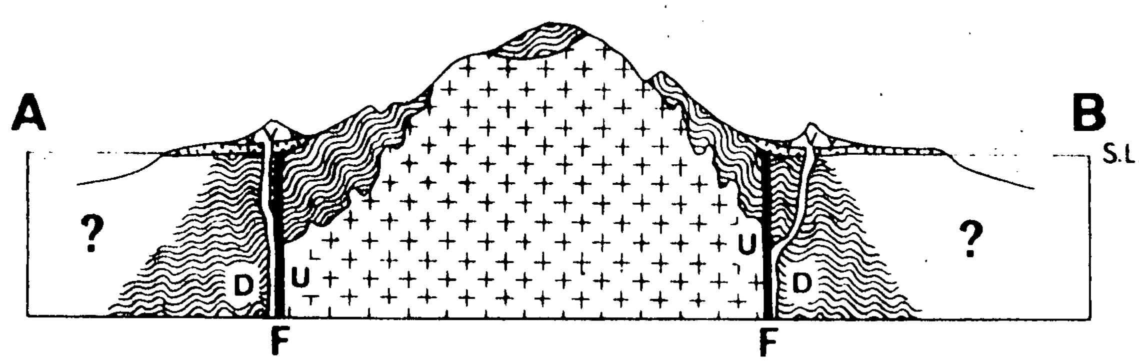
GOODENOUGH ISLAND
ILLUSTRATING DOMAL STRUCTURE CAUSED BY EMPLACEMENT OF PLUTON



Plan modified after Davies and Ives (in press)

DIAGRAMMATIC SECTION

Scale: $\frac{V}{H} = 2$



Cretaceous to Recent time. Most of the known hydrothermal mineralization can be attributed to late Tertiary minor intrusions of intermediate porphyries. The more deeply emplaced holocrystalline intrusives and the extrusives are rarely genetically associated with significant mineralization, except in the Wau-Edie Creek area. However, volcanic breccias preserved in conduits or deeply buried in large pyroclastic piles have served as favourable host formations for the deposition of mineralizing exhalations from later dykes and sills which have crystallized before reaching the surface. Fringing limestones which accrete on the flanks of volcanic islands during periods of volcanic quiescence and later become deeply incorporated in a volcanic pile by further eruptions, are susceptible to iron metasomatism and copper-iron sulphide mineralization by later intrusives.

3. The Central Highlands Orogenic Belt and the Owen Stanley Metamorphic Belt together constitute a pre-Miocene orogenic zone in essentially sialic crustal material which has been transversely disrupted at several places (Fig. 2) by left-lateral strike slip displacements probably related to north-westerly movement of the Pacific oceanic plate relative to the Australian continental block. Laterally directed crustal displacements and vertically directed orogenic tendencies in the eastern part of the orogenic zone appear to have progressed independently, even in detached parts of the zone. The orogenic tendencies were probably motivated by the anatectic generation of low density magma which rose diapirically,as typified by the domal granite-cored structure of Goodenough Island, whereas the lateral forces originated from the physical conflicts between continental and oceanic crust. This segmented zone of crystalline rocks has been a positive structural element of long standing and may represent the ultimate orogenic phase of a Palaeozoic orthogeosyncline.

The application of the concept of orogenic geosynclinal development in this region is quite speculative and must necessarily remain so because of the tectonic complexity, the masking of sedimentary lithofacies by metamorphism, and the apparent subsequent segmentation of the orogenic zone. Absolute dating studies could throw some light on this aspect.

4. An intrusive habit for synorogenic anatectic magmas is suggested by the domal structures on Goodenough and Fergusson Island in the D'Entrecasteaux Group (Davies & Ives, in press). These forms are strongly indicative of emplacement of magma by diapirism; here the shape of the intrusives has not been modified by subsequent intrusion around the margins as seems to have been the case in the gold-producing areas of Wau, Kainantu and Misima Island. The absence of hydrothermal gold mineralization of any significance in the D'Entrecasteaux Islands may reflect both a single period of intrusion and also crystallization of magma at much greater depth than at Wau, Kainantu, Misima Island and Woodlark Island. The faults around the periphery of the domal structures on Goodenough and Fergusson Islands suggest that the granitic cores had, and possibly still have, emergent tendencies even in the solid state, motivated by buoyancy or pressure from deep magma chambers.

It is conceivable that a steep domal island such as Goodenough Island (Fig. 5) with a core of anatectic granite, granodiorite or diorite (dependent on composition of source materials) and a metamorphic shell might, through prolonged processes of erosion, isostatic adjustments and, possibly, magmatic pressures directed from below, become an island composed entirely of plutonic rock. Such a model may explain the apparently anomalous occurrences of plutonic intrusives covered or flanked by pyroclastics which are so commonly environments of mineralization on Woodlark, Guadalcanal and Bougainville Islands.

5. The Solomon Chain is at the present time a strong positive structural element relative to the sea-floor. The many occurrences of Lower Miocene shoal limestones suggest that parts of the Chain were nearly emergent in Lower Miocene time. Metamorphic rocks, which occur principally in the south-eastern part of the Chain, are mostly amphibolites derived from volcanic rocks of early Tertiary or older age. Both structural and petrological characteristics of the Solomon Chain suggest a complex interplay of vertically directed orogenic movements motivated by the rise of dioritic magma and independent tectonic movements of minor sialic elements against the Pacific oceanic plate. The vertically directed orogenic forces motivated by rising dioritic magma appear to have been initiated long before the north-westerly striking fault system which dominates the Chain; in southern New ireland a major fault of this system cuts across one of the older intrusive centres which is flanked by sediments and covered by volcanic agglomerate and breccia. Recent andesitic vulcanism may derive from reactivation of much older magma chambers and find its way to the surface along superimposed zones of tectonic weakness.

6. The known centres of copper-gold mineralization in the Solomon Chain are associated with centres of multiple medium-acid magma injection which have yielded plutonic, hypabyssal and explosively effusive rocks representative of successively younger activity. As in the Central Highlands-Owen Stanley orogenic zone, the mineralization seems to have been introduced preferentially by acid intrusives of shallow emplacement. Fractured diorite and andesitic pyroclastics are favoured host formations for mineralization within this region.

7. The origin and localization of the pre-Miocene dioritic intrusives within the Solomon Chain is a subject for conjecture. They may lie along the axis of a Mesozoic orthogeosyncline - but this is difficult to substantiate because of the apparent deficiency in metasediments in the region, and the abundance of meta-volcanics and basic to ultrabasic intrusives. It may be that the dioritic plutonic masses represent the sialic stumps of a geosyncline which once occupied a position adjacent to and on the Pacific side of the Central Highlands - Owen Stanley orogenic zone. Orogenic development of such a geosyncline and concomitant segmentation by superimposed transverse faults with large left-lateral displacements could have resulted in the separation and north-easterly migration of centres of synorogenic plutonism (such as Goodenough Island may be). With continuing north-easterly migration, emergence and erosion, the plutonic stumps, with very little, if any metasediment still attached, would reach a limit to north-easterly migration at the edge of the Pacific plate (the "Andesite Line") and there become aligned along the Solomon Chain by relative lateral movement of the Pacific Plate in a north-westerly direction as suggested by Weeks (1959).

8. Except for manganese oxide deposits near Port Moresby and on Cape Vogel, all known metallic mineralization within the New Guinea mobile belt appears to have been introduced by nearby intrusive igneous rocks. There is no strong evidence to suggest a sedimentary syngenetic origin for any metallic mineralization, other than sea-floor deposits of manganese oxides. However the most likely environment for syngenetic sedimentary metal accumulations would be in the fine dark sediments deposited slowly on the ocean floor and later buried beneath the more rapidly deposited, generally coarser, sediments which constitute the bulk of a geosynclinal sedimentary pile.

9. The basic intrusives which so often occur in deep-water dark shales in the lower parts of geosynclinal sedimentary accumulations (as in the Port Moresby region and also on the Huon Peninsula)

need not necessarily be identified with an early intrusive phase of geosynclinal orogenesis, as generally accepted. It seems more likely that they are merely an expression of a normal capacity of oceanic crust or subcrust to generate basic magma which in regions far removed from orogenic land would be intruded as thick dolerite and gabbro sills in submarine basalt piles to produce a basic igneous complex such as the Ophiolite Province east of longitude 149°30'E on the Papuan mainland. The basic intrusives which may appear to have played a part in the orogenic cycle have probably been brought to the surface by tectonic movements associated with the diapiric rise of medium-acid magma generated by anatexis of younger terrigenous sediments, or, by the anataxis of both non-terrigenous oceanic sediments and basic intrusives and submarine extrusives which are often present beneath thick geosynclinal accummulation of terreigenous clastic sediment.

We have pointed out earlier that the present-day structural configuration of the New Guinea mobile belt is largely the product of Cainozoic earth movements with a strong lateral component related to north-westerly movement of the oceanic crust of the Pacific Ocean relative to the Australian continent; that is, roughly parallel to the north-eastern continental margin. The early effects of this Cainozoic torsional stress relationship between oceanic and continental crust was the separation of two linear, orogenically well developed, orthogeosynclinal axes from the continental margin. The inner orogenic axis may have been part of the pre-Permian Palaeozoic Tasman Geosyncline, and the outer one the trough of a Permian to Upper Jurassic orthogeosyncline. One of us (J.E.T.) is of the opinion that the separation from the continent was effected by dilatational rifting hinged in the region of the Central Highlands of New Guinea (where the northern continental margin seems to assume an easterly trend) commencing in Upper Cretaceous or Paleocene time. The separation of an outer Mesozoic axis from the continent probably preceded the separation of the Palaeozoic axis and thereafter the two axes were translated north-easterly independently. The method of north-easterly progression of these sialic elements was initially by left-lateral strike-slip displacement along transverse, north-north-easterly striking, faults such as that which displaces the Owen Stanley Metamorphic Belt across the south-western end of the Musa Valley (see Figure 2). Once segmentation of the linear crystalline sialic zones was achieved in this manner the sialic segments moved independently within the oceanic crust. Evidence of such movement of sialic segments is inferred from the oceanic crustal rocks (peridotites, gabbros, basic submarine lavas, and oceanic sediments) which have been faulted or otherwise raised above sea level on the oceanic side of the crystalline sialic components within the New Guinea mobile belt. The best example of this situation is the Papuan Basic Belt which he interprets as a north-easterly dipping sheet of oceanic crust two to three miles thick, and exposed down to the peridotite (dunite) layer by underthrusting of the front of the sialic Owen Stanley Metamorphic Belt. Throughout their north-easterly progression across the mobile zone, the segments of (?) Palaeozoic and (?) Mesozoic metamorphosed geosynclines maintained inherent orogenic tendencies motivated mainly by anatectic generation of low density magma from metasediments and the diapiric rise of that magma towards the surface. This was augmented by buoyancy of sialic metasediments surrounded by higher density oceanic crust. It would seem that the dioritic cores of those islands of the Solomon Chain included in the Solomon synorogenic metal province (Figure 4) are discrete plutonic "stumps" derived from the anatexis of Mesozoic geosynclinal metasediments which have survived the passage across the mobile zone from the continental margin; continuing erosion consequent on the inherent orogenic tendencies could account for the virtual absence of pre-Tertiary sialic metasediments in the Solomon Chain.

The (?) Palaeozoic orthogeosynclinal axial zone is now represented by the Papua-New Guinea synorogenic metal province (Fig.4); it is characterized by granodioritic intrusives into metasediments of greenschist and higher metamorphic facies. The tendency of this zone of crystalline sialic rocks to "migrate" north-easterly is evidenced by the apparent displacement of segments from the mainland to the position of the D'Entrecasteaux Islands. Here also, the diapiric intrusive habit of the anatectic granodioritic magma is illustrated by the domal granodiorite cored structure of Goodenough Island - with further emergence this island would be eroded down to an igneous "stump" such as the granodiorite batholith in the core of Woodlark Island and the dioritic core of Guadalcanal.

If this concept of migrating orogenic axes of geosynclines is to be accepted then some explanation must be found for the continuance of anatectic magma development long after anatexis in geosynclines of the same age, still incorporated in the continent, had ceased (e.g. the Bowen Basin and other intermontane basins of the Tasman Geosyncline). It may be that there is a regional rise in iso-geotherms in the direction of the Pacific margin culminating at the "Andesite Line", or, the continual tendency of the leading edge of sial segments to elevate the oceanic crust by under-thrusting or imbricating it may cause sufficient local elevation of iso-geotherms to keep the anatectic processes operative. A corollary of this would be that after passage across the mobile belt, when all metasediments had been either shed by erosion or assimilated by anatexis, a recycling of anatectic intrusives would result in a gradual change in magma composition (including metal content) due to loss of the more volatile components from the system. This may be the explanation for the differences between the igneous petrology and mineralization of the Solomon synorogenic province and that of the Papua-New Guinea synorogenic province.

Thick Miocene and younger sedimentary accumulations in the New Guinea mobile belt although intensely deformed have for the most part been deposited over belts of non-orogenic, basic, oceanic crust and accordingly have not been invaded by anatectic medium-acid magmas which seem to have a greater mineralizing capacity than the gabbroic magmas generated in oceanic crust.

Of the four primary metallogenic provinces nominated, the two synorogenic zones offer by far the best prospects for further gold and base-metal discoveries. The Papua-New Guinea synorogenic province has a long history of gold prospecting by the panning of the alluvials of the larger river systems. It is of course possible that important gold lodes which have not shed gold into the main river systems remain undetected. Any base metals found in the past have been encountered incidentally or accidentally in the search for gold. Gold mines at Wau, Misima Island and Woodlark Island have closed down when gold values, often superficially enriched, have receded as the pyrite, and in some cases galena, sphalerite, and, to a very minor extent, chalcopyrite, content of ores increased with depth. In no case has the base-metal content of these lodes been sufficiently high to warrant continuing economic exploitation as base-metal producers.

Search for base metal orebodies in New Guinea presents considerable difficulties peculiar to the terrain and climate. Gossans as a rule are not developed; even in the 'dry belt' around Port Moresby, where the land surface is comparatively mature, sulphide persists to within a few feet of the surface. Elsewhere oxidation products are rapidly removed by erosion, and the lode outcrop is hidden by dense vegetation - forest, jungle, or even grass - or by soil, alluvium or landslip. On the other hand chemical processes may, if conditions are favourable, act very rapidly. Solution is aided by abundant humic acids and free carbon dioxide in the soil water; manganese-bearing gold and silver orebodies show strong evidence of fairly rapid removal of silver and gold in solution. Commercial grade bauxite on Manus Island over Pleistocene or Recent volcanics (Owen, 1954) has developed quite rapidly, in contrast to its formation in Australia where a long period of exposure on a near-peneplaned surface to seasonal groundwater fluctuations is postulated. Laterite occurs even on alluvium in the lower Fly and Sepik river valleys. Nickel minerals are concentrated at the base of the soil profiles even in very steep terrain. Accordingly metal content is likely to have been removed from the lode surfaces and must be sought by geochemical methods. Fortunately, it has been demonstrated that careful sampling of sediment in minor streams will give leads to the metal bearing sections of a given stream valley and enable surface anomalous areas to be located, and delineated by soil sampling methods.

Whereas the Papua-New Guinea synorogenic province has received considerable attention from prospectors, and specific mineralized localities have been cursorily examined by a few major mining companies it can be fairly stated that the Solomons synorogenic province provides virtually virgin prospecting territory with the bonus feature that the known copper mineralization and its geological environment on Bougainville and Guadalcanal have characteristics suggestive of "porphyry copper" deposits. This orogenic belt has not, at least until recently, received the prospecting attention it would appear to warrant as favourable environment for Tertiary "porphyry-type" deposits.

This Solomons orogenic zone conforms in part with the "Outer Melanesian Zone" which Glaessner (1950) recognised as an orogenic belt extending south-eastwards, beyond the geographic limits of this review, through the New Hebrides and Fiji. If the truly orogenic portion of this Zone which, in the Solomon Chain, as characterized by dioritic pre-Miocene plutonic basement and subsequent explosive andesitic vulcanism, does extend through the New Hebrides and Fiji Islands, comparable petrogenic and metallogenic features, including the favourable environment for "porphyry-type" -copper mineralization, may be present there.

The New Guinea mobile zone, one of the least known sections of the circum-Pacific mobile zone, appears to have been dominated by a tectonic regime of torsional shear at least as far back as Cretaceous time. Its elucidation presents a formidable challenge in many fields of investigation, including crustal and sub-crustal composition, eugeosynclinal sedimentation, orogenic motivation, petrogenesis and metallogenesis.

It is hoped that the challenge of this region will be accepted in the near future by Australian earth scientists, using the rapidly developing techniques of absolute dating, theoretical petrology, marine geology, local and regional geochemical studies, and geophysical crustal investigation, including land-based, airborne and submarine methods.

VII. REFERENCES

A.P.C., 1961 - Geological Results of Petroleum Exploration in Western Papua 1937-1961 by The Australasian Petroleum Company Proprietary. J.geol.Soc.Aust. 8.1 pp.1-133.

A.P.O.C., 1930 - The oil exploration work in Papua and New Guinea conducted by the Anglo-Persian Oil Company on behalf of the Government of Australia 1920-29, 4 Vols. London.

BAKER, G., 1946 - Preliminary Note on volcanic eruptions in the Goropu Mountains south-eastern Papua, during the period December, 1943 to August, 1944. J.Geol.54, pp.19-31

BAKER, G., 1952 - Opaque oxides in some rocks of the basement complex, Torricelli Mountains, New Guinea .. Amer.Miner.37, pp.567-577

COLEMAN, P.J., 1962 - An outline of the geology of Choiseul, British Solomon Islands. J.geol.Soc.Aust. 8.2, pp.133-157

DAVID, T.W.E. ed. BROWNE, W.R., 1950 - The geology of the Commonwealth of Australia. Arnold & Co. London.

DAVIES, H.L., 1958 - Efontera lead-zinc prospect, Kainantu, Eastern Highlands of New Guinea; interim geological report. Bur.Min.Resour.Aust. Rec.1958/99 (unpubl.)

DAVIES, H.L., 1959 - The geology of the Ajura Kujura Range. Bur.Min. Resour.Aust. Rec. 1959/32 (Unpubl.)

DAVIES, H.L., & IVES, D.J., (in press) - The geology of Goodenough and Fergusson Islands, Papua. Bur.Min.Resour.Aust. Rep.82.

de KEYSER, F., 1961 - Misima-Island-Geology and Gold Mineralization. Bur.Min.Resour.Aust. Rep.57

DEKKER, F.E., & FAULKS, I.G., 1964 - The geology of the Wabag area, New Guinea. Bur.Min.Resour.Aust.Rec. 1964/137

DOW, D.B., 1961a - The relationship between the Kaindi Metamorphics and Cretaceous rocks at Snake River, T.N.G. Bur. Min.Resour.Aust.Rec.1961/160. (Unpubl.)

DOW, D.B., 1961b - Report on the Mount Victor gold prospect near Kainantu, T.P.N.G. Bur.Min.Resour.Aust.Rec.1961/113 (Unpubl.)

DOW, D.B. & DAVIES, H.L., 1964 - The geology of the Bowutu Mountains, New Guinea. Bur.Min.Resour.Aust.Rep.75

DOW, D.B., & DEKKER, F.E., 1964 - The Geology of the Bismarck Mountains, New Guinea. Bur.Min.Resour.Aust. Rep.76

DOW, D.B. & PLANE, M.D., 1963 - The Geology of the Kainantu Goldfields. Bur.Min.Resour.Aust.Rec.1963/64 (Unpubl.)

EDWARDS, A.B. 1954 - Lead-Zinc ore from Kulumadau Mine, Woodlark Island, New Guinea. Comwealth Sci.Ind.Res.Org. Miner.Invest.Rep.602

EDWARDS, A.K.M., 1951 - Report on examination of an area included in D.S.C. No.1 N.B., Morambu River, Gazelle Peninsula, New Britain. Terr.Pap.N.Guin.rep.(Unpubl.)

FISHER, N.H., 1935a - Geological Report Day Dawn South. Terr.N.Guin. rep. (Unpubl.)

FISHER, N.H., 1935b - Geological Report Kupei Goldfield Bougainville, T.N.G., Terr.N.Guin. rep. (Unpubl.)

FISHER, N.H., 1937 - Geological Report on the gold-bearing area of the Wewak district. Terr.N.Guin. rep. (Unpubl.)

FISHER, N.H., 1938a - Geological Report on property of Mount Kaindi Prospecting and Treatment Syndicate. Terr.N. Guin. rep. (Unpubl.)

FISHER, N.H., 1938b - Geological Report on Anderson's Creek Lode. Terr.N.Guin. rep. (Unpubl.)

FISHER, N.H., 1938c - Geological Report on Upper Ridges Lode. Terr.N.Guin. rep. (Unpubl.)

FISHER, N.H., 1939a - Ore geology of the Day Dawn Mine Econ.Geol.34.2. pp.173-189.

FISHER, N.H., 1939b - Metasomatism associated with Tertiary mineralization in New Guinea. Econ.Geo. 34.8 pp.890-904

FISHER, N.H., 1939c - Geological report on the area between Wau and Garaina, River Terr.N.Guin. rep.(unpubl.)

FISHER, N.H., 1940 - Geological Report on the Enterprise Mine, Edie Creek, Terr.N.Guin. rep. (Unpubl.)

FISHER, N.H., 1941 - Geological Report on the Sapphire-Moresby King, Laloki and other mines, Astrolabe Mineral Field, Papua. Terr.N.Guin. rep. (Unpubl.)

FISHER, N.H., 1942a - Geological Report on Talele Goldfield and environs, in Terr.N.Guin.Geol.Bull. 3.

FISHER, N.H., 1942b - Geological Report on the sulphur deposits of New Britain. in Terr.N.Guin.Geol.Bull.3. pp.40-49

FISHER, N.H., 1944 - Outline of the geology of the Morobe Goldfields. Proc.Roy.Soc.Qld 55.4. pp.54- 58

FISHER, N.H., 1945 - The Fineness of Gold, with special reference to the Morobe Goldfield, New Guinea. Econ.Geol. 40.7. pp.449-563

FISHER, N.H., 1957 - Catalogue of the active volcanoes of the world including solfatara fields. Part V. Melanesia Int.Volc.Ass.

GARDNER, D.E., 1957 - Iron ore deposits near Cape Lambert, New Britain Bur.Min.Resour.Aust. Rec.1957/76 (Unpubl.)

GLAESSNER, M.F., 1950 - Geotectonic position of New Guinea. Bull.Amer. Ass.Petrol.Geol. 34, pp.856-881

GROVER, J.C., 1955 - Geology, Mineral Resources and Prospects of Mining Development in the British Solomon Islands Protectorate. Interim Geol.Surv. Brit.Sol.Is.Mem.I.

GROVER, J.C. (ed.), 1960 - TheBritish Solomon Islands Geological Record 1957 - 1958. Reports on investigations into the geology and mineral resources of the Protectorate.

GROVER, J.C., PUDSEY-DAWSON, P.A. and THOMPSON, R.N.M., 1958 - The Solomon Islands - geological exploration and research 1953 - 1956. Geol.Surv.Brit.Sol.Is. Mem.2

HARTMAN, R.R., 1962 - Geophysical Report of Reconnaissance Airborne Magnetometer Survey over Gulf of Carpentaria for Delhi-Australian Petroleum Ltd. by Aeroservice Ltd. (Unpubl.)

McMILLAN, N.J. & MALONE, E.J., 1960 - The Geology of the Eastern Central Highlands of New Guinea. Bur.Min.Resour.Aust.Rep.48

NOAKES, L.C., 1938 - Report on the Black Cat-Bitoi River Area. Terr.N.Guin.Rep. (Unpubl.)

NOAKES, L.C., 1939 - Geological Report on the occurrences of lignite at Matakan Plantation, New Ireland. Terr.N.Guin.rep. (Unpubl.)

NOAKES, L.C., 1941 - Report on Edie Creek Mine. Terr.N.Guin.rep.(Unpubl.)

NOAKES, L.C., 1942 - Geological Report on the Island of New Britain, in Terr.N.Guin. Geo.Bull.3

NOAKES, L.C., & GARDNER, D.E., 1959 - Lae hydro-electric projects, New Guinea; reconnaissznce investigation of the Sankwep River Scheme. Bur.Min.Rescur.Aust. Rec. 1959/22 (Unpubl.)

NYE, P.B., & FISHER, N.H., 1954 - The Mineral Deposits and Mining Industry of Papua-New Guinea. Bur.Min.Resour.Aust.Rep.9

OWEN, H.B., 1954 - Bauxite in Australia. Bur.Min.Resour.Aust.Bull.24

PATERSON, S.J. & KICINSKI, F.M., 1956 - An account of the geology and petroleum prospects of the Cape Vogel Basin Papua. Bur.Min.Resour.Aust. Rep.25 pp.47-70

PATERSON, S.J. & PERRY, W.J., 1964 - Geology of the Upper Sepik-August River, New Guinea. J.geol.Soc. Aust.

PHIPPS, C.V.G., 1960 - The Manganese Deposits of Hanesavo 1958. Report No.19 in Brit.Sol.Is. Geol.Rec. 1957 - 1958

PUDSEY-DAWSON, P.A.,1960 - Discovery of a sulphide body on Hanesavo, 1958. Report No.18 in Brit.Sol.Is. Geol.Rec. 1957-1958

REYNOLDS, M.A. and others, 1963 - The Sedimentary Basins of Australia and New Guinea. Bur.Min.Resour.Aust.Rec.1963/159 (Unpubl.)

RICKWOOD, F.K., 1955 - The geology of the Western Highlands of New Guinea. J.geol.Soc.Aust. 2 pp.63-82

SIEDNER, G., 1958 - A geological reconnaissance of the Nanbayat Creek area, Finisterre Range, N.G. Bur.Min.Resour.Aust.Rec. 1958/37. (Unpubl.)

STANLEY, E.R., 1916 - Report on the geology of Cape Vogel Peninsula - Mineral indications Terr.Pap.rep.(Unpubl.)

STANLEY, E.R., 1923a - Geology of Papua. Melbourne, Govt.Printer

STANLEY, E.R., 1923b - Report on the salient geological features and natural resources of the New Guinea Territory. Par.Paper 18 of 1923. Government Printer,Melbourne.

SMITH, J.W. & GREEN, D.H., 1961 - The Geology of the Musa River Area. Bur.Min.Resour.Aust.Rep. 52

STANTON, R.L., 1961 - Explanatory Notes to accompany a first geological map of Santa Isabel, British Solomon Islands Protectorate. Overseas Geol. & Min.Resour. 8.2.pp.127-169

TAYLOR, G.A.M., 1953 - The 1951 eruption of Mount Lamington, Papua. Bur.Min.Resour.Aust.Bull. 28

THOMPSON, J.E., 1952 - Report on the geology of Manus Island, Territory of Papua and New Guinea, with reference to the occurrence of bauxite. Bur.Min.Resour.Aust. Rec.1952/82. (Unpubl.)

THOMPSON, J.E., 1957 - The Papuan ultrabasic belt, with particular reference to economic aspects. Bur.Min.Resour.Aust. Rec. 1957/77. (Unpubl.)

THOMPSON, J.E., 1958 - An interim report on a geological reconnaissance of the Middle Musa area. Bur.Min.Resour.Aust. Rec.1958/24 (Unpubl.)

THOMPSON, J.E., 1960 - The iron-copper lodes, Suloga Peninsula, Woodlark Island, Papua. Bur.Min.Resour.Aust.Rec.1960/119

THOMPSON, J.E., 1961a - A reconnaissance bauxite investigation on New Hanover and nearby islands. Bur.Min.Resour.Aust. Rec.1961/140 (Unpubl.)

THOMPSON, J.E., 1961b - Magnetite beach-sands of Bougainville Island, Territory of Papua and New Guinea. Bur. Min. Resour.Aust.Rec. 1961/97 (Unpubl.)

THOMPSON, J.E., 1962a - Nickel and associated mineralization in the Territory of Papua and New Guinea. Bur.Min. Resour.Aust.Rec. 1962/157. (Unpubl.)

THOMPSON, J.E., 1962b - The Pumkuna copper-gold prospect, Bougainville Island, T.P.N.G. Bur.Min.Resour.Aust. Rec.1962/39 (Unpubl.)

TRAIL, D.S., 1961 - The Geology of Woodlark Island. Bur.Min.Resour.Aust.Rec.1961/111 (Unpubl.)

UNIVERSITY OF SYDNEY, 1957 - Geological reconnaissance of parts of the central islands of the British Solomon Islands Protectorate: by the Department of Geology and Geophysics, University of Sydney. Colon.geol and Min.Resour. 6.3 pp. 267-306

WHITE, W.C. and WARIN, O.N., 1964 - A survey of phosphate deposits in the South-West Pacific and Australian waters. Bur.Min.Resour.Aust. Bull.69

WEEKS, L.G., 1959 - Geological architecture of the Circum-Pacific. Bull.Amer.Ass.Petrol Geol., 43 (2) pp.350-380

THOMPSON, J.E., 1961b - Magnetite beach-sands of Bougainville Island, Territory of Papua and New Guinea. Bur.Min.Resour.Aust.Rec. 1961/97 (Unpubl.)