ROCK TYPES AND MINERALIZATION AT PANGUNA PORPHYRY COPPER PROSPECT, UPPER KAVERONG VALLEY, BOUGAINVILLE ISLAND

By

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ABSTRACT

A large body of porphyry-type copper mineralization occurs at Panguna in southern Bougainville. It is associated with the intrusion of quartz diorite/granodiorite into andesites, particularly with the contact zone. Metasomatism of both intrusives and andesite resulted in the formation of biotite pseudomorphing hornblende and the veining of the resultant biotite diorite and biotitized andesite by quartz-chalcopyrite veins with pink orthoclase and dark biotite selvages, respectively.

The orientation of intrusives and veins appears to be controlled by premineralization fault-joint patterns in the intruded andesitic Kieta Volcanics.

INTRODUCTION

Bougainville, at the northern end of the Solomons chain, is a north-west trending island about 130 miles long by a maximum of 40 miles wide and forms the easternmost part of the Trust Territory of New Guinea (Fig. 1).

The area of copper-gold mineralization around Panguna lies within the Kaverong Valley which drains westwards from the Central Crown Prince Range of southern Bougainville. Access is from Kieta on the coast, 12 miles to the north-east.

Gold was discovered at Kupei near the crest of the Crown Prince Range in 1930, where an elliptical shaped body of about 230 ft by 160 ft, consisting of a network of copper-bearing auriferous quartz stringers, grading about 8-10 dwt/ton gold was subsequently worked (Fig. 2). Shortly afterwards a similar but much smaller occurrence of faulted quartz-sulphide veins, averaging an estimated 15-20 dwt/ton gold, over 18 in. width was discovered at Panguna, and worked until the onset of the Japanese invasion in 1941. N. H. Fisher (1936) visited the area for the New Guinea Administration, and described the occurrence of gold and copper in association with porphyry and agglomerates. J. E. Thompson (1962), Senior Resident Geologist for Papua and New Guinea, visited the Panguna-Moroni area and suggested reconnaissance geochemistry and mapping over a wide area of the Crown Prince Range in the search for large, low grade centres of copper-gold mineralization.

In 1963, the Atlas Copper mine at Toledo in the Philippines was visited by K. M. Phillips of C.R.A. Exploration Pty. Limited, who suggested that a similar geological environment of diorite intrusive into Tertiary andesite might be found in New Guinea. The copper mineralization of Kupei and Panguna, recorded by Fisher and Thompson in particular attracted his attention because of the close apparent similarity in age, rock types, and quartz veining with the occurrence at Toledo. From April to July, 1964, K. M. Phillips and his party outlined an area of widespread copper mineralization by geochemical stream sediment and soil sampling. The rocks exposed at Panguna were found in fact to be similar to those at Toledo (viz. diorite intruding very fractured andesite rocks), and the recognition of significant porphyry-type copper mineralization led to the commencement of a testing programme.

By July 1965, eleven diamond drill holes to depths up to 800 ft had been completed, mainly on Panguna Hill. These had all cored copper mineralization of significant grade.

Subsequent escalation of diamond drilling followed, so that by July, 1967, 81 holes had been completed to an average depth of 1000 ft and an estimated 200 million long tons of ore of average primary zone grade of 0·63 per cent copper and 0·5 dwt/ton gold had been indicated.

CLIMATE AND TOPOGRAPHY

Bougainville has an equatorial climate with a poorly defined wet season. At Panguna the temperature ranges between mean monthly maxima and minima of 84°F and 57°F, with high relative humidity. Up to about 200 in. per year of rain fall on the prospect area around Panguna.

The terrain is deeply dissected, and side slopes of 30° to 45° are common. The Kaverong Valley is surrounded by hills up to 5,000 ft, while elevations within the prospect area vary between 2,000 ft and 3,000 ft above sea level. The area is covered by tropical rain forest, with fairly thin undergrowth except in areas of dense secondary growth.

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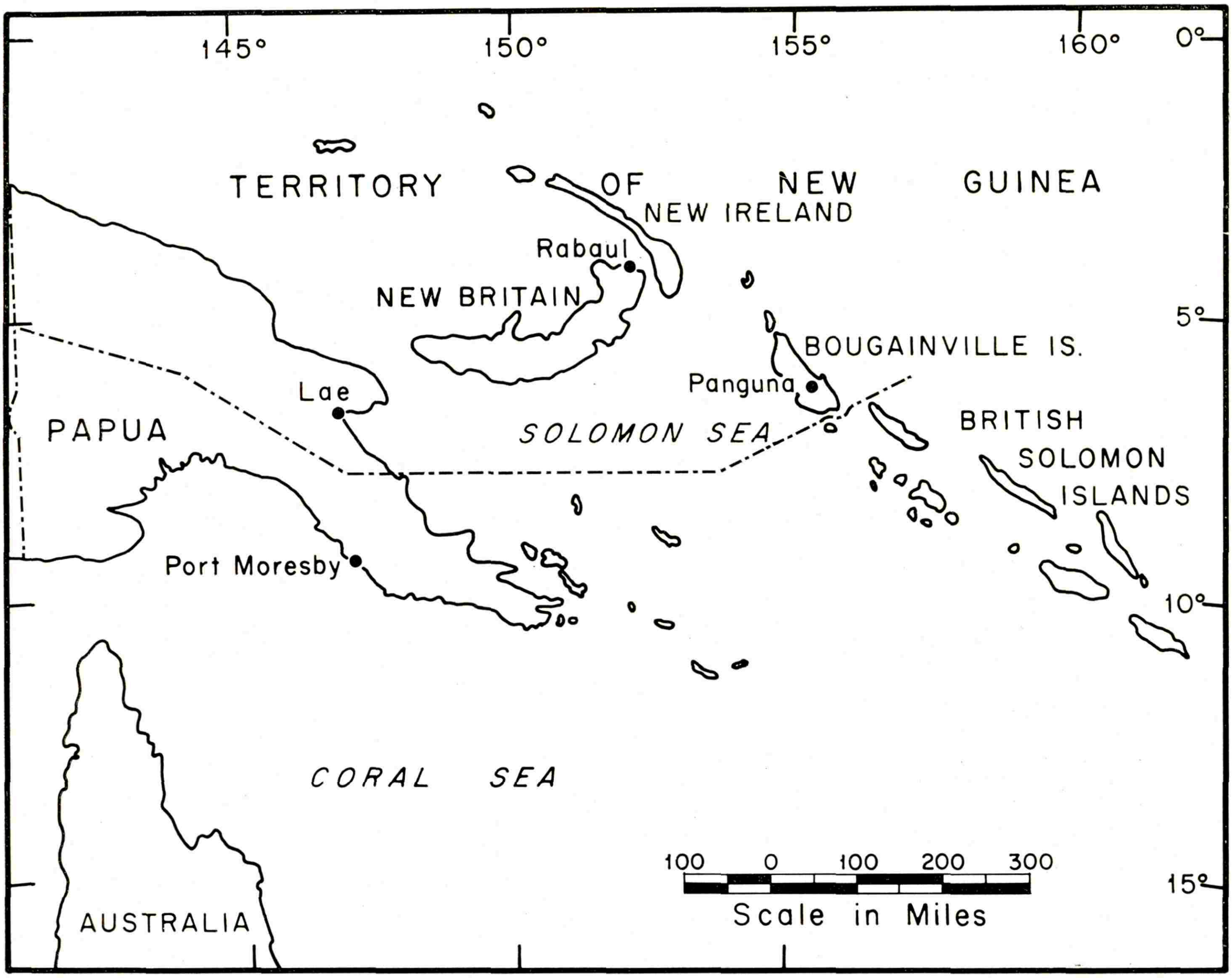

FIG. 1—Locality map, showing Bougainville Island, Territory of Papua and New Guinea.
Scale: 1 in. = 222 miles

REGIONAL GEOLOGY

The Kieta Volcanics, which are the oldest rocks exposed on Bougainville, form the Crown Prince Range and the Deuro Range in southern Bougainville (Blake and Miezitis, 1967).

They are separated from the Emperor Range in the north by the active volcano Mt. Bagana, 5730 ft, and the extinct volcanoes Billy Mitchell, Numa Numa, and Reini, and bounded on the south by the Mt. Taroka-Mt. Takuan volcanics.

The buff-coloured Lower Miocene Keriaka Limestone unconformably overlies the Kieta Volcanics. Darker fine grained, organic limestone occurs in the Kieta Volcanics near Pakia and in the Karato-Mainoki area, 9 miles WNW of Panguna.

The Kieta Volcanics consist mainly of andesitic and basic flows and pyroclastics (agglomerate, sandstone, and siltstone). In the Pakia Gap-Panguna area the beds and flows dip SSE generally at 10° to 15°, but around Kieta there appears to be a general low northerly dip. About 1 mile south of Pakia, dips are generally SSE, although small folds with dips up to 30° occur locally. An overall anticlinal arching is therefore inferred between Kieta and Panguna.

A stratigraphic sequence in the area between Nairovi and Panguna, modified from McQueen (unpublished report to C.R.A. Exploration Pty. Ltd., 1966) and Fountain (unpublished report to C.R.A. Exploration Pty. Ltd., 1967), is shown in Table 1. Correlation of the rocks of the Kaverong Valley and those on the Pakia Gap-Nairovi Village road is uncertain, as contacts are obscured by younger rocks, particularly the Pakia Gap Tuff. An overall SE dip in the rocks between Pakia Village and Panguna (Fig. 3) supports the sequence outlined in Table 1.

ROCK UNITS IN THE VICINITY OF THE MINERALIZED AREA

Volcanics and minor dykes

The volcanics and dykes are described in ascending order of age.

Nairovi Siltstone (new name)

It is inferred that the Nairovi Siltstone is the oldest unit in the area examined. It is exposed near Nairovi to an elevation of about 1700 ft above sea level at the type section on the Pakia road, and also between Nairovi and Cape Puipui. It is made up

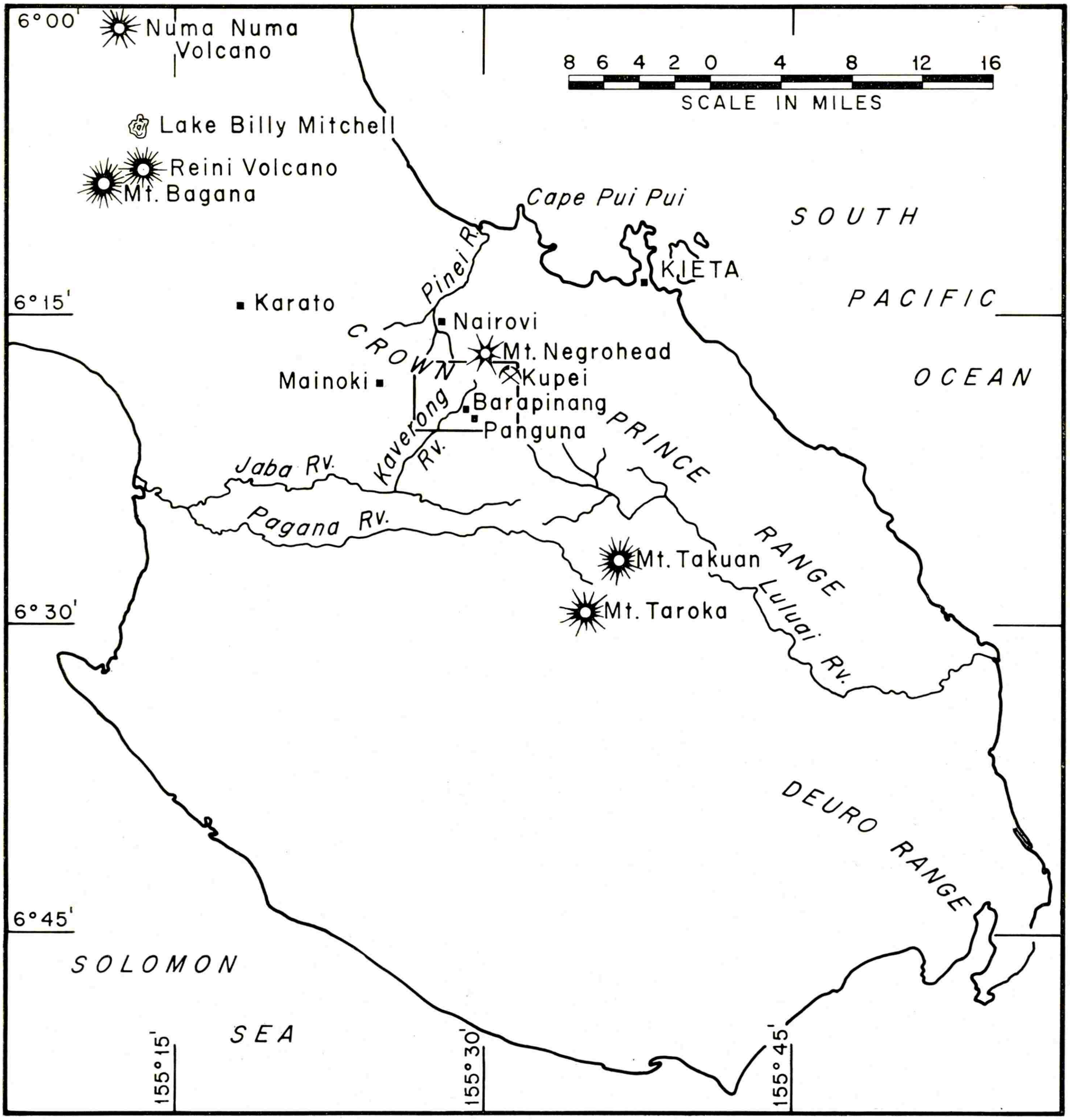

FIG. 2—Locality map, showing Panguna, Bougainville Island.
Scale: 1 in. = 8 miles

TABLE 1

Stratigraphic column
*Nairovi to Panguna, Bougainville**

Age	Rock unit
Quaternary	River gravels 0-50 ft Volcanic ash 0-100 ft Boulder terraces 50 ft
Pliocene ?	*Intrusives* Nautango Andesite Karoona Porphyry and other porphyry dykes Biuro Granodiorite Kaverong Quartz Diorite and its marginal mineralized phases — *Marginal phases*: (1) leucocratic quartz diorite (2) biotite diorite (3) biotite granodiorite
Miocene ?	Pakia Gap Tuff (+600 ft)
	Unconformity
Oligocene ? to Lower Miocene ?	Kieta Volcanics (Fm): Undifferentiated welded tuffs and agglomerates Binivan Andesite Breccia Member +1000 ft † Panguna Andesite Member +3000 ft Pinei Agglomerate Member +1500 ft Nairovi Siltstone Member +1500 ft

* Modified from A. F. McQueen, unpublished report, 1966 and R. J. Fountain, unpublished report, 1967.
† Blake and Miezitis (1967).

mainly of finely bedded, buff-coloured tuffaceous siltstones, with some interbedded massive tuffaceous sandstones and sporadic impure limestone. The limestone is fine grained, grey and (?) unfossiliferous. Dips are generally low, of the order of 0° to 20° to the north or south. In places the unit is intruded and deformed by basaltic dykes.

Pinei Agglomerate (new name)

The Pinei Agglomerate crops out at the type section on the northern side of the main divide between 1700 ft and 2500 ft above sea level along the Pakia Gap-Nairovi road. In mass appearance it is similar to the rocks seen around Kieta and is equally fairly well indurated.

The agglomerate is composed mainly of greenish andesite fragments, with lesser red andesite and pale cherty inclusions. Lenses of buff-coloured tuffaceous siltstone are common.

Dips are normally about 15° SSE. Above 2500 ft above sea level, the Pakia Gap Tuff is exposed in road cuttings. It probably unconformably overlies the Pinei Agglomerate and the Panguna Andesite.

Panguna Andesite (new name)

The Panguna Andesite is the oldest unit exposed in the Kaverong Valley, and it has been demonstrated by drilling to extend in depth at least to an elevation of 200 ft above sea level near Panguna. The type section is exposed along Panguna Creek, between the Kaverong River and Panguna. It is mineralized around Panguna and elsewhere, where adjacent to mineralized diorite.

The few dips seen in the Kaverong Valley in Panguna Andesite are at 10° to 20° SE to SSE, and the equivalent rocks are probably covered by Pakia Gap Tuff on the northern side of the main divide, where they pass down into the Pinei Agglomerate.

The bulk of this rock in the Kaverong Valley is texturally and compositionally a hornblende microdiorite and appears to have been a lava flow. It shows no sign of vesicularity. In some places there are fine grained, banded sections, whilst in others xenolithic inclusions make up a large percentage of the rock. It is possible that some sections, especially these latter types, are hard welded agglomerates, but the field relationships indicate that they are flows.

The Panguna Andesite, then, is composed of the following elements.

1. Hornblende microdiorite. This occurs as either a main rock type of itself, or as a "matrix" in the xenolithic sections. 1·5 to 2 mm euhedral hornblende crystals form 15 to 20 per cent of the rock, the remainder being mainly plagioclase laths of smaller dimensions. The hornblende is commonly grouped in glomeroporphyritic clumps.

2. Xenoliths. These may form up to about 80 per cent of the rock and range in size from 2 mm to several cm. There are apparently two main types, which are

   a. a dark grey or blue-grey porphyritic (2 to 5 mm) hornblende-augite andesite, which is the most common xenolith type, and
   b. a light coloured hornblende felspar rock of dioritic appearance.

The xenoliths are usually irregular in outline, but in some places are sub-rounded. Reaction rims have been seen around some of them.

3. Banded fine grained and very fine grained ("cherty") hornblende andesite, pale green in colour. The banded sections may be of limited extent only. They form less than 10 per cent of the diamond drill core around Panguna, but may be more common elsewhere where the andesite is less xenolithic.

Binivan Andesite Breccia (new name)

This is a crudely banded andesitic rock with pale green pyritic-epidote-chloritic material as inclusions and joint coatings which were probably formed by deuteric alteration. The rock is similar in places to the (?) xenolithic sections of the Panguna Andesite which it immediately overlies, but it may be partly agglomerate. There is occasional quartz veining, and fine grained red (?) andesite inclusions occur in places. It has been intruded by diorite dykes, presumably associated with the Kaverong Quartz Diorite.

The Binivan Andesite Breccia crops out in the higher parts of Binivan Creek (the type section), and in the high hills around the Kaverong Valley where it is normally associated with a steepening of slope due to its more massive character. Joints are commonly spaced at 5 ft, contrasting with the more closely spaced joints in Panguna Andesite.

Welded chloritic agglomerate and tuff

These rock types occur around the headwaters of Barapinang Creek and towards Mt. Negrohead, and lie above the Binivan Andesite Breccia. Various irregular andesite fragments, 1 to 8 cm in diameter, occur in a greenish chloritic matrix.

Pakia Gap Tuff (new name)

Indurated tuff occurs around the type section at Pakia Gap and in road cuttings towards Nairovi to about 2,600 ft above sea level. It (?) unconformably overlies the Panguna Andesite and the Pinei Agglomerate and appears to be thicker on the northern side of Pakia Gap.

No bedding has been observed in it, nor have equivalent rocks been recognized elsewhere in the Kaverong Valley. The rock is grey where fresh, with a greenish-grey chloritic matrix, but is commonly highly weathered to pink and yellow mottled clayey soil containing residual angular cherty pieces and broken quartz.

The rock is cut by quartz-felspar porphyry and some quartz veins.

Nautango Andesite (new name)

The Nautango Andesite is a pale grey, fine grained andesite with acicular hornblende crystals 1 to 4 mm long. It intrudes the Panguna Andesite and the Kaverong Quartz Diorite in the Nautango area where the type section is exposed as a knoll of plug-like appearance. Other types of subvolcanic andesite dykes occur also, such as those on the road west of Barapinang, but do not appear to be very common or extensive.

Volcanic ash

Most of the volcanic ash has been weathered to a brown clayey montmorillonitic matrix with black and green, 1 to 2 mm hornblende, some felspar crystals and squashed pumice fragments. Crystal ash, mainly felspar, with some hornblende, occurs in bands and lenses and makes up about 10 per cent of the total.

The clayey type ash occurs in extensive sheets, and has loosely bonded water which causes the ash to liquefy if disturbed by road plant. This has led to instability of road beds, and the need to place quantities of river gravel on roads in these sections.

The ash forms a capping on the tops of some ridges and at the flattening of slopes. In the past it has formed terraces on top of creek boulder terraces, and remnants of these terraces occur in the Panguna-Barapinang-Kaverong River systems. It varies in thickness from nil to a few feet on steep slopes, and increases to about 50 ft thick on lower ground.

River gravels and boulder terraces

River gravels are more evident around the Pakia Village area, but there are also reworked gravels in the boulder terraces around Panguna and Barapinang. Some of these terraces may have been formed by the stripping action of ash mixed with rain water as it moved from the higher slopes into the valleys. Very large blocks of Binivan Andesite Breccia, some reaching 15 to 20 ft in size, occur in the lower Panguna Valley remote from the nearest outcrop and were possibly deposited in this way.

Diorite-granodiorite intrusives associated with mineralization, and subsequent intrusives

The rocks of this group are co-magmatic, and there appears to be a tendency for the younger members to be more porphyritic and quartz rich, and to occur near the margins of the main intrusion. The intrusives are discussed in order of their apparent sequence from oldest to youngest.

Kaverong Quartz Diorite (new name)

This is typically a pink hornblende diorite, with granodiorite phases in places. It is exposed over much of the Upper Kaverong Valley and is similar to the diorite in the Luluai River area. The type section occurs in the Kaverong River about ¼ mile below its junction with Kompooma Creek.

The quartz content varies from nil to about 10 per cent generally, and is usually interstitial, but composite grains up to 3 mm have been noted. Hornblende forms 15 to 25 per cent of the rock with 1·5 to 3 mm subhedral and euhedral forms and occasional 5 mm stumpy euhedral crystals. The remainder of the rock is normally plagioclase of even grain size but occasionally phenocrystic.

Some orthoclase, up to 15 per cent, has been seen in thin sections and may account for the overall pink appearance of the rock.

The hornblende is commonly chloritic and in these cases may contain a few fine spots of chalcopyrite. The felspars are occasionally slightly sericitized, and a little epidote is present in places. Numerous small dark chloritic inclusions and large very dark biotitic zones in the Kompooma and Karoona Creek areas probably represent partially assimilated country rock, presumably Panguna Andesite. In diamond drill core in and around Panguna, about 3 to 5 per cent of the diorite consists of these dark clots.

The Kaverong Quartz Diorite has the following marginal differentiates or facies.

Biotite diorite. This rock is light grey with 0·5 to 5 mm brown biotite pseudomorphs after hornblende, and irregular biotite patches forming 15 to 25 per cent of the rock.

Felspars are grey-white to cream. A little magnetite is also present.

In texture the rock resembles Kaverong Quartz Diorite in which biotite has replaced hornblende. No definite contact between these two rock types has been seen and it is probable that there is a gradational change from Kaverong Quartz Diorite in the north through biotitized hornblende quartz diorite to biotite diorite in the south.

In places, the boundary between biotite diorite and Panguna Andesite is gradational though a darker variety of biotite diorite and a biotitized hornblende microdiorite.

Biotite granodiorite. The biotite granodiorite may be a variant of the biotite diorite containing more granular quartz. It is recognized as a separate rock type on the basis of the quartz content visible in hand specimen, although this may not be a significant difference, as the biotite diorite also has granular quartz in places, as well as finer groundmass quartz which becomes more evident macroscopically when the rock is kaolinized.

Leucocratic quartz diorite. The leucocratic quartz diorite includes microdiorite and porphyritic varieties, but is essentially similar to the biotite diorite except that it is more heavily quartz veined and carries more copper and orthoclase vein selvages. It occurs in Panguna Hill and at Kupei and forms the strong, weather-resistant feature on these ridges due to abundant sheeted, 2 mm to 8 mm wide, quartz veins. These veins are parallel to the dyke-like intrusive walls of the diorite.

The sheeted quartz-veined type of intrusion may be part of an elongated cupola which exhibits the most intensive veining in the roof and hood. The amount of veining and the intensity of mineralization in the leucocratic quartz diorite decrease in depth in both Panguna and Kupei. At depth, the leucocratic quartz diorite resembles biotite diorite where unchloritized, except for a larger amount of pink orthoclase selvage on vein walls.

The ferromagnesian minerals are mainly chloritized, probably as the result of post mineralization alteration, but pseudomorphs after hornblende remain in places. It is not known if these were biotitized before replacement by chlorite, but biotite is common throughout the leucocratic quartz diorite.

Barren late stage diorite intrusives

Biuro Granodiorite (new name). The Biuro Granodiorite is a light coloured granodiorite with 10 to 20 per cent of 1 mm quartz, 10 per cent of 1 to 5 mm hornblende, generally black and fresh, and commonly 10 to 15 per cent of 3 mm felspar phenocrysts set in a somewhat finer felspar matrix. The rock generally contains a very low percentage of copper (of the order of 0·02 per cent Cu), except where it is contaminated by pre-existing mineralized rocks into which it intrudes. The rock intrudes both Panguna Andesite and the biotite diorite phase of the Kaverong Quartz Diorite.

Karoona Porphyry (new name). The Karoona Porphyry is a light coloured rock with large distinctive quartz and felspar phenocrysts in a hornblende-felspar microdiorite or andesite matrix. 2 to 5 mm euhedral quartz grains form 10 to 15 per cent of the rock with similar sized and amounts of felspar phenocrysts, but grain size of phenocrysts and groundmass can vary considerably. The rock occurs marginal to the Kaverong Quartz Diorite, near or at its contact with the Panguna Andesite. It contains no obvious copper. The type section is in Karoona Creek.

Felspar porphyry and quartz felspar porphyries. Various types of these porphyries occur in the area. They are all generally marginal to the Kaverong Quartz Diorite or as dykes traversing Panguna Andesite.

A felspar porphyry with a rather dark, fine grained groundmass intrudes the Nairovi Siltstone in places near Pakia.

ALTERATION

The following types of alteration appear to have taken place in the mineralized area.

1. biotitization
2. chloritization
3. quartz-kaolin-pyrite alteration
4. pyrite alteration
5. propylitic alteration

Biotite appears to be related directly to the ore formation (Fig. 3) as is possibly chlorite to a lesser extent.

The other alterations appear to be of a later post-ore, retrograde nature.

Biotitization

The apparent pseudomorphing of hornblende to form the biotite of biotite diorite and leucocratic quartz diorite appears to be related directly in time and space to the mineralization. This probably took place by the introduction of K-SiO_2-Cu resulting in the formation of pink orthoclase and chalcopyrite as well as biotite. Simultaneously, in the Panguna Andesite, alteration of fracture walls to form a dark biotite selvage or intensely biotitized zones where fractures are closely spaced was followed by the emplacement of quartz and copper. In places chalcopyrite occurs as specks with the biotite in both the altered andesite and the biotite diorite.

The occurrence of biotite pseudomorphing hornblende, with the assemblage quartz-albite-orthoclase-muscovite-biotite is present in some porphyry coppers elsewhere such as Bagdad, Morenci, Ely, and Bingham (Titley and Hicks, 1966).

Chloritization

This appears to be associated with a late stage alteration and is particularly noticeable in Panguna Hill, where (?) biotite and hornblende in leucocratic quartz diorite have been altered to chlorite in association with the kaolinization of felspar. In the biotite diorite/granodiorite intrusives, a further stage of alteration results in the formation of a blue-green chlorite or chloritic clay, which turns brown on exposure to air. This alteration is fairly widespread and the blue-green colour of the chlorite is quite distinctive.

Elsewhere, as at Kupei, chlorite forms a halo in the Panguna Andesite around an intrusion, and sometimes occurs with pyrite and quartz replacing biotitized andesite.

Quartz-kaolin-pyrite alteration

This is a late alteration, generally confined to fracture zones in the Panguna Andesite at Panguna and Kupei. The rock alters to a white or grey soft pyritic clay with quartz and occasionally a little chalcopyrite. The controlling fractures may be flat and irregular, or steep. A similar alteration occurs along fracture zones in diorites. Early alteration of ferromagnesian minerals to chlorite and the incipient kaolinization of felspars appears to be an early stage, in some cases, of this type of alteration. The largest crystals appear to be the least altered and ferromagnesian minerals are probably affected more readily than felspar. The biotite granodiorite mass immediately north of Panguna Creek has been intensely altered in places. Intense silica-pyrite metasomatism along fractures and replacing the chloritized ferromagnesian minerals of the kaolinized granodiorite leads to an end product of quartz-pyrite-kaolin-chlorite, separated by harder zones and patches with strongly kaolinized felspar and chlorite. The larger felspar crystals in both zones are commonly represented now by large yellow phenocrysts of kaolin after felspar.

Pyrite alteration

The disposition of pyrite in rocks around the edge of the area of copper-gold mineralization suggests the presence of a pyritic halo. The contact zone between diorite and andesite is normally biotitized, and it is usually very thin if it is pyritic also.

As a corollary, an increasing pyrite to chalcopyrite ratio in the ore usually accompanies a decrease in copper grade for that particular area.

Propylitic alteration

There are some indications of zones of propylitic alteration in the host Panguna Andesite around the orebodies at Panguna and Kupei, represented by patchy pyrite-epidote-chlorite alteration. The overlying Binivan Andesite Breccia, with its typical steep topographic expression tends to coincide with and mark these areas in many places. In addition, the inclusions in the Binivan Andesite Breccia appear to have been (?) deuterically altered to a chlorite-pyrite-epidote mass.

Trends of alteration

While the process of alteration is not restricted to the formation of one "indicator" mineral, but affects the different minerals in the same rock in different ways according to their nature, grain size, the pressure and temperature conditions, and the presence or absence of overlapping metasomatic changes, the following trends appear to exist.

1. Hornblende→biotite→chlorite→chloritic clay
   → $+SiO_2 + FeS_2$ → pyrite
   — chlorite — quartz
2. Felspar → incipient white kaolinization
   → cream kaolinitic felspar → yellow kaolin
3. The coarser crystals and coarser grained xenoliths in the Panguna Andesite are the last to be altered, so that commonly a coarse grained hornblende-bearing xenolith has chloritic ferromagnesian minerals, while the surrounding finer grained andesite is biotitized.

Similarly, in the pyrite-silica replacement of granodiorite, the large yellow kaolinized felspar phenocrysts are the last to be replaced.

MINERALIZATION

In all mineralized rock types, chalcopyrite is the dominant primary copper mineral, associated in places with some bornite, and a little molybdenite and silver. Magnetite occurs as an alteration product due to the biotitization of andesite and as a primary mineral in quartz veins.

Pyrite is widely distributed, but, when intimately associated with the copper mineralization, appears to vary antipathically with it. Traces of sphalerite and galena have been found.

Gold appears to vary sympathetically with the copper content, and there is a suggestion that this ratio varies slightly in different rock types.

The base of oxidation rises under the ridges from the level of the main creeks to a depth below the ridge tops that reach, in places, several hundred feet. Cuprite and malachite are common oxide zone minerals. A thin chalcocite zone occurs in places.

Kaverong Quartz Diorite

The Kaverong Quartz Diorite carries weak copper mineralization throughout the Kaverong Valley, mainly as chalcopyrite, with occasional bornite, which occurs mostly in chloritic hornblende. Economically significant concentrations of copper mineralization occur in the three marginal facies.

Biotite diorite

The biotite diorite is the host rock of most of the disseminated mineralization north of Panguna, and is apparently the source of mineralization in the adjoining Panguna Andesite.

The rock is usually veined by irregular, thin quartz-chalcopyrite veinlets with pink orthoclase selvages. This type of veining is characteristic of the mineralized diorites and granodiorites. The additions of SiO_2-Cu-K seems to be involved in the mineralization process. In addition, disseminated chalcopyrite, sometimes with bornite, replaces biotite, or is associated with the replacement of pre-existing hornblende by biotite.

Biotite granodiorite

On present evidence, the biotite granodiorite facies appears to be similarly but more weakly mineralized than the biotite diorite.

Leucocratic quartz diorite

The amount of quartz veining in the leucocratic quartz diorite intrusion appears to control the degree of veining in the adjacent Panguna Andesite and the amount of copper in both rock types. Bornite tends to be more abundant in this rock type, and this may be a reflection of the association of bornite with this particular type of veining.

Panguna Andesite mineralization

The Panguna Andesite is intruded by all the diorite rock types. It is the most strongly mineralized extrusive rock in the area, due to its close spatial relationship with the Kaverong Quartz Diorite. The degree of jointing is greater in the mineralized area than outside it.

Mineralization at Panguna and Kupei in the Panguna Andesite occurs mainly in straight walled quartz veins 2 mm to 25 mm wide, which normally carry the chalcopyrite in a central zone with quartz crystals growing inwards from both walls. An altered wall zone composed of fine grained dark brown biotite forms a selvage to the veins. Closely spaced parallel quartz veins occur in the andesite adjacent and parallel to the vein-sheeted leucocratic quartz diorite dykes. The veins tend to be wider than usual (up to 5 cm) in these cases, and their width appears to be controlled to some extent by the proximity of the intrusion.

Occasionally thick quartz veins up to a few feet wide occur, but large (fracture-controlled ?) zones of biotite alteration of the andesite with irregular quartz-chalcopyrite veins are more usual. This biotitic alteration leads to replacement of hornblende by biotite in the first stage but, with increased intensity, finally results in the formation of a fine-grained, dark brown mixture of biotite-skeletal, kaolinized felspar-magnetite-chlorite rock with very little of the original texture remaining. This is the main type of alteration associated with the mineralization phase, and is most extensive where economically significant mineralization occurs in the andesite.

Considering the amount and width of veining, the percentage of copper and degree of alteration in the andesites, and the general decrease of these features with increasing distance away from the biotite diorite intrusive types, there can be little doubt that the intrusion is the ultimate source of the copper mineralization.

Some weak copper-zinc mineralization has been observed in the Binivan Andesite Breccia, above the Panguna Andesite, in the Panguna and Barapinang Creeks.

FAULTING

Whilst the island of Bougainville is aligned roughly in a NW-SE direction, the major joints and faults in the Kieta Volcanics trend at 120°. Mt. Bagana actually distorts this trend, and joint trends in the Kieta Volcanics appear to "wrap around" the volcano. Bureau of Mineral Resources mapping (Blake and Miezitis, 1967) shows this trend on a regional scale, whilst in the Kaverong Valley a fault along Panguna Creek and another through Pakia Gap are in the same direction. Faulting at 050° to 070° is also common, and may control the direction of stream channels in parts of Barapinang and Pankiranku Creeks.

Both the above trends coincide with premineralization jointing directions. This is shown by

1. minor quartz veins,
2. the dyke at Kupei (130°), and
3. Panguna Hill quartz diorite dykes (110° and 050°).

Brecciation and recrystallization in diorite shown by chlorite wrapping around granulated felspars has been observed in some diamond drill cores.

CONCLUSIONS

The rocks of the Kaverong Valley are made up of a group of andesite extrusives of the Kieta Volcanics sequence and a major intrusive called the Kaverong Quartz Diorite, which is the ultimate source of the copper mineralization. Locally the host rocks, and possibly the source rocks, are a group of biotite diorites perpiheral to the Kaverong Quartz Diorite. These rocks are the source of mineralization in the adjacent Panguna Andesite.

Late metasomatic changes in the biotite diorite resulting from the introduction of K-SiO_2-Cu were apparently responsible for the following features.

1. The formation of irregular quartz-chalcopyrite veinlets with pink orthoclase selvages.

2. The pseudomorphing of hornblende by biotite in the biotite diorite-type rocks, and the replacement of this mineral by copper minerals.

3. Biotitization associated with quartz-chalcopyrite veins in Panguna Andesite. The biotite occurs as selvages to veins and also in zones. Biotite and orthoclase appear to be the alteration minerals associated with ore. The later siliceous-pyritic argillic alterations are probably not related to ore formation. The leucocratic quartz diorite of Panguna Hill is generally more intensely altered than the biotite diorite in the area, both in the quartz-orthoclase-copper phase and later. This is evident from the greater degree of mineralization, pink orthoclase, quartz veining and argillic alteration seen in this area. At both Kupei and Panguna, the mineralization may be associated with elongated cupola vein sheets, the directions of which parallel regional joint/fault directions in the Kieta Volcanics.

Large and small zones of siliceous pyritic-argillic alteration, which are not unusual features in other porphyry copper deposits, occur in the area.

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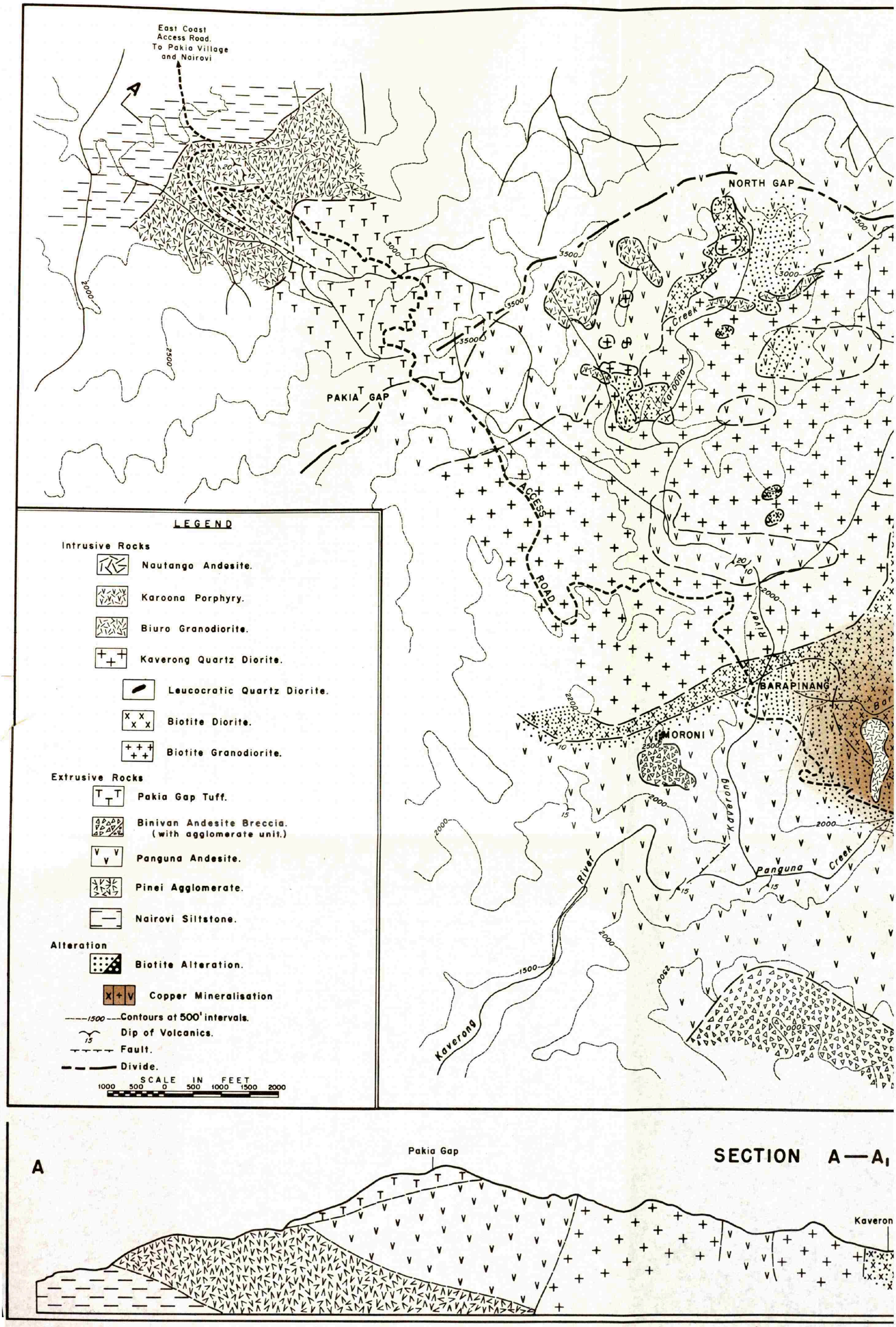
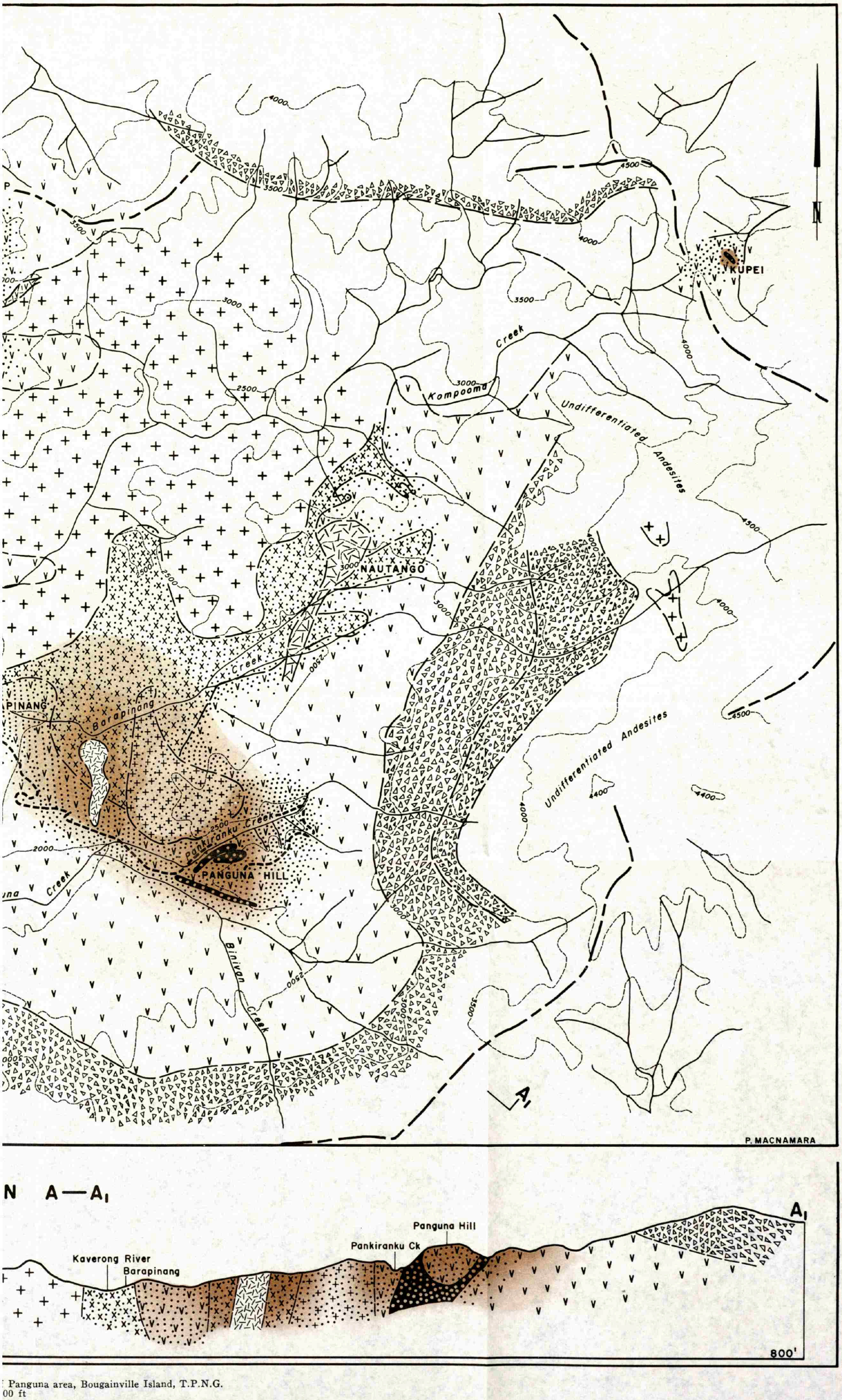


FIG. 3—Rock type and mineralization (plan and section) of Panguna area, Bougai
Scale: 1 in. = 1000 ft



Panguna area, Bougainville Island, T.P.N.G.
00 ft