

Mining Development on the Kurumbukari Plateau in the Madang Province: RAMU NiCo Project

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Abstract

Preparation is underway for the working of a nickel-cobalt ore body on the Kurumbukari Plateau just north of the Bismarck Range and overlooking the Ramu River Valley in the Madang Province of PNG. The project consists of the Kurumbukari mine site, a 135km slurry pipeline and the Basumuk Refinery. Tailings are disposed of using the Deep Sea Tailings Project (DSTP) which safeguards the environment by releasing neutralised tailings below the euphotic zone equilibrated with ocean water temperature.

Key words: Obduction, lateritisation, open-cut mining, minerals processing, environmental protection.

Introduction

The richness of Papua New Guinea (PNG) in mineral resources can be explained by its plate tectonic setting of a series of island volcanic arcs sutured onto the north moving Australian plate (figure 1). Island arcs form above subduction zones where immense heat generated by intercrustal slippage generates magma in an environment of hot convecting saline solutions derived from sea water. These solutions have the potential to dissolve precious and base metals from the magma and then redeposit them in very specific suitably altered chemical environments.

Such processes deliver an ore body before emplacement. This paper describes an ore body which has its magmatic origin in the upper mantle, crystallisation in the lower oceanic crust, emplacement by obduction¹ and then enrichment rock by the natural *in situ* process of lateritisation².

¹ Obduction is the plate tectonic process whereby remnants of oceanic crust are thrust upon pre-existing continental crust. The oceanic crust is thought to have formed in back-arc basins rather than at mid-ocean ridges.

² Lateritisation is a process which occurs over geological time in which fluctuating water tables chemically alter exposed rock formations leaving residual minerals often enriched

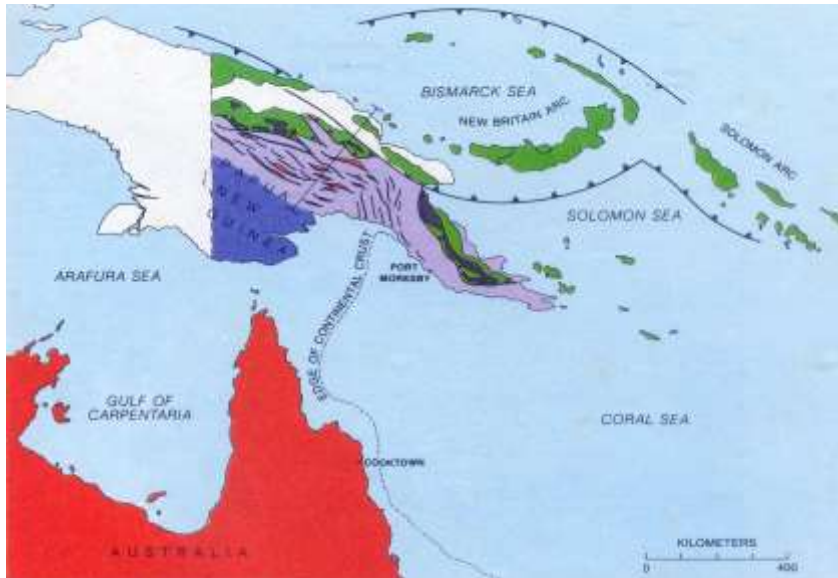


Figure 1 The NE moving Australian Plate has produced collision zones with possibly two island arcs (green) now sutured to the land mass by ultramafic³ belts (shown in dark grey) exposed in the Kurumbukari mined Marum Ophiolite and the Papuan Ultramafic Belt exposed further east) of obducted oceanic crust⁴. The ultramafic belts are potential sources of Ni, Co and Cr (the ferromagnetic metals) and possibly also the platinoids (Ru, Rh, Pd, Os, Ir, Pt). The island arcs (Mobile Zone) are potential sources of precious metals (Ag, Au) and base metals (Cu, Pb, Zn).

The processes (Figure 2) involved in the obduction of nickel (Ni), cobalt (Co) bearing⁵ (as trace elements, present in ppm) upper mantle rock onto continental crust, enrichment effect of groundwater lateritic ore formation, mining operations, transport and refining sequences, as well as re-forestation and safe disposal of tailings are discussed.

in metals of economic interest. Because geological time is involved extremely slow reactions such as dissolution of silicates can occur.

³ Ultramafic rocks are silica poor and rich in Fe and Mg. They are interpreted as the resulting from the earliest crystallisation of upper mantle magma. They are found in the lowest zones of obducted oceanic crust. The earliest crystallising minerals absorb available Ni and Co, believed to be abundant in the earth's core. Ophiolites are rock formations interpreted as originating from obducted oceanic crust.

⁴ Other structures which can be identified moving from SW to NE are the Australian plate (red), platform (blue), fold belt (purple and interpreted as folded portion of the Australian plate), and the mobile zone (green) of sutured formerly existing island arcs.

⁵ Nickel and cobalt are of significant economic interest because of their industrial usage high strength, high melting point, corrosion resistant steel (Fe alloys). They also have useful electronic and magnetic properties (forming high strength magnets as Fe-alloys), and are used in rechargeable batteries.

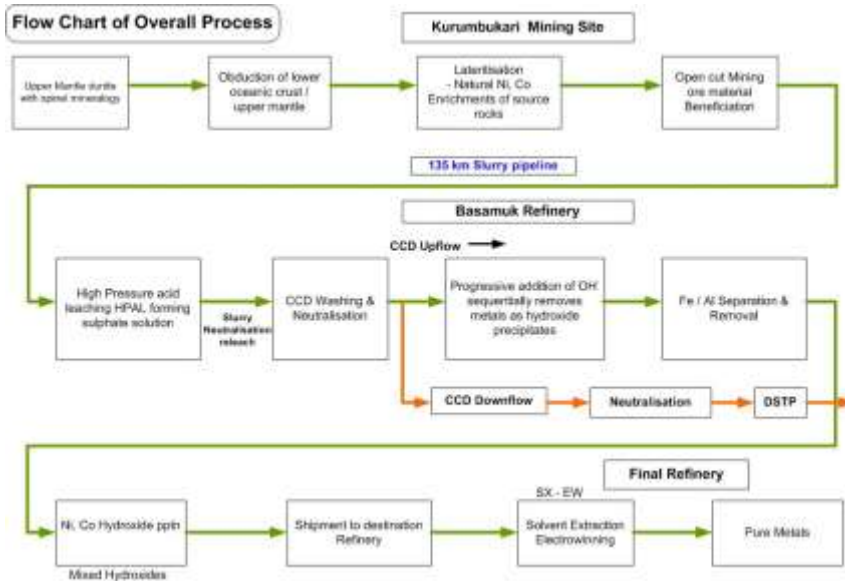


Figure 2 is a Flow Chart of the overall process discussed in this paper. The complete sequence consists of obduction of oceanic crust, lateritisation leading to supergene enrichment, open cut mining and beneficiation, recovery of metals of interest and safe disposal of tailings (DSTP) and re-afforestation of mined areas.

Source of the Ore Body

The ultimate source of what is now the Kurumbukari ore body is upper mantle (or lower oceanic crust) rock known as dunite⁶ and composed of olivine (a silicate of Fe and Mg) and spinel, here, a complex Cr-rich opaque metal oxide known as chromite. Such rock masses come under the generic classification of ophiolite. The ophiolite rock forming minerals, whilst stable at the conditions of pressure (P) and oxygen fugacity (fO_2) prevailing in the upper mantle are rapidly altered when emplaced on the earth's surface as happens when oceanic crust is thrust up onto continental crust during tectonic collision processes known as obduction.

⁶ Dunite is nearly pure Mg-rich olivine. Olivine is the earliest crystallising mineral in an ultramafic magma chamber and the crystals settle under gravity to form dunite at the base of the chamber. The olivine will absorb most of the available Ni and Co from the magma.

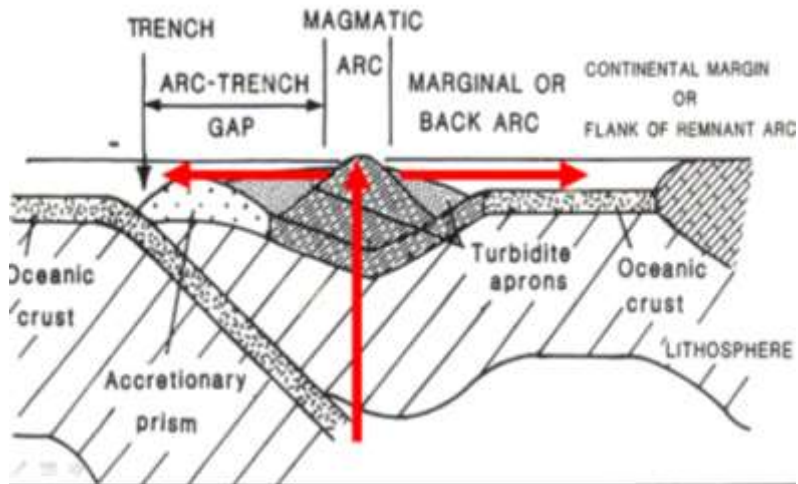


Figure 3 (Adapted from Park, Fig. 5.1) shows a possible plate tectonic interpretation of the PNG mobile belt elements. In a back arc basin a magmatic arc has experienced a second opening splitting the arc resulting from an upper mantle magmatic intrusion forming a new spreading axis (movement indicated by red lines). A later reversal of plate motion directions has led to obduction of back-arc basin crust onto the continental margin in a collision process. Applied to the PNG landmass, some back-arc basin crust has also been emplaced between the arcs and the continental crust as shown in Figure 4 where it appears as the Papuan Ultramafic Belt of interest to this paper.

Obduction

Over the past 40 million years, the PNG landmass has been formed by collision (Figures 3) and suturing (Figure 4) of island arcs (green) and also some remnants of oceanic⁷ crust (grey) onto the northern parts of PNG. These areas form the Papuan Ultramafic Belt, of which the Marum Ophiolite on which the Burumbukari mine site is located is a related but segmented westerly outcrop just north of the Bismarck Range.

The arcs were probably formed by the subduction of the Australian plate under the Pacific plate, then the convergence of the plates carried the Australian plate into the zone of subduction⁸. The continued convergence (Figure 4) has now folded and faulted sedimentary rocks along the margin of the Australian plate (purple) and also the ancient crust of Australia itself (orange).

⁷ Here “oceanic crust” is generic term. As noted elsewhere in the paper, the ophiolite crust of these outcrops has most likely formed in a back-arc basin.

⁸ A similar scenario is present in the Western Pacific Ocean just west of the Philippines where (Park, p 102) a widely separated pair of active trench systems enclose a number of active and inactive nearly parallel island arcs and spreading centres.

Rock formations which escaped deformation form the land mass platform (dark blue).

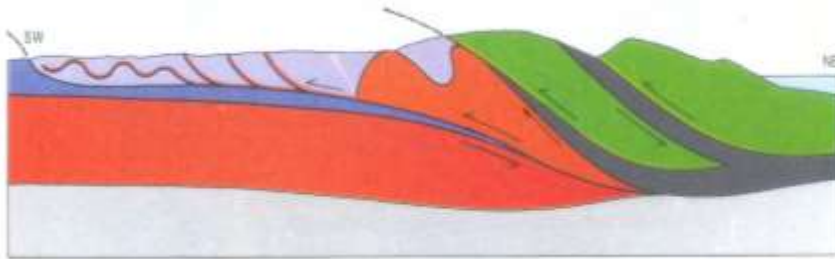


Figure 4 (Burchfiel, 1990) SW-NE Schematic crustal cross-section showing the suturing of island arcs onto the Australian Continental crust and the emplacement of ophiolites (grey) to form the PNG landmass. Colour Legend: Green: Sutured Arcs, Grey: Remnants of oceanic crust – lateritised now to produce workable ophiolite ore bodies, Purple: Folded sedimentary rocks along the margin of Australia, Orange: Ancient crust of Australia.

Similar large thrust sheets of obducted ophiolite in Tertiary (~ 60 MA) to Mesozoic (~ 150 Ma) island arcs and continental collision zones have undergone lateritization in plateau, crest and spur landforms in New Caledonia, Cuba, Indonesia and the Phillipines (Dalvi et al., 2004).

The mountainous country forming the northern sector of the PNG landmass has been emplaced by this process of arc-continent collision and back-arc basin obduction. In places such as Kurumbukari the upper mantle originating rock now outcrops as plateaus, crests or mountain spurs where it is subject to lateritisation.

Laterite Formation

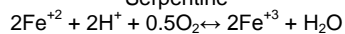
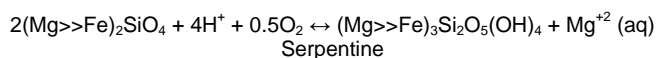
In tropical regions, hot, wet and humid conditions make the ophiolite mantle derived rocks particularly unstable and they undergo rapid (on geological time scales) physical and chemical alteration. Down flowing surface water is initially oxygenated (and so in an oxidised state) and also acidified⁹. It percolates through the rock mass causing chemical alteration known as lateritisation. As well there is biannual fluctuation in the level of the water table corresponding to the annual wet and dry seasons.

⁹ Carbonic acid is formed by solution of atmospheric CO₂ in rain water, and humic acid by contact of rain water with the surface humus layer (produced by decaying vegetation). It is of interest to note that present high levels of de-afforestation will lead to a decline in these ore forming environments.

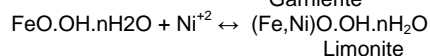
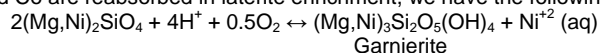
The region of stability of natural waters (Figure 5) in terms of pH and Eh¹⁰ can be used to track the reactivity of rain water as it percolates through silicate rocks, reacting with the rocks to induce metal leaching. In this process the water becomes more basic and reduced¹¹ (see red arrow) causing some metals to precipitate as oxides at a lower level. This process is known as supergene enrichment. In the context of this paper Fe and Al oxides will form giving the outcrop its characteristic yellow and red colours indicating various levels of hydration of the oxides. Ni and Co will be reabsorbed in the resulting oxides and hydrous silicates.

¹⁰ pH (negative of the logarithm of the H⁺ concentration) is a measure of acidification with pH of 0 being most acidic and 14 being most basic. Eh is related to the Free Energy of the reaction. It can also be associated with the level of oxidation (pO₂) or more generally, the level of chemical reactivity

¹¹ New minerals forming from the action of water (acidic and oxidising in this case from formation of carbonic and humic acids) are limonite and serpentine (hydrous magnesium silicate). These can reabsorb released Ni, Co with serpentine forming garnierite as in the following reactions which show absorption of H⁺ and O₂ leading respectively to the more basic and reduced ground water:



Where Ni and Co are reabsorbed in laterite enrichment, we have the following reactions:



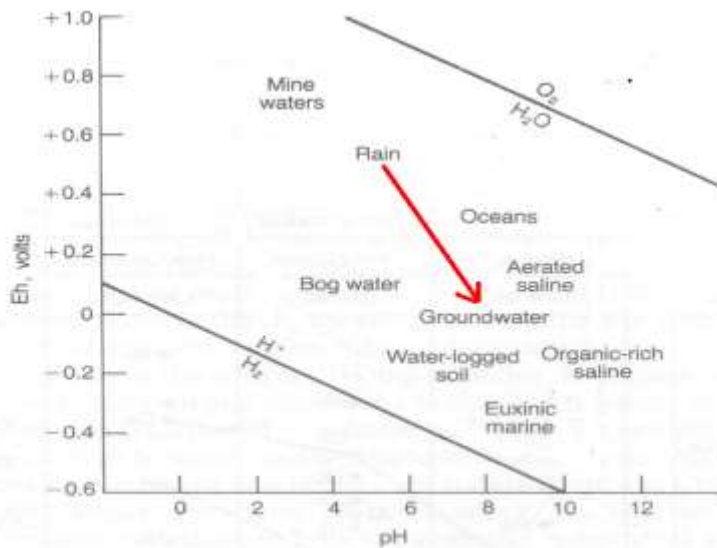


Figure 5 (Adapted from Park & Guilbert, Fig 17.1) Shows the region of stability of natural waters in terms of pH and Eh. As rain water percolates through silicate rocks it will react with the rocks leading to metal leaching. In this process the water becomes more basic and reduced (see red arrow) causing some metals to precipitate as oxides at a lower level. This process is known as supergene enrichment. In the context of this paper Fe and Al oxides will form giving the outcrop its characteristic yellow and red colours indicating various levels of hydration of the oxides.

The resulting lateritic soil/rock profile can be of economic interest. The silica released by silicate minerals can be completely removed or may be redeposited as opal veinlets. Released Iron (Fe) and aluminium (Al) ions can be readily oxidized and redeposited as iron (Fe_2O_3) and aluminium oxides (Al_2O_3) as the chemistry of the groundwater changes giving laterite its characteristic red colours¹².

¹² If the metal oxide is predominantly Al_2O_3 , the deposit is classified as bauxite and can be of economic interest. Fe-rich laterites are usually not of interest because there are richer sources of Iron ore.

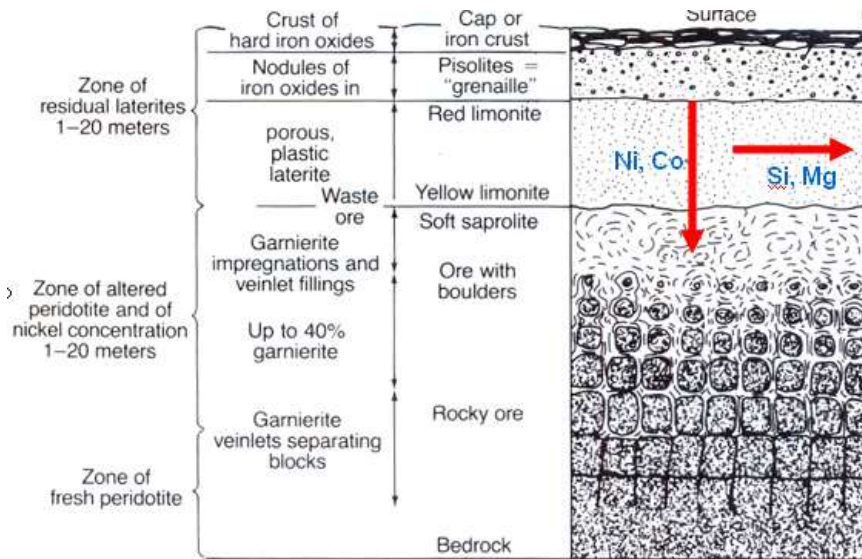


Figure 6 (Adapted from Guilbert & Park, Fig 17.5) shows a typical laterite profile resulting from the laterisation profile of an ophiolite rock outcrop. In broad terms, Si and Mg are removed with Si sometimes redepositing as opal veinlets. Ni and Co are leached downwards to be reabsorbed in limonite and garnierite, a hydrous alteration product of the olivine dunite.

Nickel and Cobalt Presence

One of the characteristics of the previously mentioned dunite is the presence of trace amounts of the economically important metals Ni and Co in the olivine. These metals are believed to be present, together with Fe, in the inner and outer metal cores of the earth. They can be absorbed by the early rock forming minerals crystallizing out from cooling molten magma in the early formation of the earth. As the remaining magma evolves it becomes more Si-rich and no longer absorbs Ni and Co. This means that rocks carrying Ni and Co will only appear at the earth's surface as a result of the previously mentioned tectonic processes where they now outcrop as laterite horizons as occurs in areas of the Pacific Rim (Indonesia, PNG, and very importantly, New Caledonia).

Kurumbukuri Laterite Profile

A schematic vertical laterite profile (Figure 7) shows areas of chemical enrichment caused by the leaching process. From the original rock minerals of olivine and spinel, Si is largely removed in solution from the profile, Fe and Al are deposited as insoluble hydrated oxides producing the characteristic yellow and red

colours of laterite. Relatively mobile Co and Ni leached downwards are absorbed by the hydrated silicate alteration products of olivine to form garnierite.

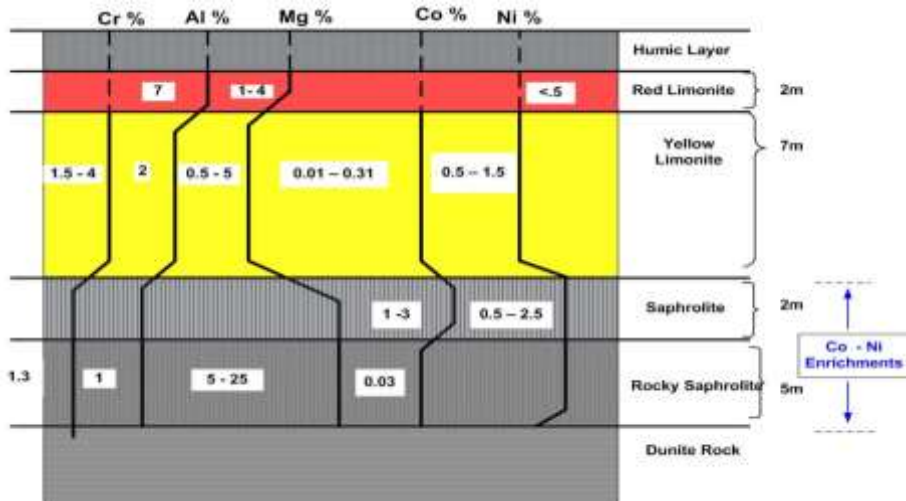


Figure 7 Schematic vertical laterite profile showing areas of chemical enrichment caused by the leaching process. From the original rock minerals of olivine and spinel, Si is largely removed in solution from the profile, Fe and Al are deposited as insoluble hydrated oxides producing the characteristic yellow and red colours of laterite, Co and Ni leached downwards are absorbed by the hydrated silicate alteration products of olivine to form garnierite. Zones of enrichment are indicated.

Where Ni and Co are reabsorbed replacing Fe there is an approximately 8 to 10 fold enrichment of Ni (0.25% to 2.5% maximum) and an 8% (0.4% to 3% maximum) enrichment for Co¹³.

Kurumbukari Mine Site

The Kurumbukari mine site consists of a de-agglomeration plant and a beneficiation plant where the mined ore is prepared as a suitable slurry for transportation over the pipeline to the Basumuk Processing Plant.

¹³ Middlemost (1984) quotes (Jacques, 1983) giving an olivine analysis from the Maurum ophiolite. Ni and Co values in this analysis were used to calculate these order of magnitude enrichments.

De-agglomeration Plant

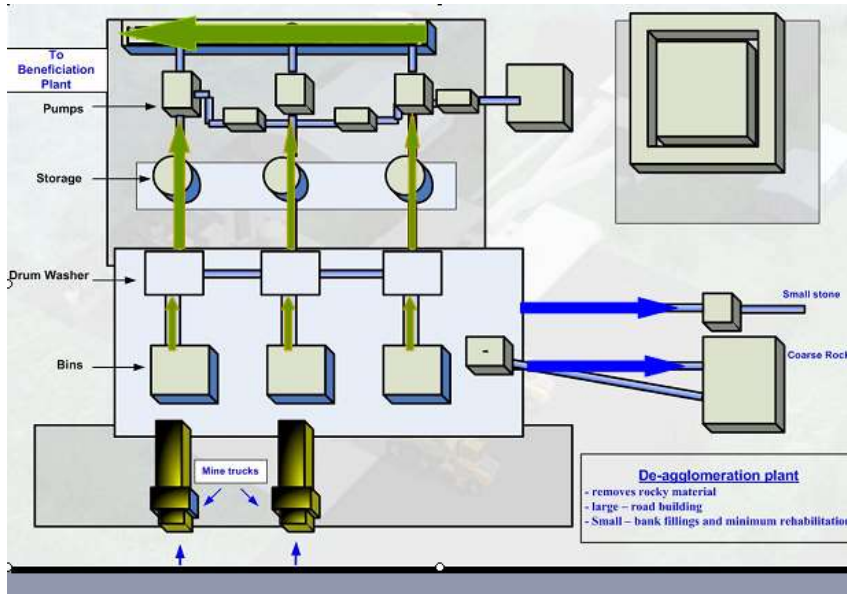


Figure 8 The de-agglomeration plant receives raw material from the open-cut mining process. This material must be converted into a physical form suitable for transportation as slurry in which the transported material remains in suspension at the available slurry velocity. The plant removes large (for land refill) and small (for road building) rock material which is unsuitable for transport. A de-sliming process is also used to remove solid particles which are too small and may cause damage to later processes. Storage tanks are important throughout all processes to keep solid material in suspension suitable for pumping by using rotating impellers to agitate the water.

Raw material from the open-cut mining process is first treated at the de-agglomeration plant for suitable sizing converting it into a physical form suitable for transportation as slurry. In the slurry transported material must remain in suspension at the available pipe line slurry velocity. The plant removes large (for land refill) and small (for road building) rock material which is unsuitable for transport. A de-sliming process is also used to remove solid particles which are too small and may cause damage to later processes. Storage tanks are important throughout all processes to keep solid material in suspension suitable for pumping by using rotating impellers to agitate the water and keep it in motion.

Beneficiation Plant

Beneficiation (Figure 9) removes worthless material from pulverised ore arriving from the de-agglomeration plant. This involves washing, concentrating and sizing of particles. To avoid

pipeline damage abrasive chromite (which itself is of economic interest) is removed prior to transportation. Flocculating agents are used to produce slurry thickening occurs prior to transportation to reduce the total volume of slurry.

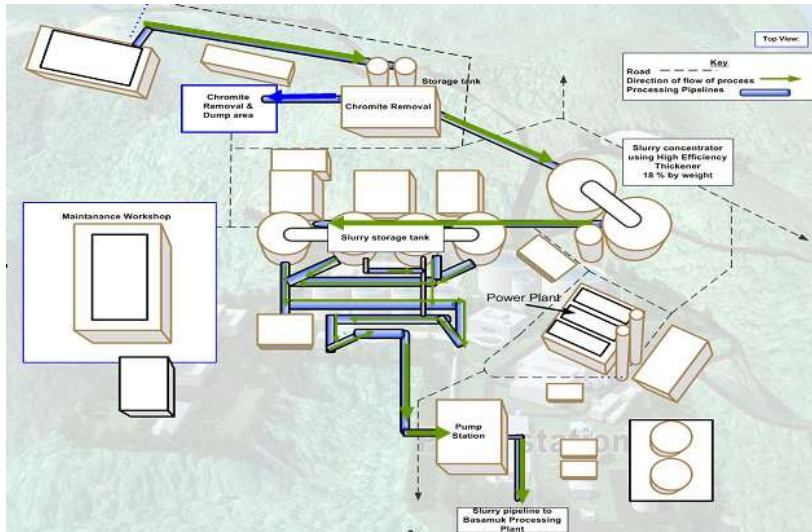


Figure 9 shows the Beneficiation plant at Kurumbukari which further prepares the slurry for transportation. The main function here is the removal of the chromite spinel (blue) which is a relatively hard metal oxide and which if not removed from the slurry (green) would have an abrasive effect on the pipeline and limit its useful life expectancy. Again storage tanks are needed to maintain the slurry suspension and prepare the pumps to transport it over the pipeline.

The full process of de-agglomeration and Beneficiation are combined in a logical diagram or flow chart (Figure 10) to show the flow processes involved in both the de-agglomeration and the Beneficiation Plants at Basumuk. Both plants prepare slurry for transportation, removing oversized material (de-agglomeration) and unsuitable material (abrasive chromite which would greatly reduce the usable life of the pipeline). Further sizing occurs prior to transportation to produce a slurry of uniform composition, which will not deposit sediment at the available slurry velocity provided by the pumps. Also shown is a thickener which reduces the volume of liquid in the slurry.

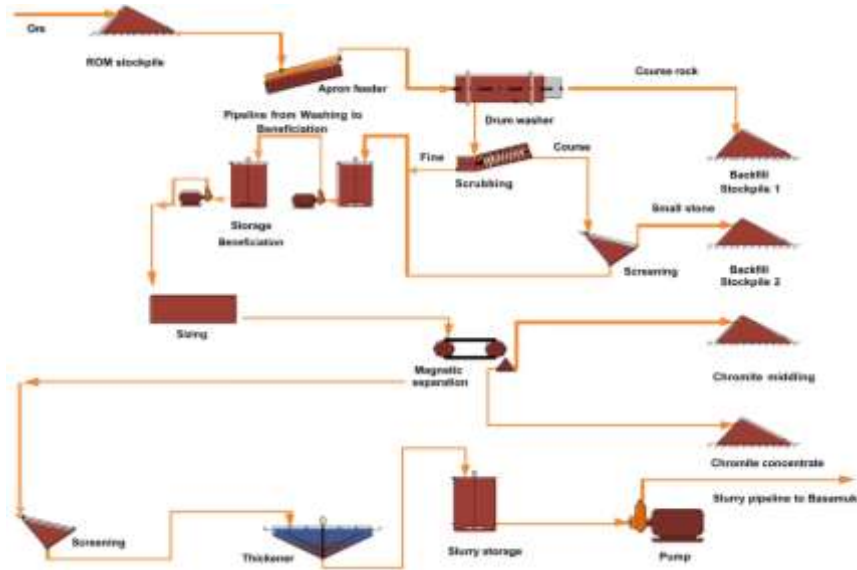


Figure 10 (Dr James Wang, personal communication) shows the logical diagram of flow processes involved in both the de-agglomeration and the Beneficiation Plants at Basumuk. Both plants prepare slurry for transportation, removing oversized material (de-agglomeration) and unsuitable material (abrasive chromite which would greatly reduce the usable life of the pipeline). Further sizing occurs prior to transportation to produce a slurry of uniform composition, which will not deposit sediment at the available slurry velocity provided by the pumps. Also shown is a thickener which reduces the volume of liquid in the slurry.

Slurry Pipeline Transportation

The slurry is a mixture with water of solid particles in suspension. Slurry velocity must be high enough to keep particles in suspension. For this long distance transportation (135 Km) particles must be fine enough to remain in suspension given available slurry velocity.

Important issues here are maintaining slurry pressure and so velocity over such a long distance. Leaks must be avoided because of subsequent loss of pressure and damage to local environments upon which communities are so dependent. The path of the pipeline also needs to void environmental damage.

An important technical feature of the pipeline is that it also provides a secure path for fiber optic cables to carry operational data communication between the mine site and the processing plant.



Figure 11 (From Ramu NiCo publicity video) shows the 135 km pipeline transporting slurry from the mine site to the processing plant. After crossing the Ramu River valley it follows the Lae Madang highway, before turning east near the coast and then proceeding to the processing plant.

Pipeline Monitoring System & Data Communication Link

The data communication network also carries data from pressure sensors strategically placed along the pipeline (Figure 12). This data provides remote control of the pipeline. Pressure changes could indicate blockages (accumulation of sediment) or leakages, the latter being indicated by a pressure drop.

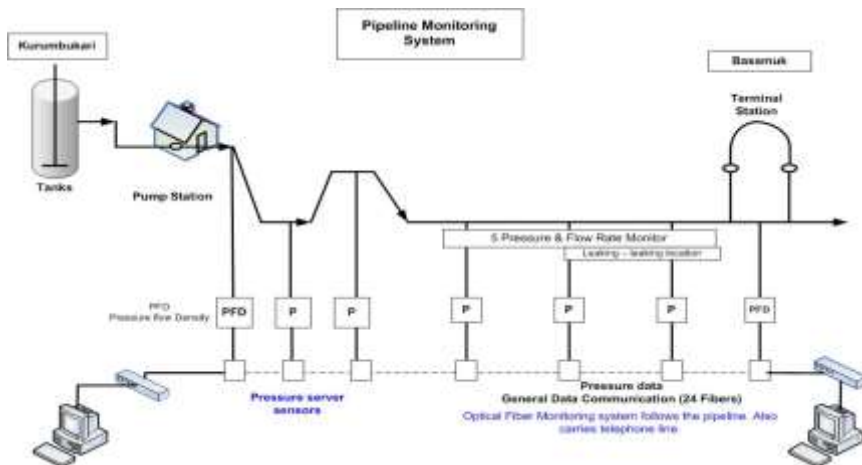


Figure 12 Shows a schematic diagram with key elements of the 135Km slurry pipeline. Storage tanks provide the slurry and pumps provide the necessary velocity to maintain the suspension. Pressure sensors are a safety feature needed to detect leaks and so avoid environmental damage. The sensors are integrated into the data communication network between sites which consists of 24 optical fibers.

Basumuk Processing Plant

Two industrial chemicals, sulphuric acid and lime, which are needed to extract metals from the slurry are produced on site. Locally quarried limestone is calcined in a lime kiln using an oil burner¹⁴. Lime is used for acid neutralisation of tailings and for removing unwanted metals as hydroxides.

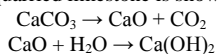
The Contact process for sulphuric acid production uses elemental sulphur imported from Canada¹⁵. Sulphuric acid is an important industrial chemical because it reacts with most metals and bases to give soluble sulphates. Since most metal sulphates are soluble, metal ores in the form of insoluble oxides can be leached from mined ore with sulphuric acid to form metal sulphate solutions in a hydrometallurgical process. The pure metals can be extracted from these solutions by means of electrolytic refining.

The formation of soluble metal sulphate solutions in huge titanium lined autoclaves using High Pressure Acid Leaching (HPAL) at the Basumuk Refinery (Figure 11) is the central chemical process at the site.

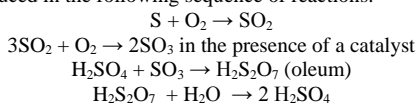
Basumuk Processing Plant Design

Major components of the Basumuk Processing Plant (Figure 13) include the electric power plant, Lime plant, sulphuric acid plant, and High Pressure Acid Leaching (HPAL) autoclaves. Further components involve removal of unwanted Fe and Al as insoluble hydroxides as well as neutralized tailings sediment. Finally Ni and Co are removed as insoluble hydroxides using higher pOH levels. Storage tanks to keep the slurry in motion and pumping stations are needed throughout to prevent sedimentation.

¹⁴ The action of heat on the locally quarried limestone is shown by the reaction equations:



¹⁵ Sulphuric acid is produced in the following sequence of reactions:



Sulphur trioxide SO_3 cannot be dissolved directly into water to form sulphuric acid as it forms with water an unmanageable fog. SO_3 is dissolved in preexisting sulphuric acid to form oleum which in turn is diluted with water to form sulphuric acid.

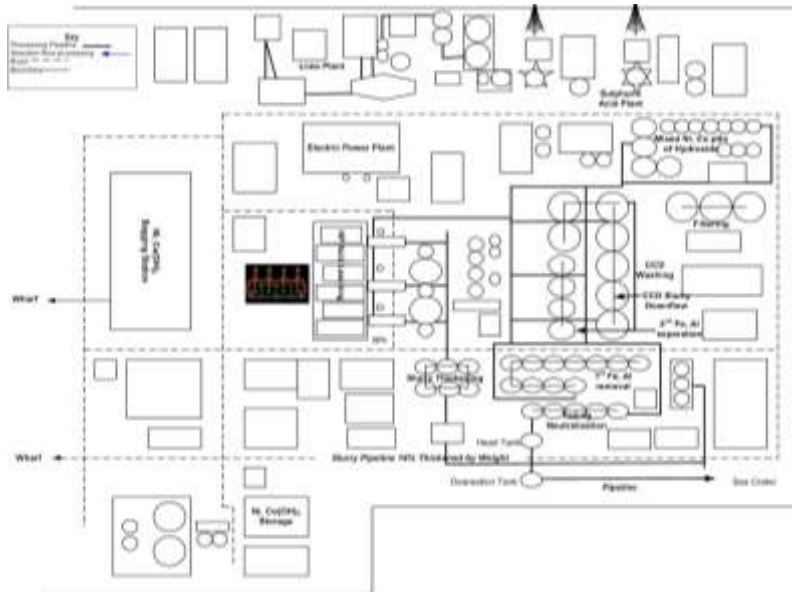


Figure 13 shows the overall ground plan of the Basumuk Processing Plant. Major components include the electric power plant and Lime plant (top left), sulphuric acid plant (top right), High Pressure Acid Leaching (HPAL) autoclaves (centre). Further components involve removal of Fe and Al as well as tailings sediment. Finally Ni and Co are removed as insoluble hydroxides. Storage tanks to keep the slurry in motion and pumping stations are needed throughout to prevent sedimentation.

Basumuk Refinery Slurry Processing

Unwanted metals (Fe and Al) are selectively removed from the slurry by hydroxide precipitation¹⁶ from the metal sulphate solution produced by the HPAL autoclaves using careful pOH/pH control. Ni and Co are then removed again as hydroxides using higher pOH values from NaOH to precipitate as hydroxides. On the far right (Figure 13) the Counter Current Decantation (CCD) process progressively washes any remaining sediment. The resulting liquid flows upwards from pumping and is reprocessed. Washed sediment flows downwards with gravity settling in each tank and is eventually disposed of in the DSTP.

¹⁶ Another very important chemical property of metals made use of in this processing plant is that they form insoluble oxides and hydroxides of varying degrees of solubility.

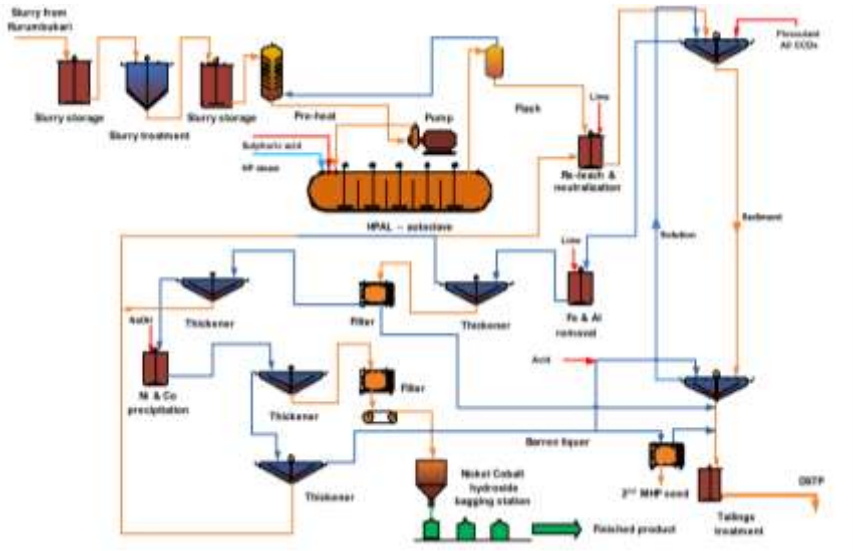


Figure 14 (Dr James Wang, personal communication) is the flow sheet which illustrates the processing sequence for extracting metals of interest from the slurry. Unwanted metals (Fe and Al) are selectively removed by hydroxide precipitation from the metal sulphate solution produced by the HPAL autoclaves using pOH control. Ni and Co are then removed again as hydroxides using higher pOH values to precipitate hydroxides. On the far right the Counter Current Decantation (CCD) process progressively washes any remaining sediment. The resulting liquid flows upwards and is reprocessed. Washed sediment flows downwards and is eventually disposed of in the DSTP.

Slurry Processing Physical diagram

The physical locations of the various subprocesses at Basumuk (Figure 15) show the general sequence of slurry thickening, the HPAL process, neutralization to remove excess acid, removal of Fe/Al, CCD washing, removal of Ni & Co from the CCD upflow and delivering further neutralized tailings to the DSTP from the CCD downflow.

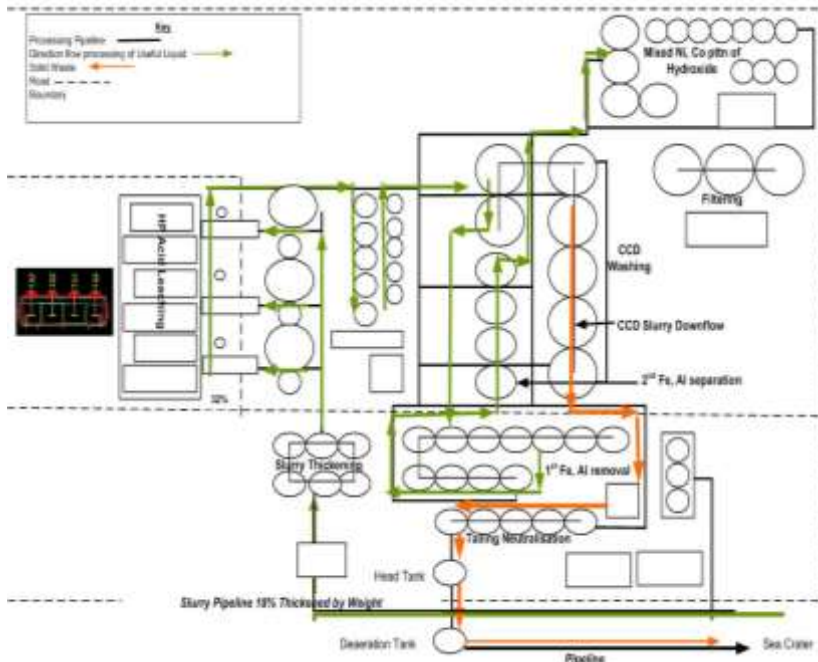


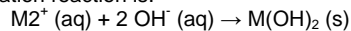
Figure 15 illustrates in summary fashion the process detailed in Figure 9 showing the various physical locations of the processing tanks. Green lines indicate the flow direct of the increasingly processed and purified slurry. The orange line shows the passage of spent slurry sediment to be disposed of in the DSTP. The general sequence is slurry thickening, the HPAL process, neutralization to remove excess acid, removal of Fe/Al, CCD washing, removal of Ni & Co from the CCD upflow and delivering further neutralized tailings to the DSTP in the CCD downflow.

Selective Precipitation of Hydroxides

Values of pH and pOH required to precipitate the various hydroxides of interest to the Basumuk processing have been calculated¹⁷ (Figure 16).

$\text{Ca}(\text{OH})_2$ (lime) and NaOH are used to produce controlled values of pH and pOH so that precipitation will occur when K_{sp} values are exceeded. Note the fortuitously close values of pH required to precipitate Fe and Al enabling them to be removed

¹⁷ The precipitation reaction is:



$x + 2x \rightarrow x$, where x M/L is hydroxide solubility

Precipitation occurs when:

$$x \cdot (2x)^2 = 4x^3 > K_{sp}.$$

This equation can be solved for x , and then necessary pH and pOH values are calculated. From Figures 16 and 17, it can be seen that very conveniently Fe & Al require an $[\text{OH}^-]$ several orders of magnitude lower to form hydroxide precipitates than do Ni and Co.

simultaneously. Similarly Ni and Co can be removed together with NaOH but separately (Figure 17) from Fe and Al.

	Ca(OH) ₂	Al(OH) ₃	Fe(OH) ₃	Ni(OH) ₂	Co(OH) ₂	Mg(OH) ₂
Ksp	5.50E-06	1.30E-33	4.00E-38	2.00E-15	1.60E-15	1.80E-11
Solubility M/L	1.11E-02	2.63E-09	1.96E-10	7.94E-06	7.37E-06	1.65E-04
[OH⁻]	2.22E-02	1.08E-07	1.01E-07	1.60E-05	1.48E-05	3.30E-04
pOH	1.65	6.97	7.00	4.80	4.83	3.48
pH	12.35	7.03E+00	7.00E+00	9.20	9.17	10.52

	NaOH	NaOH	NaOH	NaOH
Conc. M/L	1.00E-02	1.00E-03	1.00E-04	1.00E-05
[OH⁻]	1.00E-02	1.00E-03	1.00E-04	1.00E-05
pOH	2.00	3.00	4.00	5.00
pH	12.00	11.00	10.00	9.00

Figure 16 Shows calculations of pH and pOH values required to precipitate the various hydroxides of interest to the Basumuk processing. Ca(OH)₂ (lime) and NaOH are used to produce controlled values of pH and pOH so that precipitation will occur when Ksp values are exceeded. Note the fortuitously close values of pH required to precipitate Fe and Al enabling them to be removed simultaneously. Similarly Ni and Co can be removed together with NaOH (using carefully controlled concentrations as shown in the lower half of the Figure) but separately from Fe and Al. (Ksp values were taken from: bibo.chm.uri.edu/CHM112/tables/KspTable.HTM).

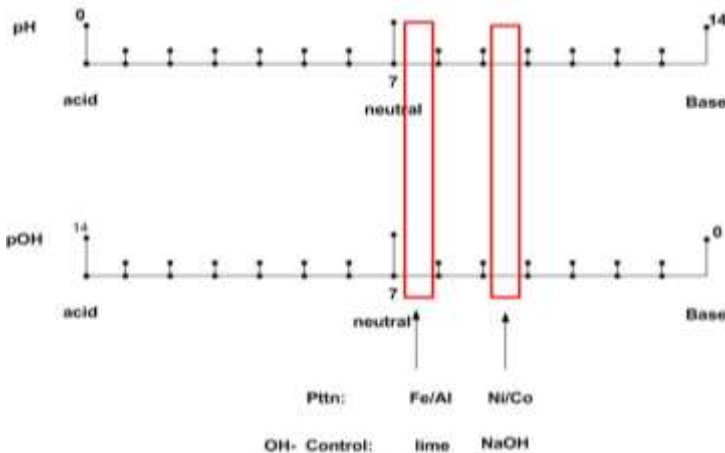


Figure 17 illustrates graphically the separate pH and corresponding pOH regions required to cause precipitation of the metal hydroxides. The regions are clearly separate enabling selective precipitation under controlled conditions using lime or NaOH as the source of pOH control.

Finally it should be noted that further off-shore refining is needed to separate the Ni and Co hydroxides and obtain the pure metals in a process of electrolytic refining (Figure 2, lowest level processing). To do this the hydroxides will have to be re-dissolved in sulphuric acid to form the electrolyte.

Deep Sea Tailings Project (DSTP)

Ore processing plants typically face the problem of safe disposal of waste material or tailings from which metals of economic interest have been removed. The method used here is to first neutralize the tailings with limestone before discharge to render them non-toxic.

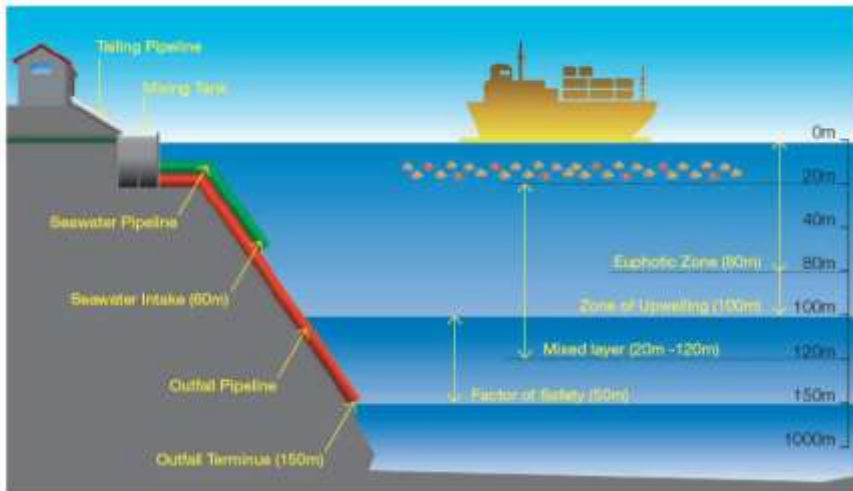


Figure 18 (Ramu NiCo information diagram) shows the structure of environmentally sensitive ocean water levels considered in the DSTP. According to findings published in the Scottish association of Marine Science (SAMS) neutralized tailings can safely enter the ocean below the 150 M layer. No upwelling of tailings is expected from this level. Also the tailings are cooled to sea water temperature by mixing with cold ocean water from the seawater intake pipeline.

Neutralised tailings are then discharge into the ocean (Vitiav Basin) in what is known as the Deep Sea Tailings Project (DSTP). Before they are discharged they are deaerated¹⁸ and then diluted with sea water (Figure 18) so that when discharged, the concentration of metal ions in the tailings will be equivalent to that of the ocean. The tailings will also be at the same temperature as the water into which they will be discharged thereby preventing upwelling by convection currents which might otherwise form.

Tailings discharge will take place below the zone of upwelling of ocean current in the bay. This is designed to ensure that tailings

¹⁸ Deaeration will remove entrapped air bubbles which could reduce the tailing density allowing it to rise rather than sink to the ocean floor.

discharge do not join convection currents moving into the euphotic¹⁹ zone and therefore into the food chain.

When considering any environmental impact of the DSTP, it should be noted that it is estimated that every year, more than 78 Mt of natural sediment enter the bay from river transport. The projected annual tailing volume of 5 Mt from the DSTP will be only 6% of total natural sediment flow. Over the expected 20 year Project life, less than 2% of the floor of Vitiaz basin will be covered by tailings. According to projections, most of the tailings will be covered by natural sediment, and will be deposited between 1,000 and 1,600 meters deep²⁰.

Summary of Overall Process

Upper mantle silicate minerals in obducted back-arc basin oceans are obducted onto continental crust in a process of crust-island arc collision. Naturally occurring laterite processes lead to enrichment of economically interesting metals to the point where mining becomes economically viable. Open cut mining removes the ore material before it is rendered in suitable for long distance transport as a slurry to a coastal processing plant where the metals are dissolved the hydrometallurgical²¹ HPAL process. Finally selective precipitation of hydroxides enables removal of Ni and Co as hydroxides for export.

All this takes place in a pristine natural environment on which local people depend for food and livelihood. Re-afforestation at the mine site, tailings neutralisation and the DSTP are all designed to preserve and rehabilitate the environment returning it to its natural state on completion of the mining and processing.

¹⁹ The euphotic zone is the shown (Figure 18) as the uppermost 80 m of the ocean, which is sufficiently illuminated to permit photosynthesis by phytoplankton and plants, which are the base of the ocean food chain. By preventing tailings from entering this zone, they should not be able to enter the food chain.

²⁰ Ramu NiCo 2006-2008 Sustainability Report discusses these issues of managing waste, in particular the issue of safe tailings discharge. Reports are available from www.highlandspacific.com.pg

²¹ The alternative is pyrometallurgical processes necessary when ores occur predominantly as sulphides or silicates. These processes require furnace heating, are expensive and potentially polluting.

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