

The Exploration of the Nickel Laterite Deposits in Irian Barat, Indonesia

C.D. REYNOLDS, I. HAVRYLUK, SALEH BASTAMAN
AND SOEPOMO ATMOWIDJOJO¹

Abstract: Nickel-bearing laterites developed in-situ on nickel-bearing peridotites were examined during the period 1969-1971 at a number of localities in the Cyclops and Waigeo areas in Irian Barat, Indonesia. The laterites occur in both forested and unforested areas and as plateau and hill-side types of deposits. The distribution of chemical elements within the profile is similar to other tropical nickel laterite deposits, i.e., concentration of Al_2O_3 and Fe in the near surface layers with an accompanying depletion of SiO_2 and MgO and concentration of nickel in the low iron portion of the profile. Exploration was by drilling (hand augers, mechanical augers and coring drills) and test pits. Through 1971 more than 50,000 meters of drilling and testpitting were completed. Samples were analyzed for Ni, Co and Fe at PTPNI's chemical laboratory on Waigeo Island. All drilling information, chemical analyses and mining classifications are being analyzed by data processing techniques. In late 1971 a 12,000 ton bulk sample was collected on Gag Island and shipped to Fort Saskatchewan, Canada for testing and evaluation studies.

INTRODUCTION

The paper briefly summarizes field methods employed by P.T. Pacific Nikkel Indonesia during their 1969-1971 exploration and evaluation of nickel laterite deposits on Waigeo Island, and adjacent islands at the western tip of New Guinea Island, and at Cyclops near Jayapura in Irian Barat, Indonesia (see Fig. 1).

Location and Access

Deposits near Jayapura are along the south and west slopes of Cyclops Mountain Range, within an area 40 Kms long and 5 Kms wide extending from Tanah Merah Bay on the west to Humboldt Bay on the east (Fig. 2). The individual deposits are Tanah Merah, Tablasufa, Amaybu, Kirpon, Rhynauwan, Ifar, Harapan and Doyo. On Waigeo Island the nickel laterite deposits occur within an 80 Kms long and 5 Kms wide belt extending from Cape Sarenbon to Fofak Bay on the west (Fig. 3). The individual deposits are; Sarenbon, Wari Bari, Kapias-Kambaloi, Wemisi, Fofak East, Fofak West and Kleine Tafelberg. Deposits are also located at Manuran Island a few kilometers off the north coast of Waigeo, on the south shore of Aljoei Bay, on the west end of Waigeo, and on the islands of Kawe, Batang Pele, Minjai Foen, the Fam group and Gag. This latter group of islands lies within a 50 Km radius of the western tip of Waigeo (Fig. 3).

Air access to Irian Barat from Jakarta is through Biak, the region's principal airport. From Biak there is a connecting air service to Sentani airfield serving the eastern or Cyclops area and to Sorong serving the western or Waigeo areas. Eastern Cyclops laterite deposits can be reached by road from Jayapura, whereas deposits on Tanah Merah Bay are more easily reached by boat from Jayapura. Waigeo Island and the islands to the west of Waigeo are accessible only by boat from Sorong. The distance from Sorong to P.T. Pacific Nikkel's base camp on the north coast of Waigeo is about 120 Kms and from Sorong to Gag Island it is about 160 Kms.

¹ P.T. Pacific Nikkel Indonesia, P.O. Box 171, Djakarta, Indonesia.

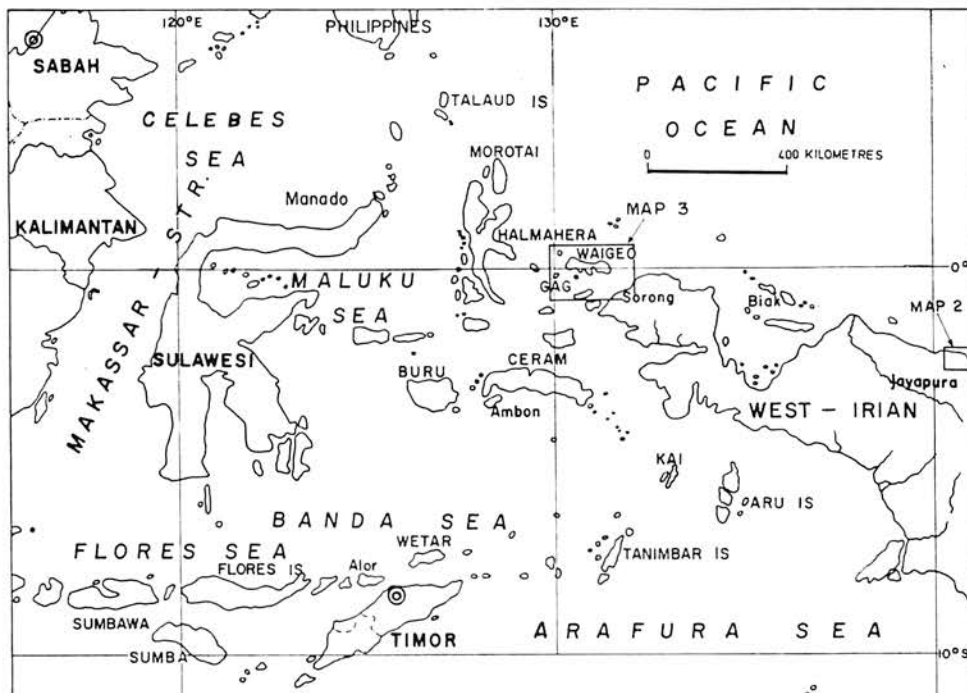


Fig. 1. Location map, West Irian Indonesia.

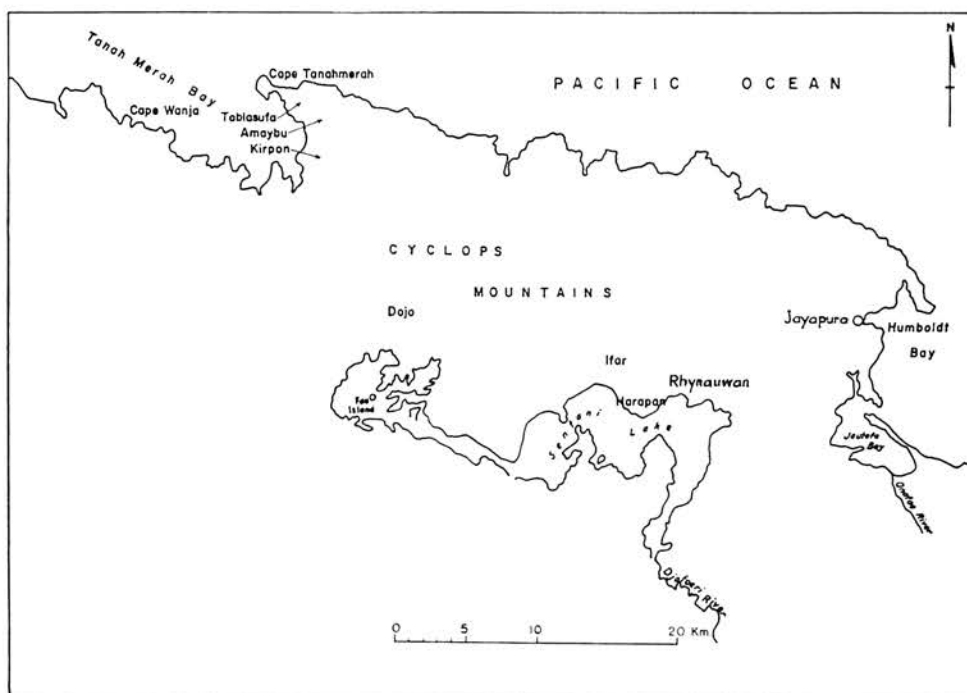


Fig. 2. Location map, Cyclops area.

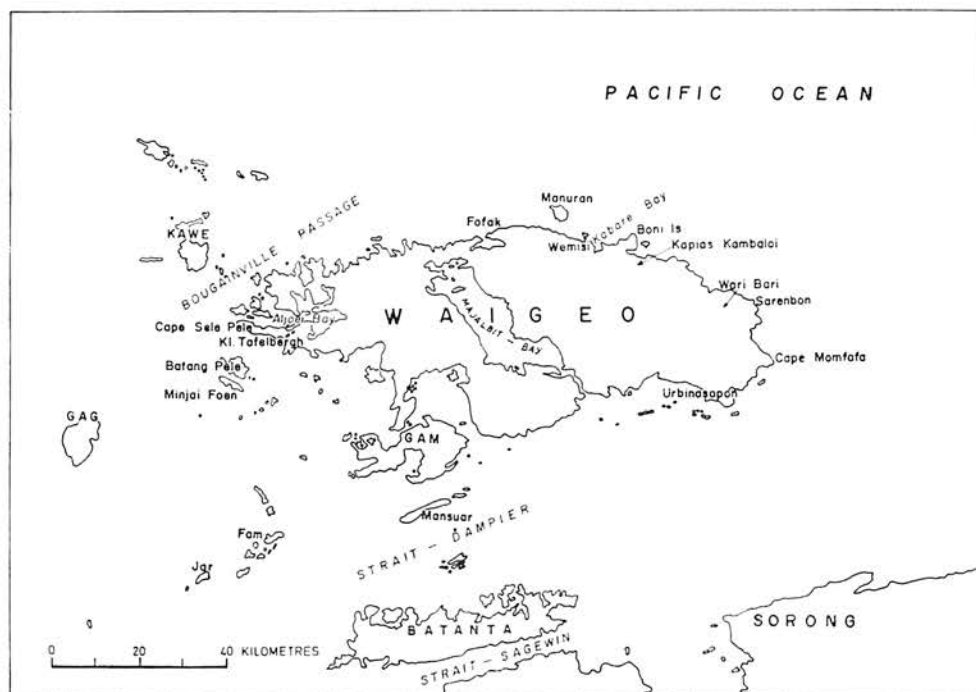


Fig. 3. Location map, Waigeo Island.

History of Exploration of Laterite Deposits

The nickel-bearing laterites at Cyclops have been described by Van Nes (1954, 1956) and those on Waigeo by Molengraaff (1957). Their exploration programs outlined a number of potential nickel laterite areas associated with dunites and harzburgites.

Pacific Nikkel Mijnbouw Maatschappij, formed in 1960, was reorganized in 1969 as P.T. Pacific Nikkel Indonesia to explore and develop these deposits under a Contract of Work with the Government of Indonesia. The participants in the Company are United States Steel Corporation, Koninklijke Nederlandsche Hoogovens en Staalfabrieken N.V. (Holland), Wm H. Müller & Co N.V. (Holland), Newmont Mining Corporation (U.S.A.) and Sherritt Gordon Mines Limited (Canada).

Exploration was started in June 1969 from the first base camp located on the small island of "Bombedari" 30 Kms east of Cape Sarenbon on the north coast of Waigeo. The camp included a chemical laboratory for the analyses of exploration samples from the field. Most of the exploration work during the first season was by hand auger drilling, supplemented by a limited number of test pits and mechanical drill holes.

During 1970 exploration was continued on Waigeo and Manuran Islands and new investigations were carried on at Cyclops, and Kawe and Gag Islands. Hand augers were used extensively for reconnaissance whereas power augers and a truck mounted coring drill were used for follow-up drilling in areas of greater economic potential.

In early 1971 extensive drilling programs were undertaken both on Gag and Manuran Islands to outline possible sources of representative materials for a large tonnage bulk sample for testing purposes. The Gag Island site was finally chosen and on November 11, 1972, a 12,000 Net Ton Bulk Sample consisting of separate cargoes of high and low iron laterites was shipped to the Sherritt Gordon demonstration plant at Fort Saskatchewan, Canada. Drilling continued on Gag during the entire year.

PHYSIOGRAPHY

Cyclops

The prominent physiographic feature in the Cyclops-Sentani areas is the 40 Km long and 10–15 Km wide Cyclops Mountain Range which extends from Cape Tanah Merah on the west to Humboldt Bay on the east. It is bounded by steep slopes on all sides. On the north and east the range rises abruptly from sea level to elevations of over 2,000 meters. On the south and south-west, the slopes are equally steep, but gravels and coarse sediments have accumulated along the toe giving that part of the profile a more gentle contour. These outwash fans extend southward into an irregular shaped basin occupied by the 25 Km long Lake Sentani, the surface of which is at an elevation of 70 meters. To the south of the lake are numerous smooth, rounded and grassy hills with elevations of 200 to 250 meters. The south slopes of Cyclops have remnants of wave-cut cliffs and terraces, from 10 to 50 meters above the present lake surface, indicating former and higher lake levels. The Sentani airport is situated on a part of the former lake bed.

The Cyclops Range is blanketed with a heavy forest cover down to sea level on the north slopes and almost down to the level of Lake Sentani on the south. All of the Tanah Merah and a part of the Tablasufa laterite areas are covered only with a light growth of bush and grass. The Ifar and Rhynauwan areas, located along the south side of Cyclops, have only a light grass cover, but at these localities, as at Tanah Merah, the lack of heavier growth may be due to the clearing of these sites during World War II operations for military encampments and the subsequent inability of the vegetation to recover its former stage of development. The eastern portion of Tablasufa and the neighbouring Amaybu and Kirpon areas have a substantial forest cover.

Drainage from the south slopes of Cyclops flows into Lake Sentani and thence to the ocean at Humboldt Bay through the Jafoeri River drainage system. Drainage in the Tablasufa areas is intermittent and passes directly into the sea.

Waigeo

Waigeo is a rugged, mountainous heavily forested island that measures 130 Kms long and about 50 Kms wide. The east and north coast are bounded by steep headlands, and in places, almost continuous and straight 100 meter high sea cliffs. There are few re-entrants along this coast that provide protected harbours (and bays). The north coast has only a few locations where there is enough flat ground for settlements of more than several hundred inhabitants. The west and south coasts are broken by many re-entrants and bays which cut deeply into the island. Aljoei Bay is a 25 kilometer long fjord-like bay on the west end of the island. The 40 kilometer long Majalibit Bay, with its restricted entrance on the south coast of Waigeo, almost cuts the island into two equal parts. Only a two kilometer wide low lying ridge separates it from Fofak Bay on the north coast. Similar to the northern coast of the island, the southern shore has no coastal plain, but is marked by precipitous slopes and cliffs.

The western and southern portions of the island are underlain by limestones upon which an extensive karst topography has developed with its characteristic sinks, deep fissures, caverns, elusive drainage and irregular hills. One isolated limestone spire south of Fofak Bay rises from sea level to an elevation of more than 650 meters.

The north central and eastern portions of Waigeo are underlain by volcanics, metasediments, diabases and ultrabasics which have been eroded into rugged mountainous terrain. The higher elevations are found within this part of the island, and the highest elevations of about 1,000 meters are found on a steep ridge rising abruptly from sea level along the north coast of the island opposite Manuran.

The principal drainages on Waigeo Island are: the Asekwor River draining the north central section of the island and debauching near the village of Kabarei and the Wari Bari River which drains the central eastern portions of the island and debauches near Sarenbon on the east end of the island. Numerous smaller rivers drain either to the south coast or into Majalibit Bay.

On Waigeo the principal nickel laterite occurrences are at Cape Sarenbon, Kapias, Kambaloi, Fofak West, Kleine Tafelberg, and at Manuran Island a few kilometers off the north coast. Topographically the laterites are found from elevations of 120 to 450 meters above the sea level. Physiographically the laterites occur both on plateau-like surfaces of moderate relief and on steep slopes. Plateau-like surfaces are preserved on parts of Sarenbon, Wemisi, Kapias, Fofak West and Kleine Tafelberg. The best preserved plateau surface is on Manuran Island. Laterites on steep slopes are found in all laterite areas but they are best developed on eastern Sarenbon, southwestern Kambaloi, all of Fofak East and the southern slopes of Manuran. In the western islands at Kawe and Minyai Foen the laterite deposits are related to plateau-like surfaces, whereas at Batang Pele and Gag island such surfaces are conspicuous by their absence and most of the laterites are on moderate to steep slopes.

The commonly recognized characteristics of laterite surfaces covered with grasses, scrub-like vegetation and bare, indurated pavement like crusts are seen at Kapias, Kambaloi, Wemisi, Fofak, Kleine Tafelberg and Manuran. Heavily forested laterites are found on the 400 meter elevation plateaus at Sarenbon and Wari Bari and at elevations of 200 meters on the western end of Kambaloi. In the western islands, the Kawe, Batang Pele, Minjai Foen and Gag deposits all have scrub growth and pavement-like laterite outcrops, however, on Gag the bare laterites are less in evidence and the vegetation is somewhat better developed and thicker than in the other areas.

EXPLORATION PROCEDURES

Each of the areas to be investigated was first reconnoitered on the ground to establish the approximate limits of the laterite, the areas of outcrop and the areas of boulder fields. The type of survey control to be used was also determined at the same time.

Survey Control

Dependent upon the local topography, the survey control was developed either by establishing a grid system with cross sections oriented 90° to a base line or by using triangulation to locate widely spaced reference points from which closed traverses were made to locate drill holes and points of geologic interest. The grid systems were laid out on the ground to fit the topography rather than to conform arbitrarily to a north oriented set of coordinates.

The triangulation nets were most useful and established most quickly in those areas where irregular terrain and long distances separated the laterite occurrences. If subsequent geologic investigation indicated the necessity of large additional amounts of drilling, then the control was changed to a grid system. Tape and compass surveys were used during 1969 to establish the grid systems or to run closed traverses from triangulation control points for the purposes of locating drill sites, geologic features, etc. To facilitate the use of and to improve the control of the closed traverse surveys, the geologist would frequently carry a small plotting board with him in the field to record his traverse as it was made. During the 1970 and later surveys, all the control was established by stadia and by the grid system method of baselines and cross sections. Depending upon the terrain, the cross sections were spaced either 100 or 200 meters apart along which drill sites were located on 50 and/or 100 meter centers.

Initially, elevations were measured by altimeters which were controlled by a continuous recording base station microbarograph. Eventually all elevations were determined instrumentally by stadia. Topography was sketched in the field as the surveys progressed and all data was compiled on 1:2,000 scale maps and sections.

Aerial photographs of Waigeo and the western islands were taken in late 1969. Photographic coverage of the Cyclops area was available from earlier surveys but it was rephotographed during early 1970. Waigeo was photographed in color and Cyclops in infra red from which false color prints were made. The photo scales were about 1:20,000. Gag Island was rephotographed during 1972 at scales of 1:10,000 from which 1:2,000 scale, 2 meter contour interval topographic maps were made.

Subsurface Exploration-Drilling

Drilling was the principal method of probing the subsurface to determine thickness and grade of the deposits. Test pits were dug, not as a substitute for drilling, but in those specific situations or localities where more detailed information was needed. Three types of drilling methods were used: hand augers, mechanical or power augers and coring drills. In all cases the sample interval was one meter.

- (a) Hand augers were used extensively during the prospecting stages of unknown areas. The hand auger is a light-weight and portable tool which made it possible to prospect large areas and to determine quickly the lateral extent and the minimum thickness of the laterites. Hand auger bits are only 35 cms long hence each sample representing one meter had to be "pulled" three times. The average depth of the hand auger holes was about 7 meters, however the deepest, located on Gag island, was 43.5 meters. There is an inherent uncertainty with the hand auger sample due largely to the small volume of sample (Table 1) and the difficulty of obtaining a representative sample in granular material. Further, the depth of penetration can be limited by small boulders or harder seams within the laterite profile. To minimize the contamination of the sample, the drill hole was reamed and cleaned after each meter of advance, however, there was always the possibility of the sample being contaminated from the surface, and the possibility of the sample reliability decreasing with depth. Subsequent to the first year's examinations, most of the areas were re-drilled with mechanical drills, and the correlation between hand augers and mechanical augers for matching depths was remarkably good.

There were as many as six hand auger crews at one time. Each crew had its own leader-recorder and each group of two to three crews was supervised by a drilling foreman or an assistant geologist.

- (b) The principal power drills were continuous-flight mechanical augers. These were used widely, first for verifying the results of the earlier hand auger drilling, and then as an independent tool in new areas. The Jacro drill is a completely portable unit which breaks into small easily transportable sections. The drill is powered by a hydraulic motor which in turn is run by a gasoline powered hydraulic pump. The diameter of the auger was 8 cm and each flight was 1 meter long. The tool string was pulled each meter, but only the material from the lower one meter was retained.

The danger of contamination from this drill is less than the hand auger, principally because the volume of sample is greater and because extraneous material clinging to the auger flight when it is withdrawn from the hole is usually easily identifiable and can be removed. As with many auger-type drills there is a tendency for rock and boulders to be excluded from the sample.

Six of these drills were in operation at one time and each had a six man crew including a trained driller.

- (c) The largest and most reliable samples were obtained with a truck-mounted (Failing 1250) drill equipped with a 10 cm single tube core barrel. The drill utilizes slow rotation and high down pressure to cut a relatively undisturbed 1 meter long core which is extruded from the core barrel by hydraulic pressure. The regular 10 cm core barrel was serrated to cut through laterite or soft rock. The drill was also equipped with standard NX double tube core barrels for hard rock drilling. Core recovery in laterite utilizing the single tube barrel was excellent. The compressibility of the laterites was such that extruded core lengths of 115–125 cms were not uncommon for each meter of depth drilled. The crew for this drill consisted of one trained driller, 4 drill helpers, a sample supervisor and an assistant sampler. The samples from each type of drill are compared in Table 1.

Table 1

Type	Auger/Barrel dia	Average weight of Sample/meter
Hand Auger (HA)	5 cm	0.8– 1.0kg
Jacro (MA)	8 cm	3.0 kg
Failing (FD)	10 cm	12 –14 kg

Subsurface Exploration-Test Pits

As indicated above, the principal exploration tools for determining the extent, depth and grade of the laterites were drills. Information developed from the drills was augmented by test pits which were used to get detailed information concerning the geology of the profile, rock distribution and percentage, in-place densities, moisture and for chemical analyses and information concerning the laterite/bedrock contact. Where possible test pits were located over FD holes in order to develop comparative information.

The test pits measured 1-1/2 meters square at the surface and tapered downward to 1 meter square at a depth of 7 meters. The test pits were advanced one meter at a time. All material excavated was weighed and the laterites and rocks separated. The volume of the broken laterite was measured. At each meter of advance the test pit walls were carefully straightened, measured and the volume calculated. A channel sample for chemical analyses was cut from each of the four pit walls, mixed and quartered to about 20 kilos. A 10 kilo moisture sample was taken from the bottom in the freshly exposed laterite. From each 1 meter interval approximately 10 boulders of 4-6 kilos each were selected for density determination and the average calculated. Four boulders of both the highest and lowest densities were analyzed chemically. The pit walls were mapped geologically, and where necessary were resampled on a lithologic basis. A 50 kilo reference sample from each meter was placed in storage.

From the test pits the following data was calculated: natural and dry bulk densities, rock percentages by weight, rock volume and densities, laterite densities and swell factors. The natural densities range from 1.5 to 2.7 and natural moistures range from 35% to 50%.

The drilling and pitting totals for the three year period are as indicated in Table 2.

Table 2. Summary of Drilling and Pitting

Year	HA Holes Meters		MA Holes Meters		Pits Meters	
1969	1,056	7,255	10	129	23	102
1970	1,584	8,168	882	7,461	56	294
1971	1,326	8,480	2,650	17,715	16	56
Total	3,966	23,903	3,542	25,305	95	452

GEOLOGIC MAPPING

Surface features to be noted during the mapping of the laterites were: the lateral limits of the deposits, the character of the laterite surface, the size and distribution of the areas of outcrop and boulder fields and the nature of the bedrock contact. Mapping proceeded along the surveyed section lines and was then extended into the intermediate areas.

Lateral Limits

Determination of the lateral limits of the laterites is generally not difficult when dealing with the plateau types of occurrences. The edge of the plateau frequently although not always marks the edge of the laterite blanket, although drilling has demonstrated that the plateau deposits tend to become thinner along their margins. These relationships were clearly seen at Kapias, Fofak West and Kleine Tafelberg on Waigeo Island, on Manuran Island, and on Kawe and Minjai Foen in the western islands.

Deposits found on steep slopes were more difficult to delineate. These occur on the lower slopes of the plateau-like deposits, such as Manuran and Fofak West, or on steep and irregular terrain apparently not related to any surface of low relief. Typical localities of these types were found at Gag Island and Batang Pele where plateau-like occurrences were conspicuous by their absence and where most of the laterite was found on moderate to steep slopes.

Surface Characteristics

Surface characteristics noted during mapping were the extent and development of the vegetation and the composition of the laterite surface.

- (a) Laterite surfaces are frequently covered with a mixed growth of small trees, bushes and grass. At Cyclops this type of vegetation was found on all deposits except those in the Tanah Merah, Ifar and Rhynauwan areas. These occurrences were covered only by grass and scattered trees, a condition which may in part result from clearings made during World War II. Laterites however can sustain a substantial forest cover. At Cyclops, the Amaybu and Kirpon areas and portions of the Tablasufa area have a thick forest cover, as do the Sarenbon and Wari Bari plateaus on Waigeo. In this latter instance the trees are of uniform height but are smaller in height and diameter than those in the surrounding rain forest on areas lacking laterite. In aerial photographs this uniformity of size gives the plateaus a smooth or "matt"-like appearance, in contrast to the irregular treetop surface common to the rain forest.
- (b) Practically all of the laterite surfaces examined exhibited some sort of crustal development. Most commonly it was an induration due to the residual accumulations of iron oxides in concentrations varying from those which only discolored the laterites to those which obliterated all of the original textures and structures. Although there are exceptions, the well-developed ferruginous crusts are most often found on the plateau type laterite occurrences of low relief. In some of the better preserved and more mature profiles (e.g., Fofak, Manuran) veinlike deposits of goethite, deposited by descending surface waters, were found as fracture fillings in laterite at depths of several meters below the surface. Many of these same surfaces also have lag accumulations of platy hydrated iron oxides resulting from the breakup of the ferruginous surface caps and fracture fillings.
- (c) Boxwork structures of chalcedony and the associated lag accumulations of fragmental silica were usually associated with those surfaces of moderate to steep inclination where erosion rates are greater than they are on the plateaus. They are the remnants of the process whereby the silica which was released by weathering, and carried with descending waters, was deposited in fractures and cavities in the underlying bedrock to produce locally what appears to be a breccia of serpentinized peridotites cemented by silica. As erosion continues to lower the surface and as the effects of surface weathering are imposed upon the lower levels of the laterite profile, the peridotites are removed, and the boxwork structures of chalcedony are left behind. This occurrence of silica is an indication of the proximity of the bedrock.
- (d) Outcrops and boulder fields of partially weathered serpentinized peridotites are common in those laterite areas of moderate to steep slopes, and generally are difficult to evaluate without subsurface investigation. An isolated "boulder" may actually be a bedrock pinnacle projecting through the surface and, conversely, an area of "outcrop" may be without roots.

Laterite/Bedrock Contact

Contact between the laterites and the underlying bedrock is irregular in profile but sharp in detail. The transition zone from hard to completely disintegrated rock can be measured within the space of a few centimeters, whereas the irregularities on the

bedrock surface may be measured in tens of meters. Detailed study of this portion of the profile is of importance because it preserves the transition zone from bedrock to laterite and contains the higher concentration of nickel, and the irregularity of the contact can influence the selection of the mining method.

ANALYTICAL CONTROL

Most of the chemical analyses were performed by the PTPNI laboratory at Kabarei on Waigeo. All samples were analyzed colormetrically for nickel, cobalt and iron. A continuous program of check analyses was carried on by independent laboratories. More than 50,000 samples were analyzed during the exploration period.

Data Compilation and Processing

Although there were various sources of information, the largest single systematic source of data for the evaluation of the laterite deposits was from drill holes. As the enormous amount of information generated by the exploration program was cumbersome to process, all data describing sample type, location, composition, etc., was coded and key punched for analyses by standard data processing techniques. The data included:

- a) Location of the deposit (Tablasufa, Sarenbon).
- b) Type of sample, i.e. from test pit or drill hole (drill type identified—HA, MA, FD).
- c) Drill hole (or test pit) number, coordinate location and collar elevation.
- d) Chemical analyses for each meter (or other) depth interval.
- e) Moisture analyses for core drill and test pits samples.
- f) Areas of influence for each drill hole.
- g) Classification of each sample interval into one of several provisional mining programs or schedules.

Standard computer programs were written to calculate the tonnages and grades of: a) individual deposits or portions of deposits, b) different types of laterites within each deposit and c) the cumulative tonnages and grades of laterite assuming different nickel cut-off grades for mining. Standard deviation, regression and frequency analyses were calculated and comparative studies were made to investigate the distribution and concentration of the constituents within the profile. All data processing was done at the data processing center of the U.S. Steel Corp. in Pittsburgh, Pa.

The computer is used to select and arrange the above mentioned blocks of laterite into a mining sequence based upon varying tonnage and grade schedules. These selected blocks are to be subjected to a mining engineering analyses comprehending the physical disposition of the laterite (distribution, topography, accessibility, thickness, etc.) and to develop practical mining plans, extraction methods, probable costs, etc. These studies will include not only the areas of initial mining but will cover all portion of the Ni laterite ore bodies.

GENERAL OBSERVATIONS ON LATERITES

The following observations are made with reference to the nickel laterite deposits examined during the 1969–1971 exploration in Irian Barat, Indonesia. In many instances the same comments would be valid for many other laterite occurrences in tropical areas.

a. The laterites are residual surface accumulations of intensely weathered and leached products of underlying materials; they occur in blanket-like deposits of varying thickness overlaying bedrock from which they were derived, and they generally conform to the contour of the bedrock surface but smooth out its local irregularities.

b. They commonly stand in positive topographic relief above their surroundings and are found underlying surfaces which can be either flat-lying or steep. Although laterites found on steep slopes are the residual products of weathering, and appear to be stable, there is evidence that movement has taken place within them by creep and mass wasting.

c. A common characteristic of areas underlain by laterites, both on flat-lying and steep slopes, is their relatively smooth surface. Where they are not covered with vegetation, these surfaces are preserved by their indurated caps which resist erosion, and by their porous character which allows all but the heaviest of rainfall to soak through the crust rather than becoming surface runoff. If this surface cap is broken or removed and the flow of water not impeded, then the surface runoff will easily erode the underlying softer materials. These same smooth surfaces are also noted on laterites in the forested areas, both on upland areas and on steep slopes. It is suggested that these smooth surfaces seen in unforested areas are relict of an earlier time when they were forest-covered. The removal of the vegetation and subsequent exposure to seasonal and climatic changes has promoted the development of the indurated porous crusts.

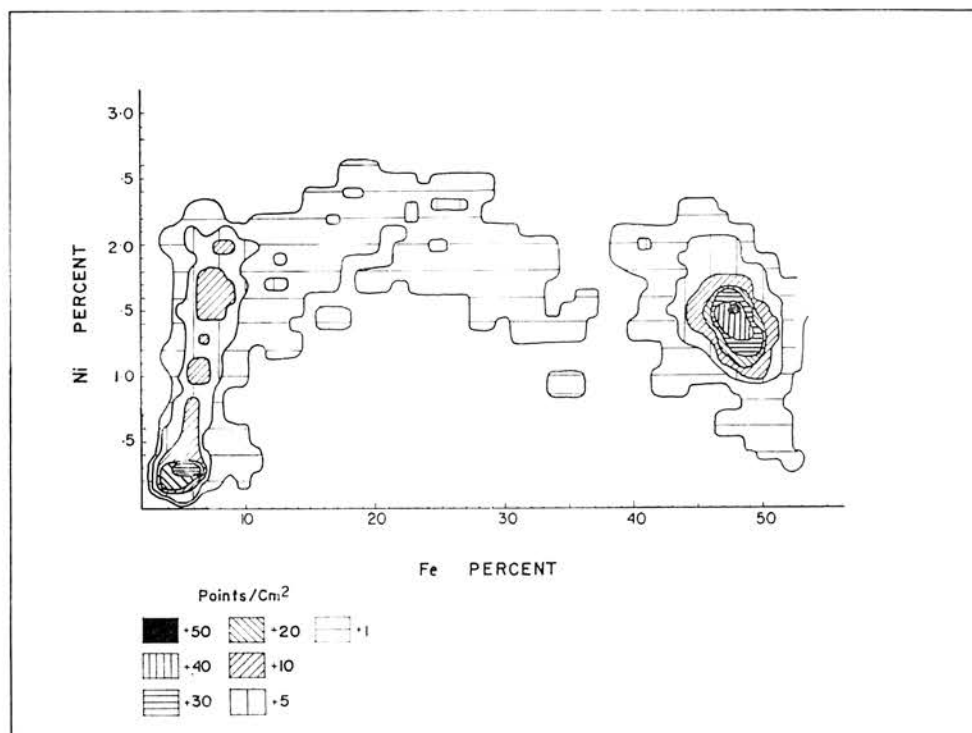


Fig. 4. Point count Ni vs Fe in laterites based on 415 analytical pairs in 32 FD holes; Manuran.

d. Laterites exhibit a vertical compositional zoning which is generally parallel to the surface. The near surface laterites are high in iron whereas the underlying ones are low in iron. On a frequency basis, the high iron values are clustered within the 40–47% Fe range and the low iron within the 8–18% Fe range. The transition from high to the low iron types is not gradational. This is illustrated in the contoured point plot of Fe vs Ni (Fig. 4) which shows concentration of materials within the indicated ranges but very few in the intermediate areas. Some of the intermediate laterite materials are probably mixtures of the high and low iron types.

e. Some of the chemical variations within the laterite profile are shown graphically in Fig. 5 which is a semi-log plot of partial chemical analyses of one typical Failing Drill core (FD 224) from Manuran Island. All of the elements appear to follow the same general distribution pattern as has been described in the published literature for other laterite areas, i.e., the residual concentration of iron and alumina at surface and the corresponding depletion of magnesia and to a lesser extent of silica. Nickel concentrations increase downward from the surface and reach their maximum levels within the low iron profile.

f. The laterite/peridotite contact is irregular in profile and resembles somewhat the teeth of a sawblade. The laterite-filled fissures, or pit-like depressions, extend downward into the underlying bedrock between intervening rock pinnacles which project upward and may break through to the surface as outcrops. Usually the rock in these pinnacles is badly fractured and jointed and occurs as separate blocks, boulders, etc. The irregular profile is the result of the apparent ease with which weathering agents have descended along joints and fractures into the sub-surface and have selectively either altered the bedrock or left it unaltered. Undoubtedly the internal characteristics of the rock, e.g., grain size, mineral composition, porosity, etc. have influenced the locale and rate of alteration. Neither the magnitude nor the configuration of the

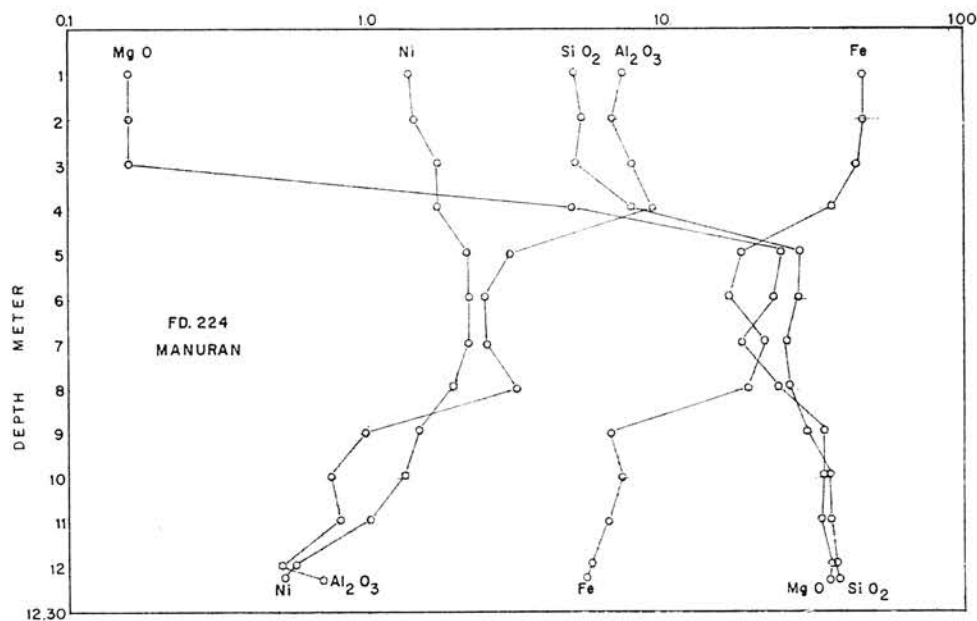


Fig. 5. Chemical variation in a complete profile.

laterite/bedrock contact are well known. On Gag Island, based upon 36 Failing Drill holes located on a 20 meter grid, the vertical difference between the tops of the rock pinnacles and the intervening trench bottoms ranged from 15–20 meters. Excavations made to date suggest that the structural control of fissures and fractures on the circulation or flow of surface waters has imposed, in plan, a geometric pattern on the laterite distribution within the bedrock.

g. The laterite/bedrock contact, although irregular in profile, is quite sharp in detail, and the transition from hard rock to completely disintegrated materials can be measured within the space of a few centimeters. The chemical changes are on a comparable scale as illustrated by the following examples:

- (1) Samples taken from the cores and rims of boulders from the low iron laterite profile were analyzed separately and the averaged results are shown in Table 3. The boulders averaged 30–40 cm in diameter and had hard fresh unweathered peridotite cores which were mantled with 5 cm-thick weathered rims composed of almost completely disintegrated rock.

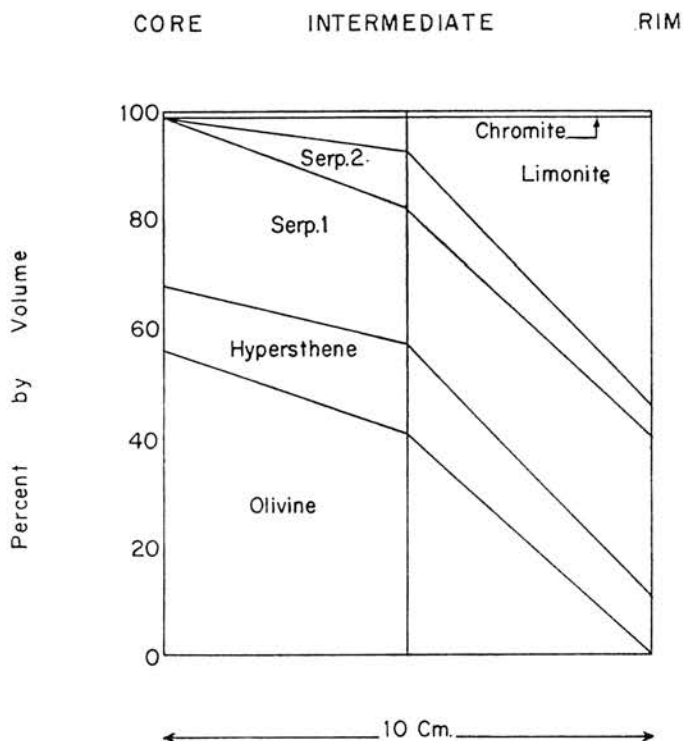


Fig. 6. Variation of modal percentage of major minerals in a peridotite boulder (Re 316).

- (2) Three samples which were collected from a 10 cm thick core to rim sequence of one rock specimen (Re-316) included the unaltered core, partially weathered rim and completely disintegrated rim. These samples were studied petrographically and chemically and the results are shown respectively in Fig. 6 (modal analyses) and Figs. 7 (semi-log plot).

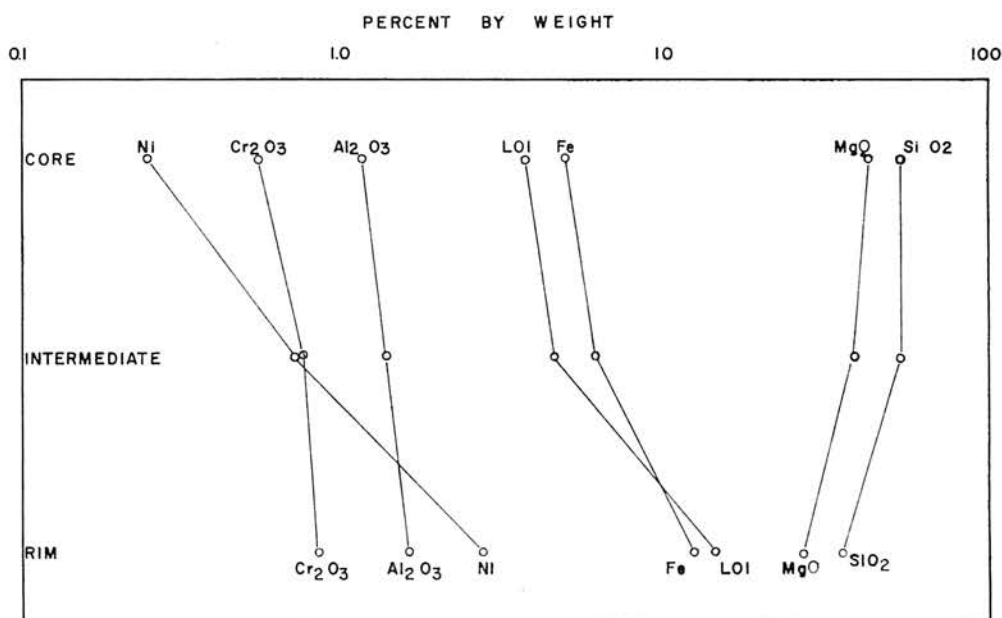


Fig. 7. Chemical variation in a peridotite boulder (Re 316).

The incipient chemical changes from unweathered to weathered rock in examples (1) & (2) are similar to those chemical changes already noted for the complete profile (Fig. 5) but to a lesser degree. The concentration ratios of the cores to rims (Table 3) and the graph of Re-316 (Fig. 7) both show slight losses of SiO₂ and MgO, slight gains of Fe and Al₂O₃ and large increases in the Ni content.

Table 3. Comparison of Chemical Analyses of Boulder Cores and Rims from Laterites on GAG Island¹

	Core %	Rim %	Concentration Ratio
Ni	0.48	1.76	3.7
Co	0.013	.02	1.5
Fe	5.19	6.61	1.3
S	0.008	.005	.6
K ₂ O	0.005	.005	1.0
Na ₂ O	0.011	.017	1.5
Al ₂ O ₃	.80	1.18	1.5
CaO	.87	.88	1.0
MgO	41.63	36.37	.9
Mn	.10	.11	1.1
SiO ₂	48.18	39.09	.9
Cr ₂ O ₃	.55	.65	1.2
TiO ₂	.015	.02	1.3
Cu	.002	.002	1.0
Zn	.004	.006	1.5
Cl	.02	.01	.5
LOI	4.59	6.38	1.4

¹ Based upon 11 pairs of Cores and Rims

The mineralogic changes taking place across this zone are recorded in the petrographic modal analyses in Figure 6. The fresh peridotite consists of olivine 56.0%, hypersthene 12.8%, serpentine 29.4%, and chromite 1.4%. Olivine occurs as irregular to polygonal shaped colorless grains with irregular shaped grains of hypersthene. Both are fractured and have a highly birefringent, pale yellow veinlet serpentine (Serp-1) along fractures and grain boundaries. In the altered rim, the olivine is completely altered to limonite and the hypersthene is present as relict, corroded grains. The highly birefringent veinlet serpentine persists into the weathered rim thus suggesting by its stability that it may have been of late deuteric origin. In the intermediate zones, a second type of serpentine (Serp-2) is found in through-going veins which cross cut the rock fabric and appear to be controlled by later fracturing. This serpentine, of low birefringence and pale green colors, appears to be developing at the expense of the hypersthene and Serp-1, under the influence of weathering. This material persists into the limonitic matrix of the rim material.

SUMMARY

The examinations of nickel laterite deposits associated with nickel bearing peridotites in the Cyclops and Waigeo areas of West Irian were carried out from mid 1969 through 1971. The occurrences were found to be blanket-like deposits developed in-situ on the bedrock surface to which they generally conform. The deposits are zoned compositionally with high iron (+30% Fe) laterite in the upper portions of the profile overlying incompletely weathered material containing 8–18% Fe. The separation between these two types of materials is generally distinct and the laterite/bedrock contact is sharp. The weathering process has depleted the surface materials of MgO and SiO₂ and residually concentrated the Fe and Al₂O₃. Nickel, mobilized in the upper horizons is generally concentrated in the low iron portion of the profile in the proximity of the bedrock contact.

During these investigations, the principle exploration was by drilling using hand augers, mechanical augers and core drills. Hand augers were used as the initial reconnaissance tool to develop information concerning the magnitude of a particular occurrence. If the deposit had an economic potential, further drilling was done with larger drills. Test pits were used principally for density data and detailed information concerning the profile. All of the data resulting from this program is being analysed by data processing techniques and preliminary mining plans are being developed. The exploration program has outlined potentially economic nickel laterite deposits which are in feasibility study for development.

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