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NICKEL AND ASSOCIATED MINERALIZATION IN THE TERRITORY OF PAPUA AND NEW GUINEA.

by

J.E. Thompson

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NICKEL AND ASSOCIATED MINERALIZATION IN THE TERRITORY OF PAPUA AND NEW GUINEA.

SUMMARY

Nickel mineralization of both the lateritic and silicate type occurs at several localities within the ultramafic zone of the Papuan Basic Belt. This Belt, which includes a discontinuous ultramafic zone along its south-western margin, extends for about 230 miles from the Musa Valley in Papua to near Salamaua in New Guinea.

Large areas of mature laterite are not developed on this ultramafic zone but, in heavily forested high-rainfall regions, thick residual clay profiles have been formed and preserved. Where these clays are derived from peridotitic rocks, they are enriched in nickel derived from olivine. The nickel enrichment increases downwards within the clay mantle and in some places supergene nickel magnesium silicate deposition occurs at the base of the clays and in fractures in the underlying peridotite.

Large quantities of nickel-enriched clay occur in the Kokoda area, Papua and in the Lake Trist area, New Guinea, but limited investigations to date, using hand augers only, indicate that the degree of enrichment is considerably less than that of the more mature nickeliferous laterites of Cuba, the Philippines and West New Guinea. It has also been noted that, unlike more mature laterites, the nickel content of the residual clays in Papua and New Guinea, usually increases towards the base of the profile. Any further testing of these deposits should be directed particularly towards the basal transition zone between fresh peridotite and clay which has not been adequately tested by the hand augering done to date. This would require mechanical drilling or deep pitting.

Many small fault wedges of serpentinite are known throughout Papua and New Guinea but, except for one occurrence in the Border Mountains in the Sepik Valley, these are probably too small and too dissected to contain economic lateritic nickel deposits.

Supergene nickel magnesium silicate mineralization has been recorded from several localities in the ultramafic zone of the Papuan Basic Belt, but none has been recorded from the lesser peridotite areas. Prospecting for nickel silicate deposits in the Papuan Basic Belt has been very limited and further efforts are warranted. In particular, the brecciated ultramafic rocks in the Wowo Gap area at the south-eastern end of the Belt warrant closer attention. Mechanical drilling or pitting in the Kokoda and Lake Trist areas may reveal nickel silicate deposits which were not detected by the manual augering of previous investigations. Bovio Hill in the Waria Valley, ten miles north-east of Garaina, offers prospects of nickel silicate mineralization not yet investigated. Zones of fractured peridotite adjoining faults or peridotite scree deposits are considered most favourable for nickel silicate deposition.

The ultrabasic rocks of Papua and New Guinea are not known to contain minerals, other than nickel, in potentially economic deposits. Small copper and gold lodes

are known but their outcrop is not impressive. Gold, platinum and osmiridium have been recovered by small ground-sluicing operations from many streams draining ultrabasic areas, but the principal gold mining activity is in regions intruded by granodiorites and acid porphyries. Chromite has not been recorded in lode form, but it occurs in small beach sand deposits on the north coast between Vanimo and the West New Guinea border and also in beaches south-east of Salamaua where the ultramafic zone of the Papuan Basic Belt is cut by the coastline. The iron and cobalt which occur as hydrated oxides in nickeliferous clays derived from peridotite could only be of interest as by-products from a well established lateritic nickel mining operation. Neither iron nor cobalt-bearing lodes have been recorded from the ultrabasic areas.

Nickeliferous sulphide lodes are not known but traces of nickel have been detected with copper and iron sulphides in stream boulders from the Bowutu Mountains area at the north-western end of the Papuan Basic Belt. Asbestos of economic grade has not been recorded.

INTRODUCTION

The Territory of Papua and New Guinea contains large areas of ultramafic igneous rocks with a primary nickel content of about 0.2%. Similar rocks in many parts of the world are the source of large, low-grade, superficial nickel deposits formed by the concentration of primary nickel into overlying residual clay by weathering processes.

In Cuba, the Philippine Islands, and West New Guinea, large quantities of residual clay with more than 1.2% nickel have been proved, but only at Nicaro, in Cuba, have such clays been economically mined and processed as nickel ore (Lutjen, 1954).

The eighty-year-old nickel mining industry of New Caledonia is based on many scattered occurrences of nickel magnesium silicate ore deposited with secondary silica in fractures in weathered serpentinite usually beneath mature laterite. This type of deposition is a concentration of the primary nickel dispersed through ultramafic rocks effected by the leaching of nickel-enriched residual soils and redeposition of nickel, in combination with supergene silica and magnesia.

The nickel-enriched clays of economic interest are universally called lateritic nickel deposits. This rather loose usage of "lateritic" is continued in this report even though mature laterites containing iron oxide accretions are very rare in the ultramafic areas of the Territory of Papua and New Guinea.

Nickel magnesium silicate deposits are widely referred to as "nickel silicate" deposits. This colloquialism is followed in this report. The nickel minerals of nickel silicate deposits are various combinations of nickel, magnesia, silica and water of crystallization which range from pale green and translucent to dark brown and opaque; green to brown nickeliferous serpentine is also a common component of many nickel silicate ores, and secondary silica is invariably present.

This report is not the result of a single specific investigation but is a compilation of information relating to the occurrence of nickel and associated minerals gained over a ten year period of general field work by Bureau of Mineral Resources geologists. Such information is, for the most part, sketchy and this report therefore must only be regarded as a guide for further work.

During 1957 and 1958, prospecting titles over large areas were granted to Bulolo Gold Dredging Limited and to several small local syndicates for the purpose of nickel prospecting. During this same period, brief inspections of some ultramafic areas were made by representatives of The International Nickel Company (Canada) and Enterprise Exploration Co. Limited (Australia). By the end of 1958 all nickel prospecting titles had been relinquished and since then activity in this field has ceased.

Geological mapping and prospecting in Papua and New Guinea are handicapped by the extensive cover of alluvium, thick residual soil and young volcanic deposits. Movements are restricted by the lack of roads, the rugged topography, the swamps and the thick rainforest. Any major prospecting venture, such as would be necessary to measure a large lateritic nickel deposit by close pattern drilling, would be costly and require careful planning. In some places helicopters could be used economically to transport personnel, supplies and equipment.

THE WORLD NICKEL SITUATION

Annual nickel production by the non-Communist countries is about 270,000 tons, of which 80% comes from Canadian sulphide ores. Other significant nickel producing countries are New Caledonia (9%) and United States of America (4%); both from nickel silicate ore. Japan, which has the smelting and refining capacity to contribute about 6% to non-Communist world production, imports nickel silicate ore from New Caledonia and the Celebes Islands.

Cuba, with immense nickel reserves in several low-grade lateritic nickel deposits, has an annual production capacity of about 44,000 tons of nickel metal but political instability does not ensure continuing production.

Large lateritic nickel deposits occur in West New Guinea, Borneo, the Philippine Islands, the Celebes Islands and Madagascar, but for various reasons they are not being mined. New Caledonia probably has large lateritic nickel deposits but while higher grade nickel silicate ore is available it is unlikely that the lateritic ore will be exploited.

The Communist countries do not import nickel and their estimated annual production is of the order of 50,000 tons of nickel metal, most of which comes from nickel silicate ores in the central and southern Urals.

Australia has no domestic supply of nickel but imports about 2,000 tons of the metal, in various forms, annually, either directly from Canada or from the United Kingdom. Some low-grade nickel silicate ore (figures not released) is imported from New Caledonia for use in the production of ferro-nickel alloys. Up to 1938 small quantities of nickeliferous pyrrhotite were mined near Zeehan, Tasmania, from lodes mineralogically similar to, but very much smaller than, the Canadian sulphide orebodies. At Mount Davies in the north-western corner of South Australia, a lateritic nickel deposit has been tested but regardless of the results, which have not been published, the remoteness of this deposit will retard its development. Small areas of nickeliferous laterite near Beaconsfield, Tasmania (Hughes 1957, 1959) and near Greenvale, Queensland (White, et al 1959) have been cursorily examined but results were not encouraging. The increasing use of stainless steel in industry has caused a sharp increase in the quantity of nickel metal imported into Australia in 1960.

The Canadian monopoly on world nickel supply has a strong stabilizing influence on the price of refined nickel. For five years prior to 30th June, 1961, the nickel price was static at 74 cents per lb. in U.S.A. and £(S)600 per long ton in the United Kingdom. The current price is 81.25 cents per lb. and £(S)660 per ton.

The bulk of the world's long-term reserves of nickel are undoubtedly contained in large low-grade (1%-2%Ni) lateritic nickel deposits in many parts of the world. However, highly efficient bulk mining and treatment of the Canadian sulphide ore, which in addition to nickel and copper, contains twelve by-product metals, has firmly established Canada as the most economic source of the world's current needs in nickel. A vigorous programme of exploration and research is increasing reserves and improving mining and milling techniques to such an extent that Canada's dominance as world nickel supplier seems assured for a long time.

New Caledonian silicate ores were the main source of nickel during the latter half of the nineteenth century but were displaced by Canadian sulphide ore about the turn of the century. Since then New Caledonia has been kept in the field as a significant producer by the application of production controls. Nickel silicate ore has also been produced in Oregon, U.S.A., Brazil, Venezuela, Russia, Greece, the Celebes, Madagascar and Tanganyika.

At present the economic cut-off grade of the New Caledonian silicate ore is about 3% and that of the Canadian sulphide ore between 1% and 3%, depending on the amount of associated copper. This disparity in cut-off grades is due mainly to the application of low-cost bulk mining and treatment of the Canadian sulphide ore and to the support given it by copper and other by-product metals. The nickel silicate deposits are inherently small, scattered and unpredictable in grade and size. They are not suited to bulk mining techniques and the associated metals - cobalt, chromium and iron - cannot be economically recovered from the nickel silicate treatment.

Cuban laterites were recognised as potential iron ore in 1886 but until 1930 their nickel content was regarded as an undesirable impurity (McMillan and Davies, 1955).

Attempts to extract this nickel were not successful until the later years of World War II when the United States Government, as an emergency measure, financed an elaborate and costly plant at Nicaro. Some nickel was produced uneconomically by this plant by the end of the war but it was not until 1954 that the Nicaro operation became economical (Lutjen, 1954); in 1959, 19,658 tons of nickel metal were produced. A second Cuban treatment plant capable of producing 25,000 tons of nickel per year was due to commence production in mid-1959 from lateritic ore in the Moa Bay area. However, political unrest has since caused closure of both the Nicaro and Moa Bay operations.

The early metallurgical problems in the treatment of lateritic nickel ore have been overcome but the high cost of the necessary installations can only be justified by very large ore reserves over which firm long-term tenure is assured. After the Cuban experience there is apparent reluctance to develop other large lateritic nickel deposits in politically unstable or under-developed countries. Interest in proved lateritic nickel deposits in West New Guinea and the Philippines and in the prospective areas of Borneo, the Celebes, Papua and New Guinea and the Solomon Islands is undoubtedly retarded by this apprehension concerning long-term security of tenure.

Although the Canadian sulphide mines can meet world demand for many years, the knowledge that no alternative source of nickel could be brought into production at short notice is cause for national concern. It seems unlikely that any local silicate or lateritic nickel ore deposit could compete economically, even on the local market, against the well-established Canadian and New Caledonian sources.

DISTRIBUTION OF NICKEL IN ROCKS

The close association of nickel with basic igneous rocks and in particular with the mineral magnesian olivine (fosterite) has long been the subject of much investigation and controversy.

From spectographic analyses of samples representing a range of differentiated phases in a basic intrusive in East Greenland, Wager and Mitchell (1951) studied the distribution of trace elements throughout the fractionation sequence. They found that nickel, with cobalt, was concentrated into the magnesian olivine and, to a much lesser extent into the pyroxene, of early crystallizing gabbro and that, in succeeding crystallizing fractions, these elements were markedly deficient, except in a final granophyric phase where the nickel content increased slightly. Ringwood (1955) suggested that this slight residual concentration of nickel in a fractionating basic magma may account for the nickel in the economically important hydrothermal sulphide deposits.

Ringwood (1955, 1956) refuted the popular theory that nickel substituted for magnesium in the olivine crystal lattice (Vogt, 1923). On the basis of experimental work, he concluded that a lowering of the solidification temperature by the presence of some iron in an essentially magnesian olivine melt permitted entry of nickel into early crystallizing fosterite at the expense of the more weakly bonded iron.

In the dunites and peridotites from which lateritic nickel deposits are derived, magnesian olivine (fosterite) always predominates. It commonly has the compositional range Fo_{85} Fa_{15} to Fo_{95} Fa_{5} and a nickel content between 0.15% and 0.30%, but ranging, in extremes, from 0.10 to 0.4%. No systematic investigations on variation of the nickel content of magnesian olivine within these limits have been carried out.

Ross, Foster and Myers (1954) found that nodular olivine inclusions in basalt from both continental and oceanic regions are remarkably constant in composition and are comparable with the olivine of the peridotite masses associated with deeply penetrating crustal fractures. They concluded that the olivine inclusions in basalt had been derived from a universal sub-crustal peridotite layer during the passage of basaltic magma from the sub-crust. The large masses of peridotite which are the source rocks of superficial nickel deposits are probably segments of this primordially differentiated peridotite layer faulted to the surface.

In view of the constant association of nickel, at about 0.2%, with the magnesian olivine of large ultramafic fault-bounded provinces, the scarcity of nickeliferous sulphide segregations within these provinces is anomalous. The nickeliferous sulphides of economic importance are almost invariably associated with feldspathic basic igneous rocks with clear intrusive relationships commonly in the form of sills and not necessarily adjoining deeply penetrating faults. If nickel is concentrated residually after fractional crystallization of a basic magma (Ross et al, 1954) then the absence of nickeliferous sulphide concentrations in the large ultramafic provinces may be due to the downward loss, into the sub-crust, of nickel concentrated residually from primordial fractionation. Conversely, the association of nickeliferous sulphide concentrations with intrusive basic magmas may imply fractionation in a confined, possibly floored chamber in which the residual magmatic concentrates are held awaiting re-distribution in the final cooling stage.

The large areas of ultramafic rocks containing nickeliferous olivine and the prevailing favourable climate for rapid chemical weathering in Papua and New Guinea make the prospects of locating economic lateritic and silicate nickel deposits more attractive than those of locating nickeliferous sulphide lodes.

NICKEL SULPHIDE DEPOSITS

Most economic nickel sulphide deposits are genetically associated with basic and ultrabasic rocks. The most important nickel sulphide minerals are the nickel-iron sulphides, pentlandite, violarite and millerite; copper and platinoid metals are common associates or by-products.

The important Canadian nickel sulphide orebodies occur most commonly as irregular, tabular bodies which persist to great depth usually near the lower margins of intrusive norites and gabbros. Other important nickel sulphide deposits with basic magmatic affinity are known in Norway, Finland and Southern Rhodesia. The nickeliferous sulphide deposits near Zeehan, Tasmania, which produced small quantities of high grade ore until 1938, are mineralogically and genetically comparable with the Canadian sulphides, but are much smaller.

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Nickeliferous sulphide lodes have not been recorded in Papua and New Guinea. Nickel in trace quantities only has been detected in some of the copper lodes near Port Moresby (Carne, 1913). Samples from a sheared sulphide lode in an ultramafic environment in Mebulibuli Creek on the northern side of Fergusson Island contained up to 0.25% nickel. It was found that this nickel was combined with primary magnetite and was not introduced with the lode sulphides (Roberts, Appendix 2).

Sulphide mineralization has been recorded from the following localities in the Papuan Basic Belt but none of these occurrences contain more than a trace of nickel:-

(1) The Foasi River, tributary of the Musa River (Smith and Green, 1960): Pyrite, chalcopyrite and possible arsenopyrite were noted but detailed minergraphic examination was not made.

(2) The Waria River, ¼ mile downstream from Sako village: irregular quartz-chalcopyrite veins up to 6 ins. wide and 20 ft. long containing some coarse gold, in gabbro which is exposed only when the river is low. Gold from this small lode has been recovered by natives by dollying and panning but the lode's small dimensions and the nearness of its outcrop to river level would not permit further exploitation. The mineragraphy of a specimen from this locality is described by Greaves (Appendix 3).

(3) Bakewa Hill near Upuru village in the Waria Valley: Edwards (1957) identified chalcocite and (?) chrysocolla in veinlets traversing rodingite derived from serpentinite by lime metasomatism.

(4) Enoto Point on the Morobe coastline between Kui and Sipoma: a quartz-chalcopyrite vein six to ten inches wide in sheared and brecciated dolerite (Dow and Davies, 1961). The sulphides in this lode are chalcopyrite, covellite, chalcocite and minor digenite.

(5) In the Paiawa and Saia Rivers and tributaries. Dow and Davies (1961) collected stream pebbles of basic igneous rocks with abundant sulphide mineralization. One specimen from the bed of Sou Creek, a tributary of the Paiawa River, contained, in order of abundance, pyrite, melnicovite, pyrite, marcasite, chalcopyrite, (?) millerite and rare pyrrhotite.

Baker (1959) described the petrography and mineragraphy of several ultrabasic rock specimens from the northern end of the Papuan Basic Belt. They contained microscopic amounts of accessory pyrite, pyrrhotite, chalcopyrite, chalcocite, bornite and rare traces of secondary native copper. He identified pentlandite rimming small particles of accessory pyrrhotite in one specimen of serpentinite from Koreppa in the Middle Waria Valley.

In a study of opaque minerals in basic and ultrabasic rocks in the Torricelli Mountains, New Guinea, Baker (1952) detected abundant accessory magnetite, ilmenite, spinels and rutile and rare chalcopyrite and pyrrhotite, but did not record any nickeliferous minerals. In olivine and hypersthene gabbros from the Cyclops Mountains, West New Guinea (Baker 1956) noted accessory pyrrhotite, chalcopyrite, bornite and chalcocite; also ex-solution pendlandite in accessory pyrrhotite.

Although prospecting coverage for nickeliferous sulphide minerals in Papua and New Guinea is poor, the apparent rarity of nickel sulphides, even as accessory constituents, in the basic rocks and sulphide minerals examined to date suggests that nickel has been fixed in the first-formed olivine crystals and is not dispersed through the later crystallizing phases, or concentrated into the latest crystallizing fraction.

Nickel sulphide minerals are rarely found in ultramafic rocks associated with circum-Pacific tectonics. Sulphides containing nickel and platinum occur in a low-grade chromite deposit in western Luzon, Philippine Islands (McClelland, 1955) and nickeliferous sulphides have been recorded at three localities in New Caledonia (Koch, 1958). These occurrences are too small to mine economically.

SUPERFICIAL NICKEL ENRICHMENTS.

Trace quantities of nickel bonded into the crystal lattice of magnesian olivine are released when this mineral, or its serpentinized derivative, breaks down chemically during weathering. Some pyroxenes also contain a trace of nickel, but in comparison with olivine they do not contribute significantly to superficial nickel deposits. The important source rocks of the nickel in both lateritic and silicate deposits are peridotites containing abundant magnesian olivine, principally dunite, a wholly olivine rock, and harzburgite, an olivine-pyroxene mixture. These rocks are commonly found together in elongated masses aligned along major faults, particularly in the young orogenic zones between continents and oceans. The peridotites are commonly serpentinized, but the degree of serpentinization does not seem to affect their rate of chemical weathering or their role as source rocks for superficial nickel enrichments.

On weathering, nickel from magnesian olivine is first concentrated residually by the removal in groundwater of soluble magnesia and silica. It is further concentrated by chemical rearrangement in the weathering mantle of less soluble weathering products. Oxidation of ferrous iron in solution causes the precipitation of insoluble hydrated iron oxides in the upper part of the weathering mantle. Aluminium and some manganese, nickel, and cobalt, also precipitate as hydrated oxides with the iron. Some nickel from the iron-rich zone is subsequently leached into the underlying clay which contains transient magnesia and silica. Under conditions of restricted groundwater circulation, nickel, magnesia, and silica may accumulate at, or near the base of weathering, where magnesian silicates may precipitate. The form in which nickel is dispersed through the upper, iron-rich zone and the underlying clay has not been identified; in the upper, iron-rich zone it may be as hydrated oxide while lower down it may be as a soluble bicarbonate (de Vletter, 1955).

The thickness of the iron-rich zone in relation to the underlying silica and magnesia-rich clay is probably a function of the time during which physiographic conditions and climate have favoured chemical weathering and the accumulation of its residual products. In Cuba, the Nicaro lateritic nickel deposit has an iron-rich zone comprising about 60% of the weathering mantle, but at Moa, about 40 miles distant, more than 90% of the mantle is iron enriched and, in some instances, iron enriched clay lies directly on hard, weathering, serpentinite (Engng.Min.J., 1954).

On flat or gently rolling country where erosion is slow, hydrated iron oxides may aggregate into pisolites, irregularly shaped accretions or thin crusts, which may eventually be cemented into a hard layer several feet thick, which has been commonly called* laterite or "ferricrete" (more recently).

On moderate to steep slopes, erosion may continually remove the upper part of the iron-rich zone of a weathering mantle as it is developing. Under such conditions laterite development is rare.

Observations in rainforest areas of New Guinea suggest that perpetual saturation of the entire soil profile inhibits the formation of laterite even though a high concentration of hydrated iron oxides may be attained. Laterite has been seen at the surface of residual soils where forest cover is lacking and rainfall is low and seasonal. Under very dry conditions or where surface run-off is high, thick residual soils do not form over ultramafic rocks but infertile rubble containing magnesite nodules accumulates. This type of weathering has been seen on Normanby Island, the southern flank of the Musa Valley and near Port Moresby.

Ore grade concentrations of nickel are rarely found in the top few feet of a lateritic nickel deposit, but are commonly encountered in the lower half of the iron-rich zone and extend down through the magnesia and silica-rich zone to the base of weathering. The distribution of nickel and other elements through the weathering profile at Ocujal, Cuba, as determined by de Vletter, (1955) is graphically shown as Fig. 1.

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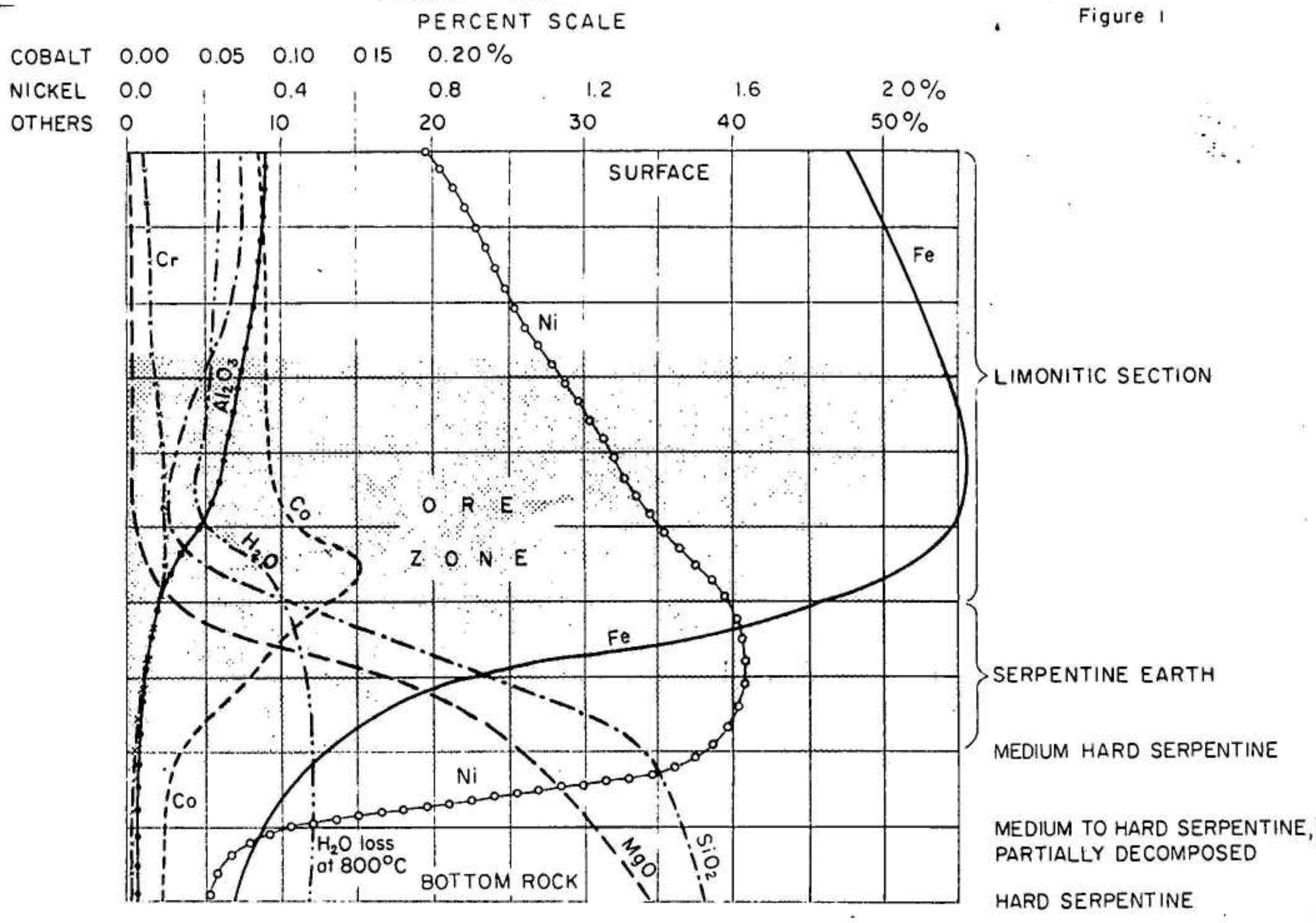
* Throughout this report the term "laterite" has been used for hard, cemented aggregates of hydrated iron oxides. This accords with field usage by most Australian geologists, but it is not entirely consistent with Buchanan's original application of the term (Fox, 1932) when, in 1907, he described as laterites ferruginous clays which could be cut with a trowel or knife when freshly quarried but which hardened on exposure. The restrictive use of laterite for hard, hydrated iron oxide accretions is preferred here because, under high rainfall conditions, many clays with an iron content often exceeding that of hard laterites are indistinguishable in the field from clays containing only small amounts of iron. "Lateritic clay" and "lateritic nickel deposit" as used in this report refer to the process of lateritization which, in the ultramafic areas of Papua and New Guinea, is only rarely sufficiently advanced to yield the hard laterite end-product.

Figure 1



CHEMICAL ZONING IN WEATHERING MANTLE OVER SERPENTINE, OCUJAL, CUBA (after De VLETTER, 1955)

Bureau of Mineral Resources Geology and Geophysics. September 1961. 0/4/1 EJ

Investigations in Papua and New Guinea have not been sufficiently detailed to determine the vertical distribution pattern of nickel and other metals in residual clays over peridotite. However, analyses of auger hole samples from near Kokoda (Plate 4 and Appendix 1) and the Waria Valley (Plate 6) have indicated that nickel increases consistently from the surface down to the limit of augering. The distribution of some metals through an incomplete soil profile on the Arumu Slopes near Kokoda is indicated in the table on page 17.

Although both lateritic and silicate nickel deposits evolve through weathering processes, rarely are both developed to ore grade in the same locality. Nickel silicates occur at the base of many of the large lateritic nickel deposits but only rarely are they of economic size. The different modes of occurrence and the different treatment processes for lateritic and silicate nickel ores do not normally permit joint mining and treatment. In New Caledonia vast low-grade lateritic deposits which cannot be treated by the processes designed for the silicate ore are not being mined while silicate ore is still available.

At Nickel Mountain in Oregon, where nickel silicate ore occurs beneath a veneer of slightly nickel-enriched laterite and clay, mixed laterite and silicate ore is mined and treated in a common plant by a complex, patented process.

Nickel magnesium silicate deposition represents the ultimate stage in the concentration of nickel derived from the weathering of nickeliferous magnesian olivine. Attainment of critical ionic concentrations of nickel, magnesium and silica for the deposition of nickel magnesium silicate probably results from either restricted groundwater movement or from repeated evaporation or both. In New Guinea, where rainfall is high, forest cover almost universal and slopes commonly moderate to steep, much nickel is probably flushed laterally both through the clays and along the base of weathering to be lost into surface drainage.

Small showings of nickel magnesium silicate have been seen at many widely separated localities in Papua and New Guinea. Factors controlling this deposition, particularly in the high-rainfall forested areas are not fully understood. In most cases, these showings have been encountered at or near the base of weathering in auger holes drilled through nickel-enriched clays. They have also been seen in the interstices of peridotite clastic deposits. Nickel magnesium silicate deposition may be more widespread than the few known small showings suggest. The zone of silicate deposition in a weathering mantle would normally be beyond the limit of manual augering and the testing of nickel-enriched clays by this method cannot be regarded as conclusive testing for nickel magnesium silicate deposits. The transition zone containing both clay and residual boulders would have to be completely traversed to test for nickel silicate deposits. This could be done only with hard rock drilling equipment or by shaft sinking.

HISTORY OF INVESTIGATIONS

The first record of nickel in Papua and New Guinea referred to a specimen of mudstone collected in 1915, and analysed in 1916, which was found to contain 0.11% nickel (0.14% as nickel oxide, in which form it is expressed in old records). This specimen was collected by Mr. W.M. Beaver, Resident Magistrate of the Kumusi Division (now the Northern District) following reports that the mudstone, locally known as "munoki", was eaten by natives for medicinal purposes. The "munoki" locality was visited by E.R.Stanley, Government Geologist, in 1916, who in departmental correspondence, described it thus:-

> " ... in a small branch of the Nahoja Creek which flows northerly into the Mamama River (a major tributary of the Kumusi River - J.E.T). It is about half a mile from the mouth of the former and situated a short distance up the first left-hand tributary."

The nickeliferous mudstone was greyish-mauve, fine-grained, about 18 inches thick and overlain by 3 feet of bedded, carbonaceous shale and 40 feet of conglomerate containing peridotite, andesite and basalt boulders. Stanley saw no nickel magnesium silicate minerals and was not impressed with the nickel prospects of the area.

After widely ranging field work during the following seven years, Stanley recognised a linear "serpentine belt" along the north-eastern front of the Owen Stanley Range extending from the Musa Valley to the Waria Valley. Although this finding was not clearly stated or illustrated in his published works, the following extract from an unpublished report (Stanley, 1921), concerned with osmiridium prospecting, indicates his recognition of a major linear ultramafic zone:-

"The main belts of serpentines pass through the headwaters of the Waria to the Gira and Aikora Rivers and follow up the right bank of the Yodda to the Adjula Kujala (Ajura Kujara - J.E.T.) Range, thence through Oivi into the valley of the Kumusi and along the little Kumusi (Mamama River). It is also met with in the Mugoni (Upper Musa) River on the right bank below Balatana village and passes into the country north-east of Mt. Brown."

In 1946, K. Washington Gray in the course of geological investigations for an oil company, collected specimens of ultrabasic rocks exposed in the Arumu River near Kokoda (Gray, 1955). He recognised a possible analogy to the New Caledonian ultramafic province and recommended further investigation for nickel silicate deposits under peneplane remnants, though he realised that large peneplaned areas in such rugged country were unlikely.

In 1952, the writer noted minor nickel magnesium silicate mineralization in serpentinite near Koreppa in the Waria Valley but, little economic significance was attached to it. Subsequent regional survey in the Musa Valley and aerial observations between the Musa and Waria Valleys (Thompson, 1957) suggested an almost continuous zone of ultrabasic and basic rocks extending south-east from the coast near Salamaua for about 230 miles to the eastern end of the Musa Valley. This zone was then tentatively named the "Papuan Ultrabasic Belt"; it contained Stanley's "belts of serpentines" and had as its south-western boundary a major fault which had been recognised by both Stanley (1924) and Gray (1955) near Kokoda. This basic province was later renamed the Papuan Basic Belt, and sub-divided into an ultramafic and a feldspathic zone (Dow and Davies, 1961).

A few widely scattered auger holes were drilled by the writer during 1957 through residual clays over peridotitic rocks of this ultramafic zone near Kokoda and also in the Waria Valley. Samples of clay from these auger holes contained up to 1.5% nickel. This was surprising as the soils were not maturely lateritized and slopes were moderate to steep. Analyses of the underlying serpentinized dunite indicated a primary nickel content of about 0.2%. The nickel enrichment in the clays was obviously a product of contemporary weathering processes (Thompson, 1957). This indicated that important nickel enrichment could occur without peneplanation and ancient weathering. This realization inspired a search for nickel-enriched clays of ore grade and dimensions.

H.L. Davies (1958) reconnoitred the mountainous block of basic and ultrabasic terrain between the Mambare and Kumusi Rivers. He collected a few near-surface residual clay samples from the Okawu Terrace area which was sampled in greater detail in 1960. The results of this sampling are contained in Appendix I of this report and discussed later in the text.

During 1957 and 1958, much of the ultramafic zone along the south-western side of the Papuan Basic Belt was cursorily examined for lateritic nickel deposits by geologists representing large mining companies and by prospectors for small locally formed syndicates. This activity lasted about twelve months and no important new finds were made.

In 1958, a small typical area of nickeliferous clay near the Arumu River in the Kokoda area was drilled with manual augers on a close grid to determine the degree of both vertical and lateral variation in nickel content. This programme was conducted under the writer's supervision and the results are discussed in a later section of this report.

In the same year, a Bureau of Mineral Resources survey party (Smith and Green, 1959) mapped a large part of the Musa Valley at the eastern end of the Papuan Basic Belt. There they did not find the simple zoning pattern of peridotite grading through a gabbro to dolerite and pillow lavas which prevails in the northern half of the Belt. They found an irregular distribution of differentiated phases within the Belt which they attributed to deformation of an originally layered basic and ultrabasic pluton. They mapped several occurrences of brecciated serpentinite and clastic peridotitic sediments as volcanic products.

Dow and Davies (1961) mapped the Bowutu Mountains at the northern end of the Papuan Basic Belt, subdividing it into ultramafic and feldspathic zones. They recommended further prospecting for lateritic nickel deposits and drew attention to copper mineralization within the Belt and to alluvial gold and platinum shedding from it.

NICKELIFEROUS PROVINCES IN PAPUA AND NEW GUINEA.

I. General

The most favourable nickel source rocks, dunite and harzburgite, serpentinized to varying degrees, are common within a discontinuous zone of ultramafic rocks up to ten miles wide along the south-western margin of the Papuan Basic Belt. Along this zone, a wide range of physiographic conditions prevail, but nowhere are conditions ideal for the formation and preservation of large lateritic nickel deposits of economic grade. Those areas within this zone which are known to contain superficial nickel concentrations are described below in order from south-east to north-west.

Other occurrences of ultramafic rocks not within the Papuan Basic Belt but which have nickel prospects are also described.

II. Areas Examined within the Papuan Basic Belt

(1) The Musa River Area (Plate 2).

The Musa River drains a large area at the eastern end of the Papuan Basic Belt.

Ultramafic rocks were first noted at the eastern end of the Didana Range by the writer during a regional reconnaissance survey in 1953. A weathered specimen of serpentinized dunite collected then, but not analysed until 1957, contained 0.64% nickel (Thompson, 1958).

In 1957, when it was appreciated that the ultramafic zone of the Papuan Basic Belt extended as far south as the Musa Valley, several Special Prospecting Authorities were taken up by Bulolo Gold Dredging Limited, and representatives of local syndicates, for the purpose of prospecting for nickel. A short-lived phase of reconnaissance prospecting followed, but no important deposits were discovered. Within twelve months these Prospecting Authorities were abandoned.

The writer visited the area again in 1958, and, later in the same year Smith and Green (1959), systematically mapped a large part of the Musa Valley. They delineated several isolated masses of ultramafic rocks on both flanks of the valley and at the eastern end of the Didana Range.

The irregular distribution of ultramafic rocks in the Musa River area is in strong contrast with the orderly alignment of an ultramafic zone along the south-western faulted margin of the Papuan Basic Belt farther north. The distribution of ultramafic rocks in the Musa River area is attributed to folding of magmatically differentiated layers (Smith and Green, 1959) and to transverse faulting. Tertiary and Quaternary lake sediments, piedmont deposits and pyroclastics further mask the continuity of the ultramafic zones.

Smith and Green regarded some brecciated and coarse clastic ultramafic rocks in this region as products of Quaternary, wholly gaseous, vulcanism. The writer prefers a sedimentary origin for these clastic deposits. Silica, serpentine and garnierite deposited interstitially in the clastic deposits, can be simply explained by the secondary deposition of the leaching products from tropical weathering of peridotite. Green (1961) suggests that this mineralization was introduced by volcanic emanations following ejection of the peridotite breccia and associated clastic deposits.

Brick-red and mustard coloured nickel-enriched soils and green nickel magnesium silicate minerals were first noted in landslips on the lower northern slopes of the Gorupu Mountains just east of Wowo Gap and on the steep slopes at the eastern end of the Didana Range flanking Wowo Gap (Thompson, 1958). At these localities the slopes are too steep for the retention of thick residual soils and thus there is no prospect of large lateritic nickel deposits. Green nickel silicate and chalcedony commonly occupy fractures in serpentinized dunite and harzburgite beneath a thin veneer of brick-red soil. Fracturing is prevalent in the serpentinized ultramafic rocks close to the large fault which passes through Wowo Gap. These fractures and the interstices in the clastic ultramafic rocks are excellent depositories for supergene chalcedony, garnierite and nickeliferous serpentine. The nickel content of the supergene minerals in this type of deposit may be of economic interest. A specimen of brecciated serpentinite from the Wowo Gap area containing 0.71%/was readily separated into a serpentinite /nickel fraction (60%) and a matrix fraction (40%) which contained 0.18% Ni and 1.20% Ni, respectively. Samples from the soil base at two localities on the western side of Wowo Gap contained 1.12% and 1.36% nickel, respectively. Partial analyses of samples taken at 4 feet and 7 feet in a soil profile near Wowo Gap gave the following results:-

Depth	% SiO_2	%Fe	%Ni	%Co
4 ft	51.60	9.23	0.81	nil
7 ft	40.00	17.45	1.33	nil

The low iron and high silica contents in these two samples suggest that nickel is present as a silicate and not as dispersed lateritic nickel.

Samples taken through a soil profile near Wowo Gap by Smith and Green (1958) had the following nickel contents:-

At 1 ft - 0.82% Ni.
5 ft - 0.96% Ni.
10 ft - 1.06% Ni.
13 ft - 0.92% Ni.

The large area of ultramafic rocks on the southern flank of the eastern end of the Musa Valley is deeply dissected and has little residual soil cover. Nickel magnesium silicate minerals have not been recorded from this area but magnesite nodules have been seen by the writer on the grassy slopes south of Silimidi Creek. In this area, thick residual soils, in some places containing lateritic pisolites, are developed on sub-horizontal coarse clastic peridotite deposits interbedded in coarse conglomerate. These soils have been tested in a few places and found to contain generally less than 0.5% nickel. (Thompson, 1958). This comparatively low nickel content may be due to dilution by components other than peridotite in the breccia.

Smith and Green (1958) have recorded sulphide mineralization in an 80-foot wide shear zone between serpentinite and dolerite exposed in the Foasi River, south of Awala, on the southern side of the Musa Valley. These sulphides include pyrite, chalcopyrite and possibly arsenopyrite. Some secondary malachite is also present. Pyrite and chalcopyrite was also recorded as disseminations, shear fillings and lenses in metamorphic rocks in the Gorupu Mountains and also exposed in the Awala River. Nickel minerals were not seen with any of these sulphides.

The most prospective area for economic superficial nickel deposits in the Musa Valley is near Wowo Gap, where nickel magnesium silicates occur in brecciated serpentinised peridotite and clastic peridotite deposits. The depth to which supergene silica and nickel magnesium silicates have penetrated into fractures and intergranular interstices of these rocks is unknown. If Green's (1960) concept of brecciation by wholly gaseous volcanic activity is correct, then the vents of such activity would be favourable sites for concentrated supergene nickel magnesium silicate deposition. Such deposits may be in the form of deeply penetrating pipes containing stockworks of secondary silica, nickel magnesium silicate and serpentine in fractured serpentinized peridotite. Further detailed mapping is required to delineate zones of brecciation in the peridotite of this area. The degree of nickel silicate enrichment in the fractured peridotite could only be conclusively determined by sluicing off overlying soil and close drilling. This area of interest presents some access problems which could be lessened by the use of helicopters or air-drops. Should nickel magnesium silicate deposits be found, the large hydro-electric potential of the Musa River might be considered as a source of power for treatment of the ore.

(2) The Kokoda Area (Plate 3)

Kokoda, the administrative headquarters of a sub-district of the Northern District of Papua, lies within the Yodda Valley, which occupies the crush zone of the Owen Stanley Fault and separates the high and rugged Owen Stanley Range on the south-west from the lesser Ajura Kujara Range on the north-east. The nickeliferous "edible earth" outcrop recorded in 1916 by Stanley (departmental correspondence) was exposed in a tributary of the Kumusi River about 30 miles south-east of Kokoda. Stanley recognised serpentinites at the eastern end of the Ajura Kujara Range but did not rate highly the prospect of economic nickel silicate mineralization. At that time the economic potential of the lateritic nickel deposits was not appreciated.

Nickel-enriched soils were discovered (Thompson 1957) on the northern slopes of the Ajura Kujara Range near where Gray (1955) collected specimens from a basic and ultrabasic suite of rocks.

The Owen Stanley Range is composed of metasedimentary rocks of low metamorphic grade and the Ajura Kujara Range is part of the Papuan Basic Belt with ultramafic rocks along most of its south-western flank and gabbroic rocks in its crestal and north-eastern foothill zones. Peridotite rocks with nickel source potential are abundant within the ultramafic zone. However, pyroxenite, as dykes and possibly as differentiated layers, occurs throughout the ultramafic zone. These pyroxenites weather to clays very similar to those derived from the olivine-rich ultramafic rocks but their nickel content is much lower. Thick residual clay covers most of the ultramafic zone and exposures are seen only in the major streams. The relative amounts of nickel-bearing peridotite and pyroxenite in the ultramafic zone are not known (and could not be reliably estimated without close drilling) because of the physical similarity of their residual clays.

The south-western slopes of the Ajura Kujara Range have a high, year-round rainfall (150-200 inches per year) and are covered with thick primary rainforest. These conditions promote rapid chemical weathering of the ultramafic rocks; the feldspathic basic rocks are less susceptible. Despite the moderate to steep slopes, a thick mantle of brick-red to mustard-yellow residual clay covers most of the ultramafic zone. The clay over the olivine-rich rocks is enriched in nickel derived from the olivine. The degree of nickel enrichment in these clays is very variable and depends on many interacting factors, most important of which are probably maturity of the clay profile and subsurface drainage. The nickel content of these clays usually ranges from 0.2% near the surface to about 1.2% at the base of the weathering mantle and rarely exceeds 1.5%.

On the south-western fall of the Ajura Kujara Range two principal areas of nickel-bearing clays have been recognised and cursorily tested. For the purpose of this report these area have been named (1) the Arumu Slopes and (2) the Okawu Terrace; and because of their different features they are described separately:-

(1) The Arumu Slopes

This area, shown on Plate 3, is about 10 miles long and 3 miles wide. It extends along the lower south-western slopes of the Ajura Kujara Range from the Ivoro Creek drainage area south-eastwards to the head of the Yodda Valley. As seen looking north and east from the Kokoda Government Station, the Arumu Slopes comprise a succession of broad rainforest-covered spurs sloping regularly towards the Yodda Valley.

Dunite and harzburgite are the predominant rock types of this area. The high rainfall and moderate relief favour the formation and retention of residual clays enriched in iron near the surface and in nickel towards the base.

During the latter half of 1957, much unsystematic augering by the writer, H.L. Davies and prospectors, indicated nickel-enriched clay wherever olivine-rich ultramafic rocks were being weathered. No useful quantitative data on either quantity or grade were obtained during this phase but many of the problems of evaluating the prospect became apparent. This early work suggested that although the Arumu Slopes contained a large quantity of nickel-enriched clay, the average nickel content was probably lower than that of the economically interesting lateritic nickel deposits of Cuba and West New Guinea.

During these early investigations analyses, such as these tabulated below, on samples taken through a clay profile near the toe of the spur on the right bank of the Arumu River focussed attention on enrichments of nickel, chromium and iron which were not apparent as discrete minerals.

	(0'-3')	(3'-7')	(7'-10')	(10'-14')	(14'-18')	(18'-22')	(22'-26')
Silica (SiO_2)	33.21	16.54	7.70	12.7	18.35	22.7	26.89
Iron (Fe_2O_3)	22.83	49.33	65.62	63.55	60.30	57.50	55.56
Chromium (Cr_2O_3)	0.1	1.97	3.55	4.15	4.10	3.00	3.00
Nickel (Ni)	0.05	0.45	0.65	0.79	1.42	1.20	1.15
Cobalt (Co)	0.008	0.002	0.01	0.005	0.005	0.005	0.007
Alumina (Al_2O_3)	20.00	11.20	4.90	3.30	2.60	3.80	Not detected
Moisture	4.50	3.00	2.40	2.40	2.40	2.20	2.40
Loss on Ignition	11.95	12.50	12.8	11.40	9.9	9.5	9.5

Examination of these analyses indicates that, except in the interval from 0-3 feet, the metals are distributed in the profile in a manner similar to the distribution in the upper half of the more mature Cuban profile (Figure 1). The high silica, relatively low iron and high alumina in the interval, 0-3 feet is attributed to contamination by andesitic tuff, although this was not detected when the samples were collected. The auger hole from which these samples were taken did not reach hard rock. The unusally low cobalt content may be due to removal of cobalt in solution by laterally moving groundwater in the profile.

In order to obtain information on the lateral variation of the nickel content of the clays, detailed testing of a very small but typical area was undertaken.

A small area of deeply weathered serpentinized dunite on a 20-30° slope near the toe of the first spur east of Arumu Creek was chosen for this detailed testing. This fairly steep slope was selected because it was confidently thought that, under the prevailing climatic conditions, chemical weathering was proceeding at such a rate that even the steeper slopes would have retained a thick soil cover and that vertical chemical zoning within the profile was the product of contemporary weathering. The relative importance of lateral, down-slope movement of nickel within the weathering mantle was not known and it was hoped that the detailed augering might throw light on this aspect.

The test area, 200 feet by 200 feet, was drilled at 20 feet centres, on a square grid pattern, with 4" Jarrett-type augers and 3-foot extension rods of ¾" galvanized water pipe. The augering was done by a team of natives supervised by W. Balmain, field assistant employed by the Territory of Papua and New Guinea Mines Division. All holes were drilled to hard rock, against which the auger could make no progress. The depths reached by the auger may not invariably represent the true base of weathering. In some cases, residual unweathered tors within the clay profile may have halted the auger. The rock-clay interface at the base of the weathering mantle was not seen but the augering indicated that it is probably very irregular. Manual augering can only indicate the minimum thickness of residual clay and it is possible that the basal part of the profile, which may contain the highest nickel content, was not penetrated. Samples were taken over each 3-foot interval commencing after rejecting the first foot which contained much decaying vegetation. All samples were gravimetrically assayed for nickel by the glyoxime method in Port Moresby. The assay results are presented in histogram form in true spatial relationship on a contour plan of the area (Plate 4). This presentation could be misleading if account is not taken of the water content of the clay samples in situ which constitutes from 30% to 40% by weight. All the nickel assays depicted on Plate 4 refer to samples which were oven dried at 105°C. Thus a dilution factor of about 35% should be applied to these assay results to determine the nickel content of the wet clay in situ.

In the estimation of ore reserves of the Levisa District, Cuba, a factor of 1.21 was used to convert cubic meters of clay in situ to dry metric tons but, it was admitted that specific gravity and moisture content ranged widely (McMillan 1955). For the purpose of assessing ore reserves in the lateritic nickel deposits of Surigao, Philippine Islands, the weathered profile was divided into four zones with the following dry weight-to-volume in situ ratios:- 1.268, 1.179, 0.889, 1.179 in order from top to bottom (Wright et al, 1958). This variation is caused by a combination of the chemical aggregation of heavy compounds, porosity after leaching, and variable water content.

The results plotted on Plate 4 indicate that, within the test area, there are definite zones of high and low nickel content broadly related to the thickness of the weathering mantle (as indicated by augering), which does not conform with the present surface. The zones of deepest weathering have the highest nickel content.

Throughout the augering programme fragments of brown, coarsely skeletal, weathered pyroxenite,(enstatitite) were recovered with fragments of weathered dunite and harzburgite. Elsewhere in the district, coarse pyroxenite dykes were noted in sharp contact with otherwise massive peridotite, but exposures are so rare that the ratio of dunite to pyroxenite in this province could not be reliably estimated.

Analyses of specimens of unweathered serpentinite and pyroxenite taken from nearby exposures in the Arumu Creek area are set out below:-

	Serpentinized dunite	Pyroxenite
	%	%
SiO_2	33.00	55.66
Al_2O_3	1.83	0.79
Fe_2O_3	7.92	4.42
FeO	1.06	2.95
MgO	44.37	34.64
CaO	0.10	0.05
Na_2O	0.65	0.70
K_2O	0.11	0.12
H_2O + (1000°C)	10.90	0.97
H_2O-	0.34	0.03
TiO_2	0.10	0.10
P_2O_5	0.04	0.03
MnO	0.05	0.07
NiO	0.25	0.05
Cr_2O_3	0.21	0.10

In the evaluation of areas of nickeliferous clays it is important to know the ratio of nickel-bearing peridotite to nickel-deficient pyroxenite beneath the clays. The residual clays from peridotite and pyroxenite are physically indistinguishable in their upper levels but, in the lower levels, the clays from pyroxenite are chocolate-brown and contain skeletal pyroxenite pseudomorphs whereas those from dunite are yellow-brown and massive. Zones of low nickel values within clays of high nickel enrichment may represent shadow zones from underlying nickel-deficient pyroxenite dykes.

Some of the positive relief at the base of the weathered profile which generally corresponds with the lowest nickel values may be due to differential resistance of pyroxenite dykes to chemical weathering. To account for the concentrations of nickel within the test area lateral (downhill) as well as vertical migrations must be invoked. The zones of deep weathering probably act as channelways and sumps in the subsurface drainage system and the concentrations of nickel may be largely due to adsorption or precipitation from nickel-bearing solutions moving through or into these channels or sumps.

Chips of green nickel magnesium silicate minerals and chalcedony were recovered from the basal few feet of many of the auger holes, but in no case was a well-defined layer of garnierite recognised.

No attempt has been made to extrapolate the results obtained in the test area to estimate the total quantity or grade of nickel-enriched clays in the entire Arumu Slopes. At this stage such extrapolation would be premature, because factors such as degree of dissection, ratio of pyroxenite to olivine rocks, and extent of flushing of the nickel from the profile into surface waters have not been adequately investigated. Detailed assessment of the area as a lateritic nickel prospect would require detailed topographic survey, close drilling, preferably with equipment capable of drilling through hard rock, and many thousands of nickel assays. However, the results of investigations to date do suggest that nickel enrichment is not as high as in the economically interesting lateritic nickel deposits of West New Guinea and Cuba.

(2) <u>The Okawu Terrace</u>

The name Okawu Terrace is here applied to the large gently undulating erosional terrace on the south-western flank of the Ajura Kujara Range between the Mambare Gorge and the Ivoro drainage area (see Figure 2 and Plate 3).

The origin of the Okawu Terrace is conjectural. It may have been formed by preferential rapid chemical weathering of ultramafic rocks in contrast to the slower, physical, erosion of the feldspathic basic rocks which form the crest and north-eastern flank of the Ajura Kujara Range. Alternatively, the terrace may have been the former floor of the Yodda Valley, much wider than the present-day floor, now elevated to its present position by fault movements and stripped of its alluvial cover by erosion. Regardless of its origin, the Okawu terrace is one of the few large areas throughout the length of the Papuan Basic Belt where the products of prolonged chemical weathering have accumulated. The terrace occupies about ten square miles which includes:-

(i) a large area south-east of the gorge of the lower reaches of Okawu Creek, and

(ii) a small area between the lower Okawu and Mambare Gorges. (Plate 3).

Figure 2.

(a) From the Kokoda airstripin the Yodda Valley - skyline is southern edge of Terrace.

(b) From the air over lower Okawu Gorge looking south-east.

(c) Camp site on Okawu Terrace - note dense rain-forest.

The Okawu Terrace is completely covered by primary rainforest and, in places, has an almost impenetrable undergrowth of bamboo and lawyer cane (rattan). Moss grows in profusion on a carpet of decaying vegetation which is perpetually moist. The high rainfall (+ 250 inches per year) and the negligible evaporation keep the residual clay mantle saturated. The area is completely unpopulated and is only rarely hunted by people living in the Yodda Valley. Game is sparse and includes pigs, cassowaries, wallabies and echidna; birds are rare and in consequence the place is strangely quiet. Nights are cold and daily afternoon rains are usual.

Looking north from the Kokoda airstrip, the southern edge of the Okawu Terrace forms the sub-horizontal, gently undulating skyline, but no hint is given of the large tract of country with moderate relief beyond this skyline. The descent from the Terrace at 3200-3700 feet a.s.l. to the Yodda Valley about 1200 feet a.s.l., is accomplished in less than two miles.

Although only four to five miles from the Mamba Rubber Plantation in the Yodda Valley, access to and operations on the Okawu Terrace are thwart with many problems attendant on high rainfall, thick forest, lack of population and local native superstition. Best access to the area is by a track, cut expressly for the purpose of investigations on the terrace during 1960, which starts on the right bank of the Mambare River near the mouth of Ivoro Creek and follows the long spur forming the western limit of the Ivoro drainage area. This track will become overgrown in time but during the next few years could be re-opened much more easily than cutting a new track through the primary rainforest.

The possibility of a large lateritic nickel deposit on the Okawu Terrace was appreciated early in 1957 but no serious attempt was made to test the area until 1960. Late in 1957, during a regional geological survey, Davies (1959) entered the Okawu Terrace area by way of Anaura Creek and collected a few residual clay samples from depths to 15 feet. Davies again visited the area briefly in 1958 and collected shallow soil/samples. W. Balmain made a rapid reconnaissance trip to the headwaters of Ivoro Creek in 1958 after completing the detailed sampling project on the Arumu Slopes. These early reconnaissance ventures were severely hampered by labour troubles, adverse climatic conditions and inadequate augering equipment. All auger holes drilled during these investigations bottomed at 15 to 20 feet on a hard layer which was later identified from chips in the bottom samples as a lateritic "hard-pan". Clay samples from above this false bottom contained only a trace of nickel. The results of partial analyses of specimens taken through the upper part of a clay profile in this area in 1957 are set out below:-

Depth	%Fe_2O_3	%Al_2O_3	%TiO_2	H_2O (1000 C)
0 - 3'	7.59	25.26	0.17	12.5
3'- 6'	10.0	24.13	0.29	13.1
6'- 9'	9.8	23.62	0.22	12.9
9'- 12'	12.1	25.0	0.30	13.9
12'- 15'	11.3	19.43	0.27	2.5

The alumina content of these samples is surprisingly high, and the iron content low, particularly as serpentinite (Al_2O_3 less than 2%) crops out nearby and was thought to underlie the profile drilled. This anomalously high alumina content was first attributed to alumina segregation in an advanced state of lateritization which implied underlying iron and nickel enrichment. This optimistic inference provided stimulus for a more concerted effort to test below the laterite layer in the Okawu Terrace. Subsequent investigations showed that clay above the lateritic hardpan represents a decomposed andesitic tuff layer and is not part of the peridotite weathering profile.

In June 1960, a base camp was established by the writer on the south-western edge of the terrace and a deep augering programme was commenced. The project was taken over by H.L. Davies and completed in early August 1960. Assay details are tabulated in Appendix 1 and augering locations and depths are shown on Plate 5.

Although thick clay profiles were expected and it was known that, at least in some places, a hard lateritic layer would have to be penetrated, the difficult access precluded the use of mechanical drilling equipment. The manual augering equipment proved very successful, though slow, to depths of 70 feet. This success is largely due to the perseverance and ingenuity of H.L. Davies and his native team. Three-foot lengths of ¾" galvanized water pipe were used as extension rods and linkage was affected by normal water pipe unions. Heavy fish-tail and chisel bits fitted with appropriate couplings were used to penetrate the hard laterite layer (in holes OP1 and OP2 this layer could not be penetrated) and to break through small unweathered rock "floaters" within the clay.

For the holes deeper than 15 feet a scaffolding was constructed from bush timber and vines with platforms about every ten feet through which the drill string was raised and supported. By this arrangement drill strings up to 70 feet long were successfully handled and the laborious process of breaking-down was eliminated. Without support, drill strings of ¾" water pipe more than 20 feet long tend to break at the unions. At depths of 50 to 70 feet the limitations of this equipment were, in order of importance:-

1. Inability to lift wet, slurried, clay which was commonly present near the base of the weathering mantle.

2. Risk of breakage at unions when lifting through very wet clay which would squeeze into the hole.

3. Breakage of auger blades against hard rock.

The equipment could be improved by modifying the design of the auger bits, and by the use of stronger extension rods and unions. Spiral auger bits proved unsuccessful in these clays. Deep manual augering is slow, the drilling of the first 40 feet usually took from 6 to 7 hours, but below 40 feet where the clay was very wet, the rate of drilling slowed to about three feet per hour.

Early in the investigation, recognition of a widespread cover of tuff and a very deep clay profile below the tuff, caused the abandonment of a close, pattern-drilling programme in favour of traverses of holes at about 500 foot intervals on spur crests where the tuff cover was probably thinnest. Some shallow holes to test only the thickness of the tuff were drilled between deep holes. The distribution of auger holes as shown on Plate 5 does not appear very orderly, but the results, (see Appendix 1) although not adequate for quantitative calculations of reserves, are indicative of the degree of nickel enrichment over a fairly typical part of the Terrace. With a larger party, better communications and more elaborate equipment, wider coverage would have been possible, but, in the light of the results obtained, such detailed investigation does not now seem warranted.

Nickel assay results for all auger-hole samples from this project are tabulated in Appendix 1. All samples were oven dried at 105°C. before assay; in situ the clays contain about 35% moisture.

The Okawu Terrace is not an attractive lateritic nickel prospect for the following main reasons:

(1) the presence of tuff cover, (up to 26 feet in OP9);

(2) the presence of a nickel-impoverished lateritic zone immediately below the tuff;

(3) the nickel content of the weathered mantle below the hard laterite, although increasing with depth, usually approaches 1% only within the basal 10 feet;

(4) adverse access and operating conditions; particularly the high rainfall and thick forest.

The nickel content of the drilled profiles on the Okawu Terrace is generally lower than in the test area on the Arumu Slopes and considerably lower than the average nickel content of the lateritic nickel deposits of Cuba, the Philippines, and West New Guinea, where ore reserve calculations are based on a cut-off grade of about 1.2% nickel. Very few samples from the weathered mantle on the Okawu Terrace attained this figure. The application of the results obtained over such a small area to the entire terrace is hazardous but the writer is reasonably confident that the tested area is typical, at least physiographically, of the greater part of the Okawu Terrace. The low nickel content may be attributable to a combination of the following factors:

(1) Low primary nickel in the underlying rock,

(2) immature lateritization.

(3) Flushing of nickel salts from the clay mantle, either into surface drainage, or with magnesium and silica into precipitated concentrations in fractures and hollows caused by differential weathering in the underlying rock.

No analyses of dunites from the Okawu Terrace area are available, but an unweathered dunite from nearby Ivoro Creek contained 0.20% nickel, that is, about the same as the peridotite parent rocks of the Cuban (de Vletter, 1955) and Philippine nickeliferous laterites (Wright et al, 1958)*. It thus seems unlikely that the low nickel content of the Okawu profiles can be attributed to a deficiency of nickel in the underlying dunite.

Immaturity of the lateritization process may explain the comparatively low nickel values on the Okawu Terrace but the presence of a lateritic hard-pan at the former surface immediately below the tuff, suggests that this is not the case.

(3) <u>Discussion of Kokoda areas</u>

The development of hard laterite (ferricrete) seems to depend largely on successive wetting and drying of the upper layers of a ferruginous clay mantle rather than on the degree of concentration of iron and alumina. It has been noted in the Waria Valley that hard laterites occur at, or very close to, the surface in grassed areas whereas on adjoining forested areas hard laterite is absent. It is a common observation that laterite areas do not support lush growth and it is often the principal factor inhibiting the vegetation. Scattered observations throughout Papua and New Guinea suggest that, at least in the high rainfall areas, rainforest tolerates very ferruginous soils while these are kept saturated by frequent rains, where the evaporation and surface run off is low and sub-surface drainage poor. Low evaporation rate and low permeability of the soils are probably more important in inhibiting the development of laterite accretions than generally acceded. In well populated areas such as the Waria Valley, which have been partly deforested by gardening, hard laterite occurs only on ultrabasic rocks in the deforested areas. In the Sagarai Valley in eastern Papua and also on the flood-plain of the Brown and Vanapa Rivers, near Port Moresby, hard laterite has formed on sandy, permeable, alluvium under thick rainforest cover.

Although hard laterites and grassed areas are commonly associated, the assumption that the processes of chemical weathering and chemical zoning of a weathered mantle are retarded in forest areas is not wholly justified. Observations in Papua and New Guinea suggest that the process of lateritization may preceed in two not necessarily dependent stages, namely,

(a) zoning of compounds by selective leaching, oxidation and reprecipitation, and

(b) accretion of iron and aluminium hydrated oxides.

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* The available data, though meagre, suggest that olivine in the peridotites of the ultramafic zones of the Western Pacific margin characteristically contain 0.20% to 0.25% nickel. This constancy in nickel content may have genetic significance in indicating a continuous primordial differentiated layer.

Under conditions where the soil is perpetually saturated, accretions of the hydrated oxides of iron and aluminium do not form even though the iron and aluminium content may exceed that normally found in hard laterite of drier or better drained areas. Where the upper layer of an iron-rich residual soil is subject to wetting and drying iron oxide accretions and bands form readily. The writer believes that the zoning phase of the lateritization process on the south-western flank of the Ajura Kujara Range is well advanced, but for reasons discussed above, a widespread lateritic crust has not developed.

The comparatively low nickel values in the weathered mantle on the Okawu Terrace and probably on other high rainfall ultrabasic areas in Papua and New Guinea may result from continual sub-surface flushing either along the base of the weathering profile or along permeable, leached zones low in the profile. Much of this nickel in solution will have been dispersed into surface waters but some may have precipitated with magnesia and silica as minerals of the garnerite group in deeply penetrating fractures and in hollows in peridotitic rocks below the thick soil profiles.

The auger programmes on the Okawu Terrace and on the Arumu Slopes, although a reasonable test for dispersed nickel in the clay mantle, have provided very little information on the possibility of economic nickel magnesium silicate deposits. Prospecting for this type of deposit could be done effectively only by pitting or by using light mechanical drilling equipment capable of penetrating at least 50 feet below the base of the clay mantle. The most likely sites for nickel magnesium silicate accumulation would be in the zones of intense fracturing or deeper weathering which could possibly be located by augering or by geophysical resistivity or shallow seismic methods.

(3) The Middle Waria Valley

Like the Yodda Valley, the Waria Valley in its middle reaches, occupies the crush zone of the Owen Stanley Fault which separates the Papuan Basic Belt on the north-east from metamorphic rocks of the main cordillera of Papua on the south-west (Plate 1).

The outcrop of the ultramafic zone of the Papuan Basic Belt on the north-eastern flank of the middle Waria Valley is generally less than one mile wide, but it widens abruptly between the Waria headwaters and the coast. Most of the ultramafic zone in the Waria Valley is concealed under flood plain and piedmont alluvium shed from the rising metamorphic mountain block on the south-western side of the Owen Stanley Fault.

All nickel prospects in the middle Waria Valley would be heavily burdened by transportation difficulties. The valley is not connected with the coast by road nor is there any existing road network within the valley. Road routes to the coast could be either across the rugged Bowutu Mountains (5,000-9,000 feet a.s.l.) or along the course of the Waria River which, after leaving the Middle Waria Valley, is deeply incised in gorges. Road construction and maintenance costs over both routes would be very high and it is unlikely that agricultural or any other mining development in the Waria Valley could contribute towards this. Aerial ropeways driven by locally developed hydro-electric power would probably be more economical than roads and have the particular advantage of comparatively low maintenance cost.

Figure 3.

(a) The faulted north-eastern front of the Owen Stanley Range (12,000 feet a.s.l. approx.) facing the Waria Valley; taken from Garaina looking south-east.

(b) The coarse piedmont fans spreading from the base of Owen Stanley Range - taken from Arihe Hill near Koreppa, Middle Waria Valley.

(i) Koreppa

Green and brown nickel magnesium silicate minerals were first seen by the writer in 1952 in a small landslip near Koreppa village about 8 miles south-east of Garaina. The landslip had exposed sheared green and black serpentinite with nickel magnesium silicate and secondary silica deposited in a network of fine fractures.

Little economic significance was attached to this occurrence until 1957 when the writer returned to the area and drilled several auger holes through the reddish-brown residual clays on slopes near the landslip. Assays on soil samples from this augering showed that, not only were nickel magnesium silicate minerals present at the base of weathering and in cracks in the underlying rock, but also that the soils, even on steep slopes, were nickel-enriched.

The area was briefly examined at different times during 1957 and 1958 by geologists of Bulolo Gold Dredging Ltd., Enterprise Exploration Ltd., and The International Nickel Company of Canada but no further interest has been shown by these Companies.

The results of nickel and cobalt assays on samples taken by the writer in 1957 from auger holes and shallow pits are shown on Plate 5.

Outcrop in the Koreppa area is poor but information gained from auger holes and pits indicates an intrusive complex of dunite, enstatite pyroxenite and bytownite gabbro. The dunite is severely sheared near a major fault which forms the south-eastern boundary of this basic-ultrabasic complex.

A green form of talc, and blue-green antigorite, are commonly associated with garnierite and secondary silica at Koreppa. Nickel magnesium silicate coatings were also seen on serpentinite boulders in coarse rubble about 1½ miles south-east of Koreppa at the base of the same line of hills, on the same fault line.

Laterite pisolites are scattered over the surface of the narrow crest of the grassed hill near Koreppa, known locally as Arihe. The soil profile on the top of this hill is reddish-brown and generally from 5 to 10 feet thick. Where developed over serpentinised dunite this profile is nickel enriched and garnierite and secondary silica have been deposited in fractures in the underlying rock. Over pyroxenite and gabbro, the nickel content of the soils is very low.

The quantity of nickeliferous soil in the Koreppa area is too small for consideration as a lateritic nickel prospect.

The area has not been adequately tested as a nickel silicate prospect. Drilling to date has been with manual augers which can penetrate the soil profile only to the first hard boulder, rarely reaching and never completly traversing the most favourable zone for nickel magnesium silicate deposition. Prospecting for nickel magnesium silicate deposits can only be conclusive if test holes or shafts are sunk well below soil base and into the zone of open fractures in the underlying rock.

Figure 4

(a) A landslip near Koreppa in the Middle Waria Valley which exposes boxworks of secondary silica and associated nickel silicate minerals in fractured and sheared, weathered, serpentinite.

(b) Fracture fillings of secondary silica in weathered serpentinite etched into relief by differential weathering. Koreppa, Middle Waria Valley.

(ii) Bovio Hill (Plates 1 and 7)

Bovio Hill, near Timanogosa and about ten miles north-west, upstream, from Garaina in the Waria Valley, is a soil-covered outlier of ultramafic rocks about 1 square mile in area, surrounded by floodplain alluvium. Nickeliferous soils were first noted in this area by J.G. Best (1957). Dow and Davies (1961) recommended testing the area as a lateritic nickel prospect, though no soil samples were taken by them.

Bovio Hill occupies a similar position to the Koreppa Hills in relation to the Owen Stanley Fault. Reddish brown soils which can be seen from the air on the crest of the hill suggest a mature soil cover, possibly developed to pisolitic hard laterite. Bovio Hill is too small to constitute a lateritic nickel prospect in its own right, but it might be considered in conjunction with large prospective areas for nickel-enriched clays near Lake Trist and in the Iwiri drainage area.

As at Koreppa, Bovio Hill probably contains small nickel magnesium silicate deposits below the soil mantle.

(4) The Lake Trist Area (Plates 1 and 7)

Lake Trist, a body of water about three miles long and a mile wide at about 5,500 feet above sea level in the mountains at the head of the Waria Valley is a familiar landmark on the air route between Port Moresby and Lae. The lake is aligned meridionally in rough conformity with the strike of the Owen Stanley Fault about two miles to the west, and of lesser normal faults nearby. The western shore of the lake is controlled by a recent normal fault with upward displacement on the west (Dow and Davies, 1961).

In 1957 Mr. J. Cavanagh, Administration forestry officer, collected specimens of ultramafic rocks from the Lake Trist area which were identified in Port Moresby by the writer. On learning of the presence of these ultramafic rocks, Bulolo Gold Dredging Ltd, sent a prospecting party into the area in search of nickel-enriched soils. The results of this prospecting are recorded in unpublished company reports.

In 1960 Dow and Davies (1961) passed through the area and reported a large expanse of ultramafic rocks, predominantly magnesian dunite, on which thick residual soils were developed. They also recorded nickel magnesium silicate mineralization in boulders of peridotite conglomerate in the upper reaches of the Iwiri River.

Dow and Davies recommended the testing* of an area of about 20 square miles immediately east and north of Lake Trist, where magnesian dunite predominates and thick residual soil cover should be present. This area has moderate relief superimposed on a consistent slope from near the crest of the Bowutu Range at about 9,000 ft. a.s.l. towards Lake Trist. Intricate dissection by a finely dendritic drainage pattern has produced an incipient karst-like topography of small, rounded, hillocks similar to

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* This testing is currently proceeding, July, 1962.

that on the Okawu Terrace near Kokoda (Thompson, 1957). This type of topography may be partly due to the initiation of an erosion cycle on a large area of thick, homogeneous clay and partly due to solution weathering of dunite.

The results of investigations by the Bulolo Gold Dredging Ltd, prospecting party have not been published but it is understood that their efforts were particularly concentrated between Lake Trist and the Owen Stanley Fault and that they used only manual augering euipment. They have shown no further interest in the area since their initial investigations.

Although only about 12 miles from a coastline with potentially good harbours, the prospective area near Lake Trist is extremely difficult to approach. The Bowutu Mountains with peaks up to 9,000 feet above sea level lie athwart any direct route from the coast. These mountains are extremely rugged and the steep slopes are subject to frequent landslips. The mountains (except for landslip scars) are completely covered with thick forest. Below 4,000 feet, tropical rainforest prevails; above 4,000 feet this gives way to moss forest, stunted hardwoods and an undergrowth of thin creeping bamboo through which it is extremely difficult to cut tracks. The Bowutu Mountains are unpopulated, and virtually trackless, probably because of their ruggedness and the lack of good gardening and hunting grounds.

An amphibious Otter aircraft landed and took off from Lake Trist and supplies were successfully dropped at the southern end of the lake during the prospecting by Bulolo Gold Dredging Ltd. in 1957.

As with the other known nickel prospects of the ultramafic zone of the Papuan Basic Belt, the Lake Trist area has been superficially tested for nickel-enriched soils only. The results of these investigations have apparently not been very encouraging. Nickel magnesium silicate deposits have not been specifically sought beneath the clay mantle, because, on surface indications, the prospects do not appear sufficiently encouraging to justify the difficult and costly task of transporting mechanical drilling euipment capable of penetrating into the underlying dunite. The prospects for nickel magnesium silicate deposits in the Lake Trist area are at least as good as those for lateritic nickel deposits. The peridotite breccias and the peridotite conglomerate reported by Dow and Davies (1961) in the headwaters of the Iwiri River may be favourable host rocks for the deposition of supergene nickel magnesium silicate particularly if located where they receive subsurface drainage from large areas of nickeliferous soil. Future investigations in this area should include drilling or shaft-sinking through the entire weathering profile over dunite to determine whether nickel silicates have been deposited in economically interesting concentrations at the base of weathering.

(5) <u>The Coast Near Salamaua</u> (Plates 1 and 7)

The ultramafic zone at the northern end of the Papuan Basic Belt is exposed along the coastline between Tambu Bay and Lake Salus. Gabbro and serpentinite are exposed on many headlands as far south as Buso village.

This coastline, except for the Buiawim outwash fan, is characterized by deep embayments indicating recent regional subsidence. Lake Salus is such an embayment, isolated from the sea by rapid longshore spread of sediment from the Buiawim outwash fan. The sediments of this fan were derived mainly from the upfaulted metamorphic mountains at the head of the Buiawim River, and transported through the relatively passive ultramafic zone.

This area has not been seriously examined for nickel mineralization but is included as a lowly-rated prospective area where access presents no serious problem. In 1957, the attention of the writer was attracted by the reddish-brown soils on the bracken covered hills directly behind Dot Inlet. Three auger holes were sunk through these soils but a specimen of the underlying rock could not be recovered. However, the following assays indicate that at least one of the holes (G) was drilled over a nickel source rock:-

Sample No.	Depth	Ni%	Co%
E 1	0 - 3'	Nil	Trace
E 2	3 - 7'	Trace	Trace
E 3	7 -11'	0.08	0.05
E 4	Bottom	0.02	Trace
F 1	0 - 3'	0.12	Nil
F 2	3'- 7'	0.12	Trace
F 3	7'-11'	0.13	0.02
F 4	11'-15'	0.13	Trace
F 5	15'-17' Bottom not reached	0.21	0.01
G 1	0' - 3'	0.10	Nil
G 2	3' - 7'	0.14	Nil
G 3	7' -11'	0.36	0.10
G 4	11' -15'	0.67	0.11
G 5	15'- 17'	1.07	0.06
G 6	Bottom	1.04	0.04

Assays by R.J. Gluyas & Co., Adelaide.

If, as implied by the embayed coastline, the northern end of the Papuan Basic Belt has undergone regional subsidence, then old, maturely leached, soil profiles might be preserved. No specific prospect either for nickel-enriched soils or for nickel magnesium silicate deposits is known, but the hills between the lower Buiawim River and the Owen Stanley Fault trace are considered worthy of reconnaissance investigation. Coastal and stream exposures indicate that this area contains ultramafic rocks, with pyroxenite probably in excess of peridotite. The oldest soil profiles in the area will be on the crests of ridges and any future investigations for nickel-enriched soils and nickel magnesium silicate deposits should be first directed towards these crests.

III. PROSPECTIVE AREAS NOT YET EXAMINED WITHIN PAPUAN BASIC BELT

It is possible from aerial reconnaissance and study of aerial photographs to dismiss many parts of the Papuan Basic Belt as prospective for large lateritic nickel deposits. However, the entire ultramafic zone of the Basic Belt must be considered as prospective for nickel silicate deposits. The following areas not yet examined on the ground are considered particularly worthy of investigation for nickel silicate mineralization:-

(1) Between the Mambare and Waria Rivers.

Orange coloured soil exposed by numerous landslips can be seen from the air. The stunted vegetation also suggests a wide ultramafic zone. Although too mountainous to contain large lateritic nickel deposits, it may well contain nickel magnesium silicate mineralization. This area sheds gold, osmiridium and platinum into the alluvium of the Gira and Aikora Rivers.

(2) Between the Kumusi and Musa Headwaters.

South of Mount Lamington and the Hydrographer Range. This tract includes some large areas of undulating topography which are probably formed on Quaternary pyroclastics deposited on an ultramafic terrain. Nickel enrichments either in old lateritic profiles or as nickel magnesium silicate deposits may be buried under the volcanic cover. It is most unlikely that such deposits could be easily located, and if present they would not be suited to economic large-scale mining.

(3) The Mount Brown - Keveri area, high in the Owen Stanley Range, between the Musa Valley and Abau on the south coast. Smith and Green (1959) did not record any major faulting on the southern flank of the Musa Valley which could be correlated confidently with the Owen Stanley Fault which in the Kokoda area, clearly marks the south-western boundary of the Papuan Basic Belt. Thus, it is possible that ultramafic rocks extend south of the area mapped, into the uplands of the Owen Stanley Range. This area is too rugged to contain large lateritic nickel deposits. The Keveri Valley which lies within this area contains some alluvial gold which was worked intermittently during the period 1904-1926 for only mediocre returns.

IV. ULTRAMAFIC AREAS OUTSIDE THE PAPUAN BASIC BELT

Ultramafic rocks are known in many areas outside the Papuan Basic Belt. In most cases they occur as narrow slivers aligned along major faults and are too small or too dissected to contain the large quantities of nickel-enriched soils. Nickel magnesium silicate mineralization has not been reported from any of these lesser ultramafic area. However, they have not been specifically prospected for this type of mineralization which normally would be concealed under the soil mantle.

Ultramafic rocks are know in the following areas:-

(1) Milne Bay

(2) D'Entrecasteaux Islands

(i) Normanby Island

(ii) Fergusson Island

(3) The Eastern Highlands District

(i) The Upper Ramu Area

(ii) The Kami Area

(iii) Chimbu

(4) The Bismarck-Schraeder Ranges

(5) The Sepik District

(i) The Border Mountains

(ii) The Oenake Mountains

(iii) Wewak area

(6) Port Moresby.

These occurrences and their known mineral associations are briefly described below.

(1) Milne Bay

A basic intrusive complex with peridotite, pyroxenite, gabbro, basic pegmatite, and wholly-biotite rocks is emplaced in dolerite and meta-volcanic rocks in the mountains of the southern arm of Milne Bay between Waga Waga village and the Sagarai Valley (Plate 1). This basic complex is not part of the Papuan Basic Belt but is an isolated, non-linear, intrusive mass emplaced in a thick pile of submarine doleritic lava.

The area is very deeply dissected and has very little residual soil cover. Platinum and gold are shed from peridotite phases of this intrusive and concentrated into low-grade alluvial deposits in the Sagarai River, Gabahusuhusu Creek and Debolina Creek (platinum only). Gold lodes occur in gabbro at Oura Oura on the divide between Milne Bay and the Sagarai Valley and copper mineralization is known near the contact of gabbro and meta-volcanic rocks. It is unlikely that supergene nickel deposits, either ofthe lateritic or silicate type are preserved in this area.

(2) D'Entrecasteaux Islands

(i) Normanby Island

"Serpentine" was first recorded by E.R. Stanley (1916a) near Sewa Bay on the south-western coast of Normanby Island. The writer visited this area in 1958 and noted that the sparsely timbered 3,000 foot mountain (known locally as "Bubuessa") which overlooks Sewa Bay from the north-east, is mostly serpentinised peridotite and pyroxenite. This massive outcrop is part of a north-easterly trending ultramafic zone which crosses the island and separates mica-schists on the east from an entirely different complex on the west which includes acid gneisses, medium-acid intrusives, folded (?) Tertiary sediments and young andesitic volcanics.

Stanley (1916a) recorded "magnesite and meerschaum" on the divide between Sewataitai Bay and Sewa Bay, presumably near Mount Bubuessa. He also noted "serpentine" at Kuanaura near the northern tip of the eastern bulge of Normanby Island; this is supported by the occurrence of alluvial platinum, with gold, which is being won by natives in this area. Gold and platinum are also shed from the northern slopes of Mount Bubuessa into gravels of the main north-draining streams. Several attempts at alluvial mining on this fall have proved uneconomic.

Around the base of the south-western flank of Mount Bubuessa a very thin veneer of red soil, derived mainly from ultramafic scree, is locally nickel-enriched at the base to slightly more than 1%. The quantity of this nickel-enriched soil falls far short of that required for a mining venture. Nickel magnesium silicates were not seen but it is likely that they do occur with secondary silica cementing the talus at the base of the mountain. Here again serious prospecting for nickel magnesium silicate deposits has not been undertaken.

(ii) <u>Fergusson Island</u>

A previously unrecorded ultramafic mass was seen by the writer in 1958 along the rocky north-eastern coastline of Fergusson Island between Sebutuia Point and Point Gilawelabana (Mebulibuli Peninsula) and also in exposures in the lower reaches of Mebulibuli Creek. The coastal exposure is characterised by gossanous weathered surfaces on black or very dark green serpentinized dunite and harzburgite and by the bright orange coloured soils exposed by small landslips. Grass, bracken patches, and stunted tree growth on Mebulibuli Peninsula typify the infertile, iron-rich soils of an ultramafic terrain in a moderate rainfall region.

The southern and western limits of this ultramafic mass are not known* but, as most of this part of Fergusson Island is mountainous, large quantities of nickel-enriched soils are probably not preserved. No nickel magnesium silicate mineralization has been recorded from this area but small deposits could be present at the base of the soil mantle.

Within this ultramafic body, sulphide mineralization occurs in a steeply dipping shear zone, some 4 to

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* Fergusson Island was subsequently mapped by Davies and Ives (1962) and several small ultramafic areas were noted.

6 feet wide, which crops out on the right bank of Mebulibuli Creek about ¼ mile upstream from the first major junction. This outcrop is mostly blue pug containing fragments of marcasite and black, glassy, opalized, sulphide-bearing, serpentinized dunite. The principal sulphide is marcasite but pyrite is also present. A specimen from this locality assayed 0.25% nickel. This nickel was identified by W.M.B. Roberts and W.B. Dallwitz (Appendix 2) with fine magnetite derived from the original dunite; it was not introduced during later pyritization. It is assumed that the nickel transferred from the olivine crystal lattice in the original dunite to primary magnetite or to magnetite released during serpentinization and before opalization and pyritization.

(3) The Eastern Highlands District

(i) The Upper Ramu Area

Mackay (1955) recorded "serpentine" in a discontinuous, north-westerly trending zone about 4 miles long and up to 150 feet wide between the headwaters of the Ramu and Orlowat (Faientina) Rivers, south of the Kainantu-Goroka road. This "serpentine" is associated with a system of large faults. The small area and the lack of soil cover preclude the possibility of nickel-enriched soils of economic interest. Nickel magnesium silicates have not been recorded from the area. Platinum is shed from this serpentine zone into the headwater tributaries of the Ramu River where it is won with gold in small alluvial mining operations.

(ii) The Kami Area

MacMillan and Malone (1960) mapped two masses of serpentinite near Kami about 12 miles south of Goroka. One is about two miles long and a mile wide; the other is smaller. Soil specimens from the surface of the larger serpentinite mass contain only a trace of nickel. Nickel magnesium silicates have not been recorded. Physiographic and climatic conditions in the New Guinea Highlands are not as favourable for rapid chemical weathering or for the retention of residual soils as conditions in the lowland areas with higher rainfall and thick forest cover.

(iii) Chimbu

Basic intrusives which crop out as wedges along faults of the Bismarck Fault Zone (Rickwood, 1955) in the western part of the Eastern Highlands District, include serpentinite. The extent of these occurrences is not reliably known, but Rickwood's reconnaissance mapping suggests that they are probably too small for consideration for lateritic nickel mineralization. No nickel silicate mineralization has been reported from this area. Small samples of massive chromite reputedly collected by natives from an undisclosed locality in this area have been seen.

(4) The Bismarck-Schraeder Ranges

Basic and ultrabasic rocks, including peridotite, occur in the rugged northern foothills of the Bismarck Range near the Imbrum River (MacMillan and Malone, 1960) and probably on the northern front of the Schraeder Range, farther north-west. These intrusives adjoin and have probably intruded along major faults parallel to the Markham-Ramu graben valley. This area has not been examined in detail but aerial observations strongly suggest that the topography is generally too steep to retain the mature soil profiles required for economic lateritic nickel enrichment. Nickel magnesium silicates have not been recorded from this area.

(5) The Sepik District

(i) The Border Mountains

Stanley (1938), in the course of reconnaissance mapping for an oil company, noted deeply weathered "serpentine" in the eastern foothills of the Border Mountains on the northern flank of the western end of the Sepik Valley. The westerly extension of this ultramafic province into the Border Mountains and beyond, into West New Guinea, has not been investigated. Lateritization is widespread throughout the Sepik valley; it is thus likely that nickel-enriched soils will occur over the ultramafic rocks on the lower slopes of the Border Mountains. However cover of Tertiary limestone and marine clastic sediments may limit the area of interest.

This area has not been examined specifically for nickel mineralization and both lateritic and silicate-type nickel deposits may occur there. However, the remoteness of the area detracts greatly from its prospective rating.

(ii) The Oenake Mountains

The Oenake Mountains which extend from near Vanimo westwards to West New Guinea border are composed of gently folded, marine, clastic sediments and limestone of Upper Miocene age deposited on serpentinized ultramafic rocks. These ultramafic rocks are clearly an extension of the ultramafic zone of the Cyclops Mountains in West New Guinea, on which thick nickel-enriched lateritic soils of probable economic grade and dimensions have been formed.

In the Oenake Mountains, the cover of marine sediments precludes any possibility of mature nickel-enriched soils. Low on the flanks of the Cyclops Mountains, ultramafic rocks are exposed beneath the sedimentary cover. It is possible that while the Miocene sediments of the Oenake Mountains were being deposited, the Cyclops Range to the west was emergent and that weathering in that area has continued from Late Tertiary time through to the present day.

(iii) Wewak Area

G. Baker (1952) in a laboratory study of opaque oxides in a suite of specimens of igneous rocks from the Torricelli Mountains, noted peridotite from Babiang near Wewak. The extent of this peridotite must be very restricted as it has not been recorded by field geologists who have worked in this area.

(6) Port Moresby

Serpentinite crops out discontinuously along a narrow fault zone which extends from Kila for about 10 miles north-westerly through Barune village, 3 miles north-west of Port Moresby. This zone is too small to be of economic interest and neither climate nor physiography are conducive to the formation of thick residual soils. Magnesite nodules are sparsely scattered over the serpentine outcrops in the valley north-west of Barune.

OCCURRENCES OF MINERALS ASSOCIATED WITH NICKEL

(1) Chromium

Chromite, a chrome-iron spinel, is a common accessory mineral dispersed as small euhdral crystals through ultramafic rocks. Massive chromite lenses are the usual source of chromium ore.

Massive lode chromite has not been recorded in situ in Papua - New Guinea but a small specimen was collected by the writer (1957) on a hill slope near Koreppa in the Waria Valley and other small specimens reputed to have been found in the Western Highlands, New Guinea, have been seen.

Chromite does not decompose readily by weathering and thus concentrates residually in the clay mantle, particularly at the surface. With other heavy minerals it may be further concentrated in river alluvium and finally in beach deposits. Alluvial and beach deposits are only rarely of economic importance.

All major streams draining to the north-east coast originate in the upfaulted Owen Stanley Range and have cut deep gorges across the more stable Papuan Basic Belt. Most of the sediment load borne by these streams comes from the metamorphic rocks of the Owen Stanley Range is transported across the Papuan Basic Belt and deposited along the coastline.

Rapid erosion of loosely compacted andesitic pyroclastics from Quaternary volcanic activity at Mount Lamington and older volcanics in the Hydrographers Range and at Cape Nelson have contributed much magnetite and ilmenite to the beach sands of north-eastern Papua. In the beaches near the mouths of the Musa, Kumusi, Mambare, Gira, Waria and Bitoi Rivers, the heavy minerals of ultramafic provenance are subordinate to those of metamorphic or volcanic provenance.

The alluvial flats and beaches at the mouths of the Paiawa, Saia, and Alealer Rivers, between Salamaua and Morobe contain concentrations of heavy minerals with ultramafic affinity, including magnetite, ilmenite and chromite, and probably platinum and osmiridium. The small beaches in Sachsen and Hessen Bays at the mouths of Alealer and Saia Rivers, respectively, have light brown sands containing much olivine and chromite which is concentrated at the top of the beaches and in the mouths of the rivers. These rivers rise in the ultramafic zone of the Papuan Basic Belt, near Lake Trist and drain entirely basic and ultramafic igneous terrain.

Alluvial concentrations of fine-grained chromite and magnetite have been noted on the surface of the river flats at the base of the Arumu Slopes near Kokoda, particularly near Botue Village and also in the alluvium of Zarau Creek near Koreppa in the Waria Valley.

Two specimens of naturally concentrated "black sand" collected by the writer from small beaches between Vanimo on the northern New Guinea coast and the West New Guinea border contain the following minerals:

	Opaque Minerals		Non Opaque Minerals			
Specimen No.	Magnetite	Chromite & ilmenite	Zircon	Monazite	Rutile	"Other Minerals"
1	7.3%	87.6%	0.4%	0.1%	Trace	4.6%
2	6.9%	87.9%	Trace	Trace	Trace	5.2%

"Other Minerals" included feldspar, garnet, calcite, staurolite, pyroxene and quartz. The "Chromite and Ilmenite" fractions were chemically analysed and found to contain Cr_2O_3: Fe_2O_3 rations of 58.7: 17.8 and 56.9: 23.8 respectively.

A sample of "heavy black beach sand" from "the north-east coast of Papua" described by Baker and Edwards (1954) contained from 41% to 68% chromite, less than 5% magnetite, about 10% ilmenite, 4.4% zircon, some hematite and 10% transparent minerals including hypersthene, enstatite, augite, garnet, hornblende, tremolite, olivine, epidote, rutile, brookite, spinel, feldspar and quartz. Neither the conditions of sampling nor the exact locality of this sample are known but it is thought that the sample may have been taken from the top of one of the small beaches on the coast of Cape Vogel where a thick sequence of Tertiary sediments containing ultramafic clastic components is being eroded.

E.R. Stanley (1916b) referred to "chrome, spinel and manganese" in association with serpentine at Cape Vogel but the writer has not been able to locate this occurrence.

(2) Cobalt

Cobalt has not been specifically sought in Papua-New Guinea, but assays of a few soil samples from nickel investigations in the Kokoda and Waria River areas indicate that, like nickel, it is retained and zoned within residual soils over ultramafic rocks. The cobalt content of soil samples from these areas is about one tenth of the nickel content.

In the lateritic nickel ores of Cuba, the Philippines and West New Guinea, cobalt as black hydrated oxide, (asbolan, asbolane or asbolite) is associated with manganese wad segregations. Small black, powdery nodules and streaks were consistently recorded in the logs of auger holes drilled through nickel-enriched soils in Papua-New Guinea, but these were not assayed separately for cobalt.

Very few of the known sulphide lodes in Papua-New Guinea have been specifically assayed for cobalt. In the early days of copper mining near Port Moresby, only trace quantities of cobalt and nickel were detected in the sulphide ores at Laloki, Mount Diamond and Dubuna (Carne, 1913).

(3) Iron

Chemical weathering of ultramafic rocks readily yields iron-rich clays and laterite with nickel, chromium and cobalt impurities which are particularly undesirable in the steel industry. These impurities are difficult to eliminate and the lateritic iron ores cannot complete with the hematite and magnetite ores, except in the manufacture of ferro-nickel.

Proposals to exploit major lateritic nickel deposits in Cuba, the Philippine Island and West New Guinea include the ultimate recovery of an acceptable iron matte. That this can be done economically on a large scale has yet to be demonstrated.

No systematic investigation has been undertaken of the iron content of residual clays over ultramafic rocks in Papua-New Guinea. Some assay data were obtained incidentally during investigations of lateritic nickel deposits.

The iron contents of samples through a clay profile near Arumu Creek in the Kokoda area (see page 17) indicate the degree of iron enrichment in immature residual soils on medium slopes over serpentinized dunite. It is noteworthy that despite the high iron content (49-65% Fe_2O_3). hard laterite is only rarely developed. In some of the more mature clay profiles over ultramafic rocks a gradual colour change from brick-red in the upper part to mustard-yellow in the lower part was observed. It is assumed that the upper darker coloured zone is more ferruginous than the lower zone; this has not been confirmed by systematic sampling and assaying for iron.

Magnetite and ilmenite are significant accessory minerals in ultramafic rocks and may be concentrated, residually on weathering surfaces or alluvially in rivers and in beach sands but such deposits are rarely of value as iron ore.

Magnetite lodes have not been recorded in the ultramafic provinces of Papua and New Guinea.

(4) Platinum and Osmiridium

Alluvial platinum has been recorded from most of the alluvial gold workings in areas where basic and ultramafic rocks are known. These include the Timun River in the Western Highlands, the Ramu River headwaters, the Bitoi River, the middle and lower reaches of the Waria River in the Morobe District; the Gira, Aikora and Mambare Rivers in the Northern District; the Dawa Dawa and Sagarai Rivers and small streams near Waga Waga in the Milne Bay District.

Traces of alluvial platinum with gold have also recently been recorded by Dow and Davies (1961) in the Paiawa and Saia Rivers between Salamaua and Morobe. The heavy mineral concentrates in this area may also contain platinum and osmiridium.

In 1919, Evan R. Stanley (1921) aroused prospecting interest in alluvial osmiridium which was known to occur in auriferous gravels of the Gira and Aikora Rivers and in the Milne Bay area. In the succeeding two years, annual production of osmiridium from the Gira Goldfields rose to 360 ounces but over the following five years annual production of osmiridium dropped back to about 50 ozs as gold mining declined on the Gira Goldfield.

For a few years after a minor rush in 1932, small amounts of alluvial platinum were won from the headwater tributaries of the Dawa Dawa River, which flows northward into Milne Bay. The main tributary worked was Debolina Creek which contained alluvial platinum but no gold. Other streams nearby which drain into the Sagarai Valley or directly to Milne Bay contain both platinum and gold. The alluvial platinum deposits in the headwaters of the Dawa Dawa River were soon proved unpayable and the field was quickly abandoned.

(5) <u>Gold</u>

Gold is more commonly associated with acid igneous rocks than with basic and ultrabasic rocks. However, alluvial gold and at one locality, lode gold, have been recorded from within the Papuan Basic Belt (Dow & Davies, 1961). The alluvial gold in the Aikora River is shed from ultramafic rocks near the Owen Stanley Fault and not from the metamorphic rocks of the main range.

At Juni in the Waria Valley, gold is shed from a granodiorite (Fisher, 1939) which may be a differentiated phase of the Papuan Basic Belt (Dow and Davies, 1961) or a younger intrusive.

Davies (pers. comm.) noted a trace of alluvial gold in the upper reaches of Okawu Creek near Kokoda. It is possible that some of the alluvial gold of the Yodda Valley may have come from the basic and ultrabasic rocks of the Bowutu Mountains and not entirely from the Owen Stanley Range as has been assumed in the past.

Traces of alluvial gold have also been recorded by Dow and Davies (1961) in Wuwu, Wiwo, Mo, Paiawa, Buso and Saia Rivers which drain the north-eastern flank of the northern part of the Papuan Basic Belt.

The Papuan Basic Belt should not be disregarded as a possible province of economic gold mineralization. No spectacular gold finds have been made by prospectors to date but systematic search guided by geological mapping might be more fruitful.

Gold is also associated with the basic intrusives at Milne Bay and on Normanby Island.

(6) <u>Copper</u>

Dow and Davies (1961) recorded copper minerals at several localities in the northern half of the Papuan Basic Belt, and Smith and Green (1959) noted chalcopyrite and secondary copper minerals associated with serpentine and dolerite on the southern flank of the Musa Valley.

Copper sulphides were noted by G. Baker (1959) during an examination of thin and polished sections of several specimens of both non-feldspathic and feldspathic basic rocks of the northern half of the Papuan Basic Belt.

A small outcrop of copper sulphide, with secondary copper oxides and carbonates, in metasediments is known near a contact with intrusive basic rocks near the old Oura Oura gold mine in the Milne Bay District, but this has not been tested in depth.

In the instances of sulphide mineralization cited above, nickel is not a significant associate of copper. Small amounts of pentlandite (a nickel-iron sulphide) were noted by Baker (1959) fringing accessory pyrrhotite in serpentinite from Koreppa in the Waria Valley and millerite, a nickel sulphide, (Greaves, in Dow and Davies p.32, 1960) is a minor constituent in a sulphide-bearing gabbro boulder taken from a tributary of the Paiawa River.

The possibility of copper mineralization should be kept well in mind when prospecting in the basic and ultramafic provinces of Papua and New Guinea, and any sulphides encountered should be assayed for copper, nickel and gold.

(7) Asbestos

Extremely fine veinlets of green asbestos have been seen by the writer in serpentinized dunites in the Wowo Gap and Kokoda areas in the course of nickel investigations. These occurrences are not important commercially. Commercial asbestos deposits are commonly associated with granitic intrusives in ultramafic rocks. Dow and Davies (1961) have mapped medium acid plutonic rocks in close association with ultramafic rocks in the Bowutu Mountains between Garaina and the Morobe coastline. Asbestos deposits may occur in this area.

CONCLUSIONS

The Territory of Papua and New Guinea has large areas of ultramafic rocks with a primary nickel content of about 0.2%. In the areas of high rainfall and thick forest cover, nickeliferous olivine of the ultramafic rocks weathers readily to release nickel into the residual clay profile where it is concentrated by chemical zoning into the lower parts of the profile. Similar processes may also lead to the deposition of nickel magnesium silicates (garnierite and associated minerals), with secondary silicia, in fractures and hollows in decomposing peridotite at, or near, the base of weathering.

Nickel enrichments in clay, which are loosely referred to as "lateritic nickel deposits", have been examined in the Musa, Kokoda and Lake Trist areas. Near Kokoda and Lake Trist the quantity of nickel-enriched clay is probably of the order of several 100 million tons but the grade of enrichment is much lower than the lateritic nickel deposits of Cuba, the Philippines and West New Guinea. Although investigations in the Kokoda and Lake Trist areas have been limited to manual augering, the results to date indicate that peak nickel values of from 1% to 2% are attained near the base of weathering over dunite (or, at least, at the limit of augering, which is not necessarily the base of the clay profile). Unlike the more mature lateritic profiles in Cuba, the nickel values do not appear to decrease in the lower part of the profile. This may reflect a different weathering history or it may indicate that the zone of maximum enrichment was beyond the reach of manual augering equipment.

The Musa Valley area does not contain any large areas of nickel-enriched clay worthy of further investigation as lateritic nickel deposits. However, there are areas of fractured and brecciated serpentinite near Wowo Gap and in the eastern end of the Musa Valley which warrant further investigation for possible nickel silicate deposits.

The investigations thus far have not been conclusive in indicating whether or not commercially interesting nickel silicate deposits exist within the ultramafic provinces of Papua and New Guinea. It is recommended that any future investigations should be more particularly directed to the location of nickel silicate deposits, commencing at the localities where nickel silicates have been recorded.

Although testing of the nickel-enriched clays has not provided encouraging results, it should be kept in mind that only manual augers have been used and that conclusive testing can only be done with equipment which can penetrate the entire transition zone between clay and hard rock where maximum nickel enrichment and nickel silicate deposition is expected.

Of the several areas of ultramafic rocks outside the Papuan Basic Belt, only the Border Mountains at the western end of the Sepik Valley seems to have prospects for large lateritic deposits. Very little is known of this area and a rapid reconnaissance investigation is recommended.

Other areas outside the main Basic Belt are small and considered prospective only for nickel silicates.

Iron, chromite and cobalt are associated with nickel enrichments in residual clays, but they have not been found as lodes or magmatic segregations in the ultrabasic rocks. Specimens of lode chromite reputed to have come from Chimbu in the Western Highlands District have been seen but the parent lode has not been visited.

Platinum, osmiridium and gold are shed from many ultrabasic areas into alluvial deposits along the north-eastern flank of the Papuan Basic Belt, in the Milne Bay District, and in the Eastern and Western Highlands Districts. Platinum and osmiridium derived from ultrabasic rocks have been won in the course of alluvial mining for gold by individuals and small syndicates but the major gold producing areas are associated with granitic intrusives or andesite volcanic rocks.

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APPENDIX 1

THE RESULTS OF AUGER SAMPLING THROUGH NICKELIFEROUS CLAYS ON THE OKAWU TERRACE, KOKODA AREA, PAPUA

(see Plate 5)

SITE	TOTAL DEPTH	TUFF THICKNESS	SAMPLE INTERVAL	% Ni.	REMARKS
OK Series near Upper Anaua Camp					
OK1	36'8"	10'	10'-11'	0.13% (PH 4.3)	10'-12' Laterite concretions and crusts
	Rock		11'-12'	0.20% (PH 4.45)	
	bottom		12'-13'	0.67% (PH 4.8)	
			13'-14'	0.78% (PH 4.95)	
			14'-18'	0.72% (PH 5.5)	
			18'-22'	0.74% (PH 5.65)	
			22'-26'	1.25% (PH 5.45)	
			26'-28'	0.57%	
			28'-31'	0.66%	
			31'-34'	0.57%	
			34'-36'	0.40%	36'8" Weathered dunite.
OK2	11'	11'			Mustard coloured gritty clay (drilled to determine thickness of tuff only)
OK3	8'6"	8'6"			Mustard coloured gritty clay (drilled to determine thickness of tuff only)
OK4	7'6"	7'6"			Grey and mustard coloured (drilled to determine thickness of tuff only)
OK5	9'	9'			Grey and mustard coloured (drilled to determine thickness of tuff only)
OK6	10'	10'			Mustard coloured gritty (drilled to determine thickness of tuff only)
OK7	32'8"	12'3"	12'-14'	0.48%	Light yellow clay
	Rock bottom		14'-15'	0.65%	Hard laterite, orange brown
			15'-16'	0.62%	Talc flakes in lateritic clay
			16'-17'	0.46%	
			17'-18'	0.89%	Laterite concretions
			18'-19'	0.92%	
			19'-20'	0.98%	
			20'-21'	0.66%	Some silica stringers
			21'-22'	0.54%	
			22'-23'	0.52%	
			23'-24'	0.88%	
			24'-25'	0.31%	Vermillion colouring in clay
			25'-26'	0.44%	Black wad (mn & Co. oxides?)
			26'-27'	0.92%	Silica stringers, 1/16" wide.
			27'-28'	0.82%	
			28'-29'	0.74%	Abundant talc flakes
			29'-30'	0.58%	
			30'-31'	0.55%	Talc and silica
			31'-32'	0.74%	
			32'-32'8"	0.46%	
			32'8" (rock)	0.18%	Weathered dunite with silica stringers.

SITE	TOTAL DEPTH	TUFF THICK-NESS	SAMPLE INTER-VAL	% Ni.	REMARKS
OK8	9'	8'6"			Mustard coloured gritty tuffaceous clay
OK9	5'	5'			
OK10	9'	9'			Drilled to determine thickness of tuff only
OK11	11'	11'			
OK12	9'	9'			
OK13	11'	11'			
OK14	9'	9'0"			Mustard coloured gritty clay
OK15	4'	4'0"			" " " "
OK16	37'4" Rock bottom	8'6"	8'6"-10',	0.51	
			10'-13',	0.61	
			13'-16',	1.08	
			16'-19',	0.68	
			19'-22',	0.50	
			22'-25',	0.71	
			25'-28',	0.96	
			28'-31',	0.96	
			31'-34',	0.69	
			34'-37'4",	0.57	Abundant talc
			$37\frac{1}{4}$",	0.16	Weathered dunite with silica stringers
OK17	8'6"	8'6"			Mustard coloured gritty clay
OK18	10'	10'0"			" " " "
OK19	10'6"	10'6"			Drilled to determine thickness of
OK20	9'6"	9'0"			" tuff only " " " " Laterite fragments
OK21	9'0"	8'6"			" " " " "
OK22	12'6"	12'6"			" " " clay
OK23	40'0" Rock bottom	12'6"	13'-16',	01	
			16'-19',	0.19	Laterite concretions and crusts
			19'-22',	0.63	
			22'-25',	0.72	
			25'-28',	0.69	
			28'-31',	0.68	
			31'-34',	0.65	
			34'-37',	0.77	
			37'-40',	0.89	
			40',	0.26	Rock - weathered dunite (?)

SITE	TOTAL DEPTH	TUFF THICK-NESS	SAMPLE INTER-VAL	% Ni.	REMARKS
OK24	7'	6'6"			Gritty clay, some laterite } drilled to determine thickness of tuff only.
OK25	12'6"	12'0"			Gritty clay, some laterite } drilled to determine thickness of tuff only.
OK26	40'0" Rock bottom	5'6"	5'6"-7',	0.48	
			7'-10',	0.80	Silica and laterite
			10'-13',	0.47	Silica fragments in mustard clay
			13'-16',	1.06	Silica fragments in mustard clay
			16'-19',	0.92	Silica fragments in mustard clay
			19'-22',	0.53	Slurry
			22'-25',	0.72	Black wad at 23'
			25'-28',	0.69	
			28'-31',	0.79	
			31'-34',	0.82	
			34'-37',	0.86	Weathered boulder at 36'
			37'-40',	0.79	
			40',	0.054	Silica replacing dunite.
OK27	7'6" Rock bottom	4'0"			4'- 4'6" Silica fragments; 4'6"-7'6" Mustard coloured clay with silica
			7'6",	0.124	7'6" Weathered dunite or laterite.

OP Series, near Okawu Creek Camp

SITE	TOTAL DEPTH	TUFF THICK-NESS	SAMPLE INTER-VAL	% Ni.	REMARKS
OP1	19' Hard laterite bottom	16'			Grey granular tuff, 2" silicified tuff at 12"
			16'-19',	nil	Hard laterite, not penetrated.
OP2	14' laterite bottom	12'			Tuff, cemented at 12', hard laterite 12'-14', not penetrated, perched water table in tuff at 5 ft.
OP3	25' Rock bottom	10'	10'-13',	0.15	10'-11', 11'-13' laterite fragments
			13'-16',	0.24	Laterite fragments
			16'-19',	0.29	Laterite fragments
			19'-22',	0.65	Mustard clay streaked black, talc
			22'-25',	0.51	Weathered dunite on bottom
OP4, OP5, OP6, OP7, OP8, - not drilled					
OP9	47'6" Rock bottom	26'	19'-26',	nil	Light brown gritty clay, some cemented tuff, silica nodules with grey clay
			26'-28',	0.04	Red brown clay, with laterite fragments.
			28'-31',	0.14	Red brown clay, with laterite fragments.
			31'-34',	0.19	Red brown clay, with laterite fragments.
			34'-37',	0.40	Clay
			37'-40',	0.23	Clay
			40'-43',	0.25	Clay
			43'-46',	0.67	Clay
			46'-47-6",	0.70	Silicified weathered dunite.

SITE	TOTAL DEPTH	TUFF THICK-NESS	SAMPLE INTER-VAL	% Ni.	REMARKS
OP10	41' Probably bottomed on boulder	10'0"			Gritty clay to 10 ft., 10'-11' Hard laterite.
			11'-13',	0.27	
			13'-16',	0.32	
			16'-19',	0.40	
			19'-22',	0.59	
			22'-25',	0.54	
			25'-28',	0.58	
			28'-31',	0.54	
			31'-34',	0.48	
			34'-37',	0.62	
			37'-40',	0.79	
			40'-41',	0.64	Blue-green clay
			71'	0.72	Light blue rock (silicified dunite?)
OP11	53' abandoned in wet clay	17'	17'-19',	0.02	17'-20' Hard laterite, followed by clay
			19'-22',	0.13	
			22'-25',	0.22	
			25'-28',	0.41	
			28'-31',	0.41	
			31'-34',	0.37	33' White flecks and vermillion streaks in brown clay
			34'-37',	0.43	
			37'-40',	0.55	
			40'-43',	0.57)	
			43'-46',	0.45)	
			46'-49',	0.65)	Very wet slurry
			49'-52',	0.64)	
			52'-53',	0.69)	Hole abandoned, rock not reached
OP12	43' abandoned in wet clay	20'			Light brown gritty clay. 17'-20' wet.
			19'-22',	0.07	20'-22' hard laterite, followed by clay
			22'-25',	0.37	
			25'-28',	0.40	
			28'-31',	0.32	
			31'-34',	0.21	
			34'-37',	0.26	
			37'-40',	0.40	
			40'-43',	0.40	Thick slurry, poor recovery, hole abandoned, rock not reached
OP13	70' abandoned in wet clay	19'	19'-22',	nil	Hard laterite and red clay
			22'-25',	0.07)	
			25'-28',	0.30)	
			28'-31',	0.33)	
			31'-34',	0.32)	
			34'-37',	0.34)	Tight mustard coloured clay
			37'-40',	0.42)	
			40'-43',	0.49)	
			43'-46',	0.46)	
			46'-49',	0.34)	
			49'-52',	0.38)	
			52'-55',	0.45)	
			55'-58',	0.35)	
			58'-61',	0.13)	
			61'-64',	0.33)	Wet clay
			64'-67',	0.23)	66' Black wad (Mn & Co. oxides
			67'-70',	0.76)	67'-68' talc flakes
			70'	1.08)	Hole abandoned, no rock.

SITE	TOTAL DEPTH	TUFF THICK-NESS	SAMPLE INTER-VAL	% Ni.	REMARKS
OP14	61' hard rock bottom	16'	16'-19',	nil	16'-20' hard laterite, followed by tight clay
			19'-22',	0.02	
			22'-25',	0.14	
			25'-28',	0.19	
			28'-31',	0.24	
			31'-34',	0.44	
			34'-37',	0.40	
			37'-40',	0.37	
			40'-43',	0.49)	
			43'-46',	0.55)	Wet clay, streaked light brown,
			46'-49',	0.48)	dark brown, orange, flecked
			49'-52',	0.70)	with black and vermillion
			52'-55',	0.65)	
			55'-58',	0.75)	
			58'-61',	1.08)	
			61'	1.46	Hard blue grey rock, (silicifed dunite?)
OP15	73' Hard rock bottom	18'	19'-22',	0.17	18'-19' Laterite fragments
			22'-25',	0.40)	
			25'-28',	0.58)	
			28'-31',	0.67)	
			31'-34',	0.63)	Massive mustard coloured clay
			34'-37',	0.68)	
			37'-40',	0.64)	
			40'-43',	0.73)	
			43'-46',	0.94)	
			46'	1.44	46'-50' Vermillion clay, talc, gritty feel
			46'-49',	0.43	
			49'-52',	0.92)	
			52'-55',	0.76)	50'-63' mustard coloured clay
			55'-58',	0.70)	
			58'-61',	0.83)	
			61'-64',	0.89	63'-64' Vermillion clay with talc
			64'-67',	0.90	and white fibrous mineral
			67'-70',	1.02	Wet clay
			70'-73',	1.30	Weathered dunite - rock
OP16	not drilled				
OP17	abandoned in tuff at 11'6" after striking tree root.				
OP18	65'6" hard and bottom	22'			0'-17' grey tuff, 17'-22' bleached tuff with secondary silica.
			22'-25',	0.34	22' Light brown clay with laterite fragments
			25'-28',	0.39)	
			28'-31',	0.44)	
			31'-34',	0.54)	mustard coloured massive clays
			34'-37',	0.58)	
			37'-40',	0.62)	
			40'-43',	0.78)	
			43'-46',	0.68)	
			46'-49',	0.57)	
			49'-52',	0.84)	
			52'-55',	0.80)	
			55'-58',	0.69)	
			58'-61',	0.78	63' Wet mustard coloured clay
			61'-64',	0.78	64' streaky blue clay
			64'-65'6",	1.09	Blue, granular rock silicified dunite?)

SITE	TOTAL DEPTH	TUFF THICK-NESS	SAMPLE INTER-VAL	% Ni.	REMARKS
OP19	60' hard rock bottom	13'			12'-13' silicified tuff
			13'-16',	0.48)	
			16'-19',	0.50)	
			19'-22',	0.48)	
			22'-25',	0.53)	massive, light, mustard coloured clay
			25'-28',	0.57)	
			28'-31',	0.57)	
			31'-34',	0.59)	
			34'-37',	0.59)	
			37'-40',	0.86	38'-42' We clay
			40'-43',	0.70	
			43'-46',	0.73	
			46'-49',	0.68	49' Secondary silica stringer
			49'-52',	0.92	50' Laterite fragment
			52'-55',	1.22)	
			55'-58',	1.19)	Wet clay
			58'-60',	1.03)	60' cilica stringer
			60'	1.04	Hard rock not recovered

APPENDIX II

NICKELIFEROUS ROCKS FROM MEBULIBULI CREEK, FERGUSSON ISLAND

by

W.M.B. Roberts and W.B. Dallwitz

Specimen P190 resembles closely a dark grey volcanic glass (pitchstone), and has a conchoidal fracture. It contains a spongy meshwork of fine-grained sulphide.

In thin section the rock is found to consist mainly of opal and sulphide. Structures remaining in the opal clearly show that the rock was formerly a serpentine, and that this serpentine was probably derived from olivine. In other words, the rock can be genetically referred to as an opalized, sulphide bearing serpentinized dunite.

Books of talc and a few grains of red-brown chromite are scattered through the slide. Fine-grained doubly-refracting material, possibly talc, forms abundant inclusions in the opal in places. The structures referred to in the previous paragraph pseudomorph a serpentine which consisted of antigorite veined by chrysotile. The veinlets of chrysotile have been replaced by more or less clear opal, whereas the antigorite has been made over to murky brownish opal. Black iron ore, probably magnetite (which is a common byproduct of serpentinization), is associated with the clear opal replacing former chrysotile veins.

The polished section showed the following opaque minerals to be present: marcasite, pyrite and chromite; magnetite is also present, but cannot be detected under the microscope because of its extremely fine grainsize.

Chromite forms euhedral and subhedral crystals ranging up to 2.mm in length which have been fractured and later recemented by marcasite. The crystals are almost always surrounded by a "halo" of marcasite, which, although obviously later in origin, is not replacing the earlier chromite.

The marcasite itself is present mainly as spongy masses through which irregular veins of coarser grained marcasite are emplaced. These veins are clearly controlled by a well developed jointing in the rock which has two directions roughly at 60° to each other. The spongy masses themselves represent a diffusion outwards from these mineralising channels.

Pyrite occurs in the same manner as marcasite although much less abundantly, forming spongy masses as well as diffusion textures resembling liesegang rings. This mineral appears to be moulding irregular granular areas of marcasite, but the evidence is not sufficient to state that it is of later origin.

Specimen P191 is a dark grey, chalcedonic rock containing sulphide. Marginally the rock has been stained brown and red through weathering of iron sulphide.

In thin section the rock is found to consist of chalcedony, sulphide, and fine-grained black, opaque material (magnetite - see below). Veinlets of coarser chalcedony traverse the slide; these may contain brown chalcedony showing distinct spherulitic structure. Brown chalcedony in small clots is also scattered through the main body of the rock.

This specimen is more thoroughly altered than is No. P190; none of the talc remains, and all reliable signs of former serpentinous structure have been obliterated; nevertheless, there can be little doubt that the rock is simply more highly altered and silicified material than that represented by specimen P190. The likelihood of its derivation from dunite and serpentine is strengthened by the presence of chromite, which was noted in polished section.

The opaque minerals, determined in polished section are the same as for section P190, although far less sulphide is present.

Marcasite is the principal sulphide, forming irregular thread-like veinlets having a random arrangement and distribution: sponge-like areas, as are common in section 190, are not present in this specimen.

Pyrite forms irregular masses composed of euhedral crystals .001 mm. across which are only visible at extreme magnification. Chromite occurs as in section P190, but to a slightly lesser extent, the largest crystal measuring 0.15 mm. across.

Magnetite, although quite abundant, could not be identified microscopically because of its extremely finely divided state.

<u>The source of nickel</u>

The sulphides of both rocks were tested microchemically for nickel, and all gave a negative result.

The polished sections were analysed in the X-ray fluorescence spectrograph and the presence of nickel was verified.

The finely-divided magnetite was not apparent as such under the microscope, and was only identified by its behaviour when the finely crushed rock from specimen P191 was probed with a magnet. Sufficient magnetite was separated to test microchemically with dimethyl glyoxime; a strong positive result for nickel was obtained.

These rocks have been formed by serpentinisation and subsequent silicification of dunite, and it is fairly certain that the dusty magnetite is a by-product of the serpentinisation (see above). The magnetite has picked up nickel present in the original olivine during its alteration to serpentine.

Nickelian magnetite has been recorded in the literature.

APPENDIX III

MINERAGRAPHIC DESCRIPTION OF COPPER MINERALS FROM THE WARIA RIVER, NEW GUINEA

by

G. Greaves

Following is a description of a speciment of copper ore (G.120) collected from the bed of the Waria River, half a mile downstream from Sako Villeage, New Guinea. The specimen was submitted by J.E. Thompson.

The hand specimen is massive, and consists mainly of brassy yellow sulphide and milky vein quartz.

Sulphides form about 30% of the specimen; they consist of 95% chalcopyrite and 5% pyrite and covellite.

Irregular chalcopyrite grains up to several centimetres in diameter have been extensively shattered and subsequently recemented by quartz. Minor alteration to hydrated iron oxides has taken place along the fractures.

Subhedral pyrite grains having a maximum diameter of 0.3 mm. are enclosed in iron stained quartz near the chalcopyrite grains.

Irregular covellite grains in quartz were very difficult to polish. The maximum size of the plucked covellite grains is about 1.5 mm. in diameter. When viewed in air the pleochroism, compared with normal covellite, is subdued; between crossed nicols, the mineral shows an anomalous blue interference colour as well as the typical pale orange and reddish-brown interference colour. Under oil immersions, the pleochroism was still subdued, but the interference colours were normal.

Subhedral grains of magnetite up to 0.4 mm. long and 0.07 mm. wide are enclosed by quartz and to a minor extent by chalcopyrite. Hydrated iron oxides have formed between the magnetite and quartz.

A semi-qualitative X-ray spectrographic determination for nickel by W.M.B. Roberts showed that 25-75 ppm. Ni was present. A similar determination for gold was inconclusive.

Bureau of Mineral Resources, Geology & Geophysics Canberra A.C.T. Oct. 1961. To accompany record No. 1962/157

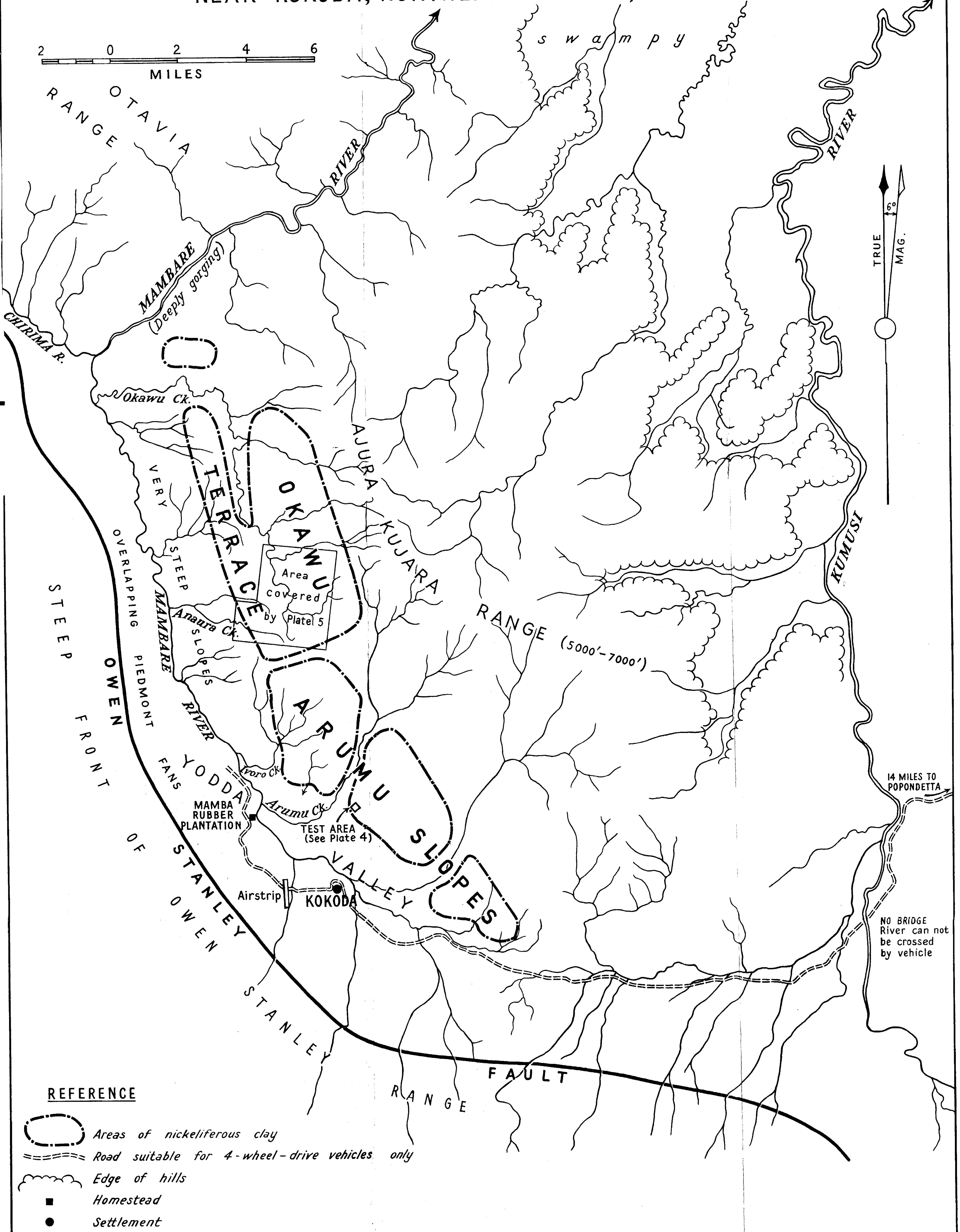
THE DISTRIBUTION OF ULTRAMAFIC ROCKS IN THE MUSA VALLEY, PAPUA

Bureau of Mineral Resources, Geology and Geophysics July 1962

To accompany Record No 1962/157

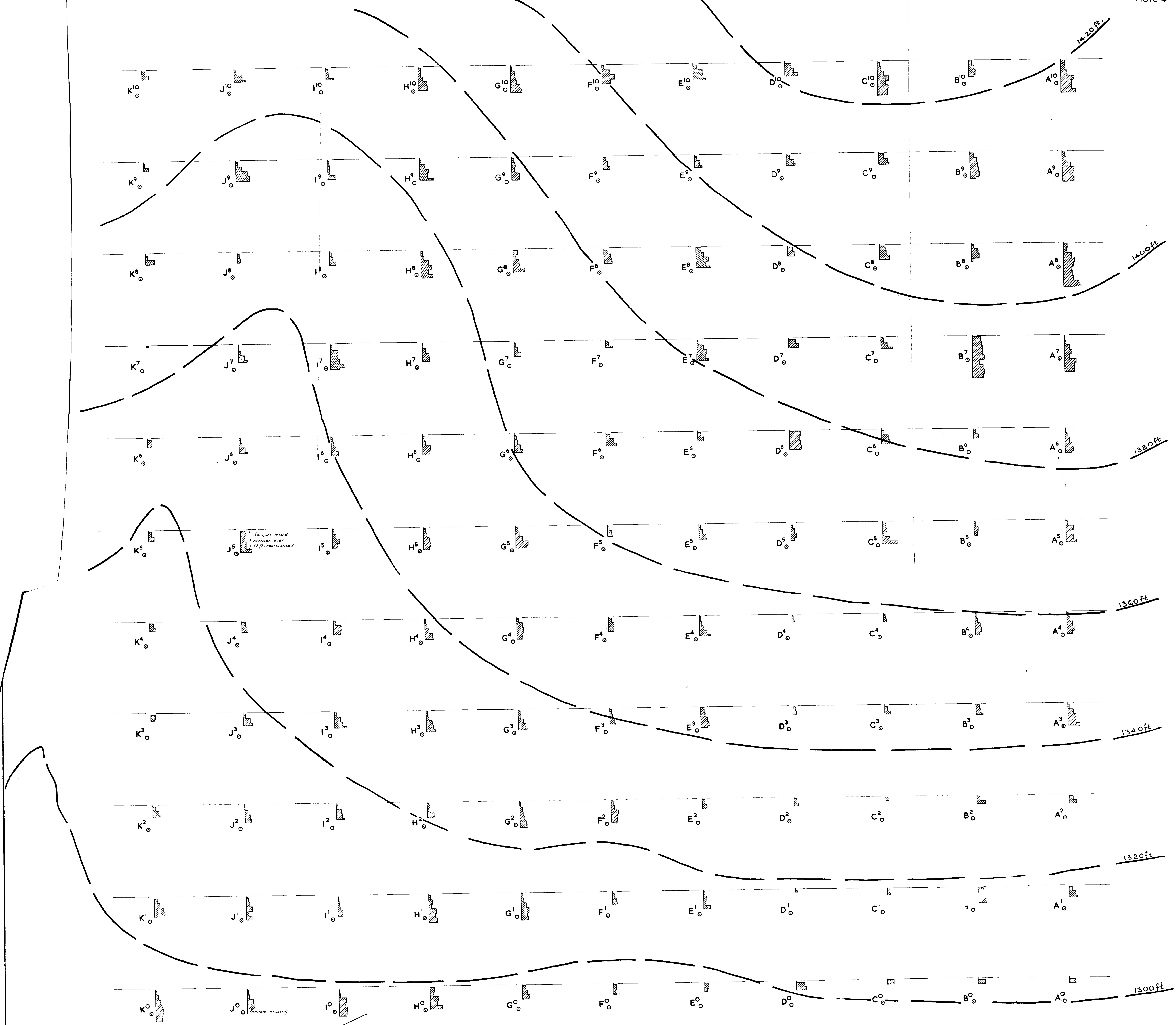
C55/8/1 JK

SKETCH MAP
AREAS OF NICKELIFEROUS CLAY
NEAR KOKODA, NORTHERN DISTRICT, PAPUA

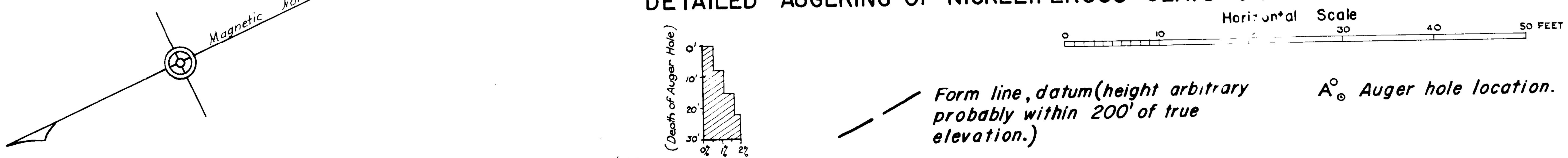


Bureau of Mineral Resources, Geology and Geophysics. October, 1961. To accompany Record Nº 1962/157

Plate 4



DETAILED AUGERING OF NICKELIFEROUS CLAYS ON ARUMU SLOPES NEAR KOKODA



C55/3/1

Bureau of Mineral Resources, Geology and Geophysics May, 1962

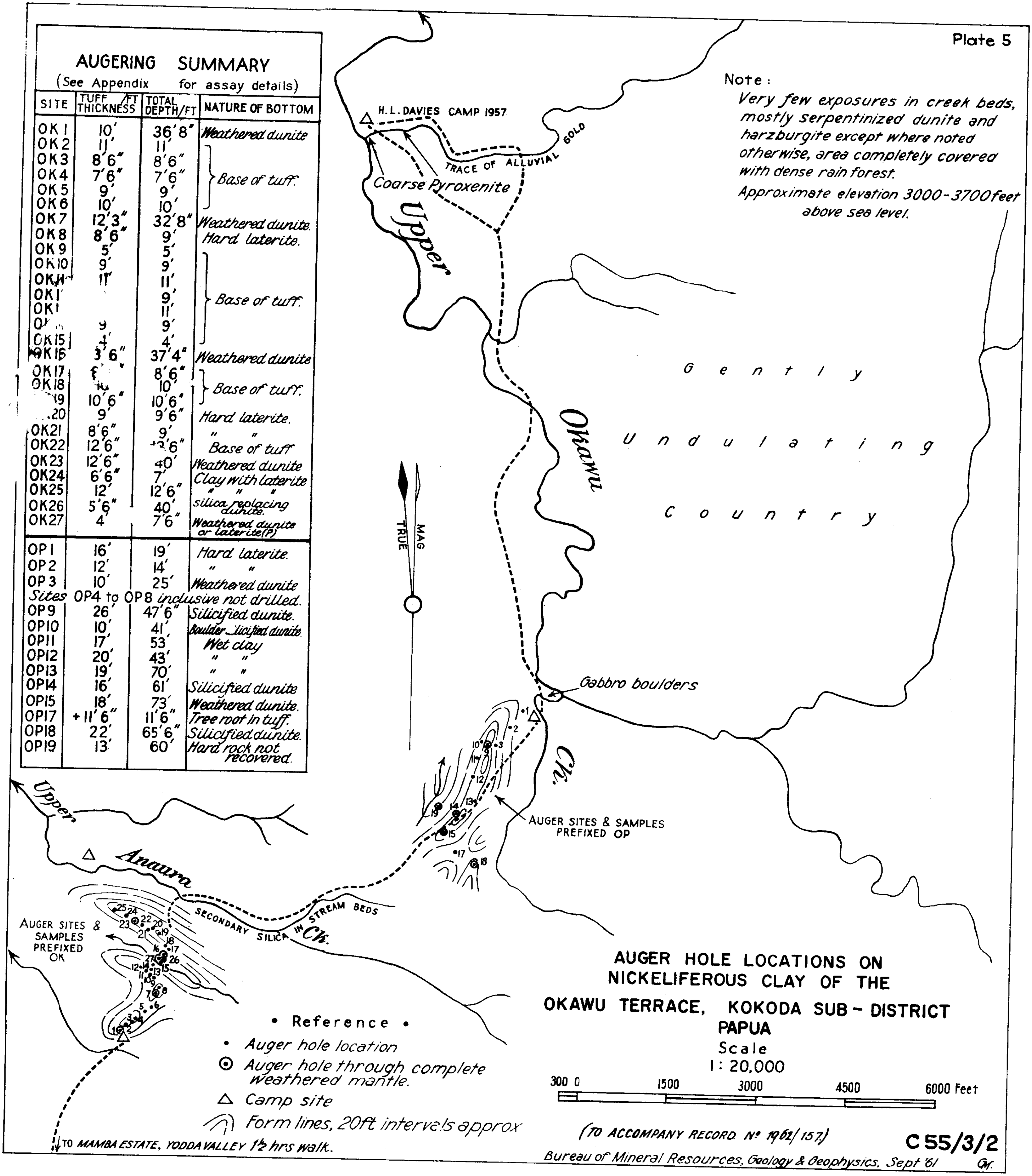
To accompany Record No 1962/157

Plate 5

AUGERING SUMMARY

(See Appendix for assay details)

SITE	TUFF THICKNESS /FT	TOTAL DEPTH/FT	NATURE OF BOTTOM
OK 1	10'	36'8"	Weathered dunite
OK 2	11'	11'	Base of tuff.
OK 3	8'6"	8'6"	Base of tuff.
OK 4	7'6"	7'6"	Base of tuff.
OK 5	9'	9'	Base of tuff.
OK 6	10'	10'	Base of tuff.
OK 7	12'3"	32'8"	Weathered dunite.
OK 8	8'6"	9'	Hard laterite.
OK 9	5'	5'	Base of tuff.
OK 10	9'	9'	Base of tuff.
OK 11	11'	11'	Base of tuff.
OK1[illegible]	[illegible]	9'	Base of tuff.
OK1[illegible]	[illegible]	11'	Base of tuff.
O[illegible]	9	9'	Base of tuff.
OK 15	4'	4'	Base of tuff.
OK 16	3'6"	37'4"	Weathered dunite
OK 17	[illegible]	8'6"	Base of tuff.
OK 18	[illegible]	10'	Base of tuff.
[illegible]19	10'6"	10'6"	Base of tuff.
[illegible]20	9'	9'6"	Hard laterite.
OK21	8'6"	9'	" "
OK22	12'6"	[illegible]'6"	Base of tuff
OK23	12'6"	40'	Weathered dunite
OK24	6'6"	7'	Clay with laterite
OK25	12'	12'6"	" " "
OK26	5'6"	40'	silica replacing dunite.
OK27	4'	7'6"	Weathered dunite or laterite(?)
OP 1	16'	19'	Hard laterite.
OP 2	12'	14'	" "
OP 3	10'	25'	Weathered dunite
Sites OP4 to OP8 inclusive not drilled.			
OP 9	26'	47'6"	Silicified dunite.
OP10	10'	41'	Boulder silicified dunite.
OP11	17'	53'	Wet clay
OP12	20'	43'	" "
OP13	19'	70'	" "
OP14	16'	61'	Silicified dunite
OP15	18'	73'	Weathered dunite.
OP17	+ 11'6"	11'6"	Tree root in tuff.
OP18	22'	65'6"	Silicified dunite.
OP19	13'	60'	Hard rock not recovered.



AUGER HOLE LOCATIONS ON NICKELIFEROUS CLAY OF THE OKAWU TERRACE, KOKODA SUB-DISTRICT PAPUA

(TO ACCOMPANY RECORD Nº 1962/157)

C55/3/2

Bureau of Mineral Resources, Geology & Geophysics. Sept '61

GEOLOGICAL SKETCH MAP OF KOREPPA NICKEL / COBALT PROSPECT WARIA VALLEY, NEW GUINEA.

SHOWING LOCATION OF SAMPLED AUGER HOLES AND PITS

Scale : 1" = 200 ft.

ASSAY DATA.

Auger Hole or Pit No.	Depth Interval in Feet	% Ni.	% Cr.	% Co.
I.	0'-4'	0·60	1·61	0·03
	4'-8'	0·92	0·78	0·04
	8'-12'	1·69	0·45	0·02
*	12'-16'	1·86	0·35	0·02
II.	0'-4'	0·58	0·38	0·02
	4'-8'	0·86	0·46	0·02
	8'-12'	0·96	0·21	0·03
*	12'-13'	1·06	0·18	0·04
III.	0'-4'	0·38	0·93	0·04
	4'-8'	0·47	0·47	0·04
	8'-12	1·01	0·42	0·07
	12'-16'	1·23	0·45	0·05
IV.	0'-4'	0·60	0·75	NOT ASSAYED
	4'-8'	0·05	1·11	
	8'-12	0·73	1·13	
	12'-16'	0·48	1·73	
V.	0'-4'	0·32	1·65	
	4'-8'	0·75	2·05	
	8'-12'	1·06	1·48	
	12'-15'	0·80	2·45	
VI.	0'-4'	0·36	2·08	
	4'-8'	0·53	2·45	
	8'-12'	0·82	2·25	
	12'-16'	0·75	2·71	
VII.	0'-4'	0·44	2·06	
	4'-8'	0·38	1·34	
	8'-12'	0·44	1·22	
	12'-16'	0·38	1·22	
VIII.	0'-1'	0·87	1·24	
	1'-2'	1·35	0·32	
	2'-3'	1·39	0·40	
	3'-4'	1·88	0·27	
	4'-5'	1·92	0·14	
IX.	0'-2'	1·14	0·57	
	2'-4'	1·17	0·76	
	4'-6'	1·70	0·33	
	6'-8'	1·97	0·50	
*	8'-10'	1·63	0·27	
X	0'-4'	1·08	1·16	
*	4'-5'	1·38	0·82	
XI.	0'-4'	0·29	1·65	
	4'-8'	0·43	1·31	
	8'-12'	0·44	1·30	
	12'-16'	0·76	1·10	
SH 25	0'-5'	0·25	1·44	
	5'-10'	0·65	0·86	
	10'-15'	0·80	0·27	
XII	15'-19'	1·35	0·64	
*	19'-20'	0·80	0·91	
SH 13	0'-2'	0·43	2·46	
*	2'-4'	1·68	0·53	
SH 55	0'-4'	0·49	1·64	
	4'-8'	0·86	2·25	
*	8'-13'	1·71	0·63	
SH 57	0'-2'	1·03	1·71	
*	2'-5'	1·62	1·13	
SH 58	0'-5'	0·53	2·00	
	5'-10'	0·82	2·37	
SH 63	0'-1'	1·42	0·38	
	1'-3'	1·42	0·69	
	3'-5'	0·82	2·44	
*				

** : BOTTOMED IN HARD ROCK; OTHERWISE SAMPLED TO LIMIT OF AVAILABLE AUGER EXTENSIONS OR BOTTOM OF PITS.*

?— · — · — INFERRED GEOLOGICAL BOUNDARY
● VII(16') SAMPLED AUGER HOLE TO 16 FT.
■ 4' PIT TO 4 FT
⊏ SHALLOW COSTEAN
○ UNSAMPLED AUGER HOLE
—— 1850' APPROXIMATE HEIGHTS FROM LINES ONLY
HARD ROCK SPECIMENS PREFIXED 'WAR'
EXPOSURES INFREQUENT, GEOLOGICAL BOUNDARIES NOT RELIABLE

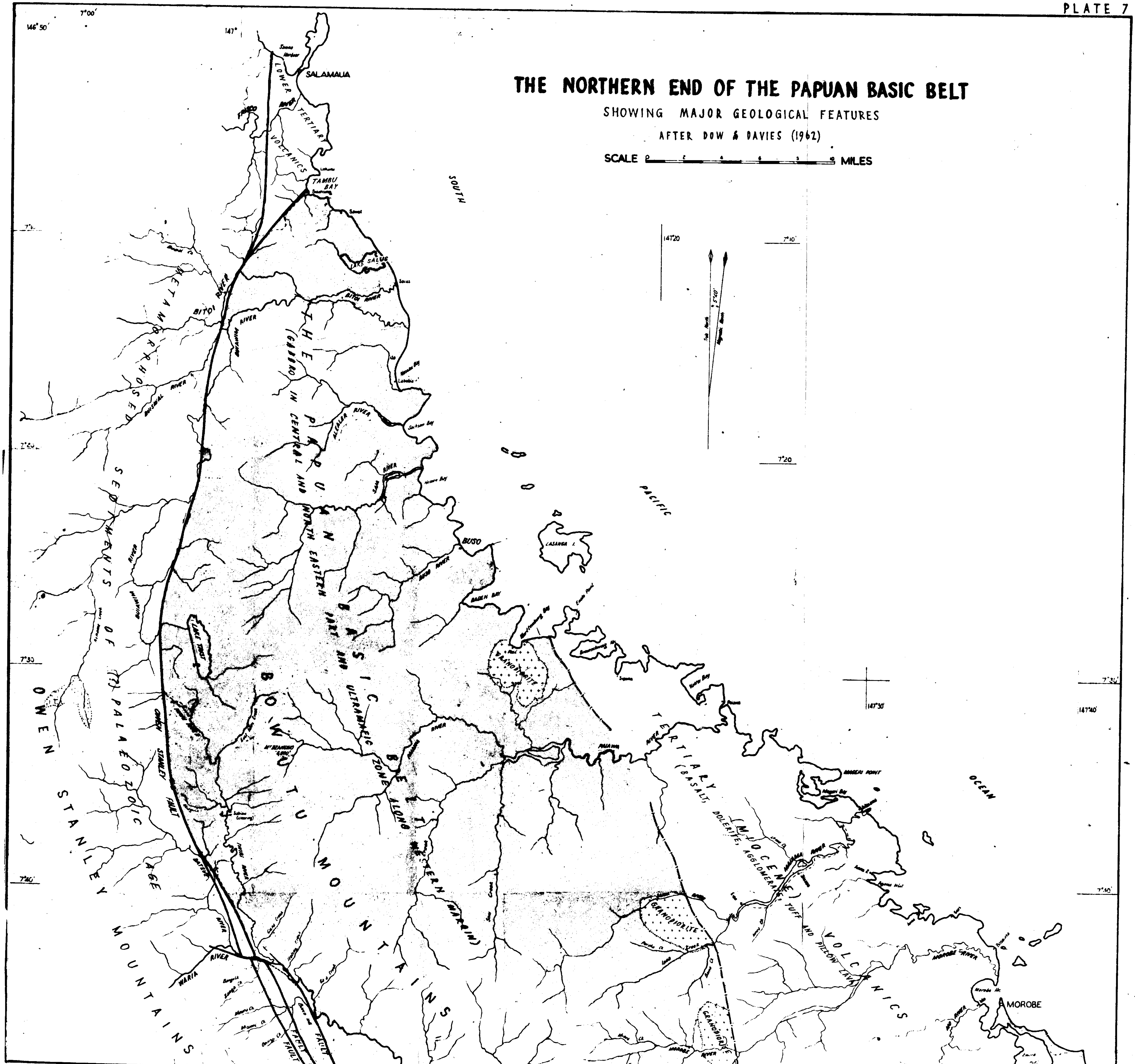
AREA EXEMPT FROM OCCUPATION UNDER SECTION 5, MINING ORDINANCE

(Bureau of Mineral Resources, Geology and Geophysics)
J.E.T. / M.L.Sz. 25·9·1958.

To accompany Record No 1962/157

B 55/15/2

PLATE 7



BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS, APRIL 1963.

TO ACCOMPANY RECORD 1962/127

Pl/16