THE NAMOSI PROSPECT: AN OVERVIEW OF POTENTIAL IMPACTS ON THE MARINE ENVIRONMENT

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1. INTRODUCTION

The Namosi Copper-Gold Prospect is a low grade, marginal prospect located on the island of Viti Levu, 35km northwest of Suva and 20km from the coast, in an area of high rainfall. Although the area has been evaluated by a number of mining companies since its discovery in the 1960's, the highly marginal nature of the prospect has discouraged development to date.

The Namosi prospect is based upon porphyry copper deposits associated with quartz mineral intrusions. This is a term applied to a type of disseminated copper deposit that is hydrothermal in origin and characterised by a large proportion of minerals uniformly distributed as disseminations or in fractures and small veins. As is common with these types of deposits, the Namosi prospect contains ore of less than 1% copper content at 0.45%. In addition, the ore body contains 0.15g per tonne of gold and an unspecified content of molybdenum. In spite of the low copper content, massive horizontal development renders porphyry deposits amenable to large scale production generally through open pit mining. The copper cut-off grade is specified at 0.3%, making the Namosi prospect a highly marginal one.

In 1992, The Government of the Republic of Fiji granted a Special Prospecting Licence to Placer Pacific Limited. This company has particular experience of the development of large low grade copper resources and under the Licence granted is carrying out a programme to characterise the resource and improve the development of the prospect. Given its marginal nature, the economic viability of the prospect will be highly dependent upon the production costs, and these in turn will be contingent upon the degree to which waste management costs can be minimised. The minimisation of costs will inevitably involve their externalisation to some degree. This is perhaps most obvious in the proposal to dispose of tailings at sea.

In addition, because of the marginal nature of the prospect, the viability of development is contingent upon considerable economies of scale. The prospect would be mined as an open pit, generating around 750 million tonnes of waste rock together with some 600 million tonnes of tailings. The excavation of the Waisoi East and Waisoi West deposits would create two open pits with diameters of 1.2 and 2km respectively (Placer Pacific 1992). This would rank the Namosi operation as among the 20 largest open pit mines in the world.

With a project of this scale, a number of environmental impacts may be anticipated, due both to the mining activity itself and to the associated infrastructural development. This includes a port facility for materials import and ore concentrate export. Imported materials would include coal for power generation to meet an estimated operational power/energy demand of 85 megawatts/550 gigawatt hours. Importation of coal would be around 20,000 tonnes per month. Moreover, the project has an anticipated water demand in the region of 2 cubic metres per second for ore grinding and concentration.

It is envisaged that the ore would be milled at the mining sites, followed by pipeline transport of the ore slurry to the coast. Here, ore beneficiation would be carried out by flotation treatment to produce copper concentrate and possibly molybdenum concentrate. These would be dewatered and stockpiled prior to shipment through the new port facility.

The Namosi operation would therefore entail the disposal of substantial quantities of waste rock, tailings and process effluents. The disposal commitment will be in excess of 90% of the original material removed and of greater volume due to comminution in the beneficiation process. It is intended that the waste rock would be dealt with by a large dump facility close to the mine. The preferred method for disposing of tailings produced by the processing operation is deep water disposal, possibly in combination with the fly ash and cooling water from the power station.

The coastal environment in the development area is a mixture of mangrove shoreline and fringing coral reef, with development of a barrier reef system up to 15km offshore, with navigable passages through it. Hence, the development has the potential to impact marine systems to a substantial extent. This overview considers some of these potential impacts of tailings disposal. Unquestionably, (Barbour 1994) mineral extraction, processing, smelting and refining can never be environmentally neutral. Accordingly, such developments need to made in full recognisance of the likely impacts and with a view to minimising the impacts to the maximum possible degree from inception through to final closedown and remediation.

2. PROCESS DESCRIPTION

The production of concentrate depends upon the comminution of the extracted ore into fine particles which can be subjected to a recovery process. This separates out the concentrated minerals from the gangue materials allowing them to be disposed of as tailings. The Namosi ore minerals are largely chalcopyrite and bornite, primary copper minerals concentrated in the ore body by past hydrothermal processes. In addition, localised above and below the copper bearing zone, molybdenite occurs. The following generalised process details have been taken from Richardson, (1993); Yarar (1994); Barbour (1994) and Nagaraj, (1995).

Typically, with minerals of low grade, cone crushers are used to reduce the size of the ore minerals in stages to <20cm then <3cm and finally to <1cm. Further size reduction is achieved by several stages of grinding with water to produce an ore slurry. Rod mills are typically used for the first stage in which ore size may be reduced to less than 3mm. To reduce the size of this output a series of ball mills are used such that 75% is reduced to less than 0.25mm in size. Wet cyclones are used for size classification, with oversize material being returned to the mill.

The crushing and milling process is designed to liberate the mineralised material from the gangue. There are numerous variations on the type of machinery which may be deployed in these operations. Modern mills may process up to 36,000 tonnes of material a day, driven by 12,000kW electric motors.

Flotation processes are subsequently used, sometimes on thickened slurry. This is the single most used technique for ore concentration. For sulphide ores a water-repellent chemical film is produced on the exposed minerals. In the process, air injected into the flotation cell attaches to the minerals and carries them to the top of the tank where they are removed from the froth in collecting cells known as launders. Flotation reagents are used to create a stable froth and also one specific to the minerals being concentrated. Regrinding may also be carried out on the non-floating residues. Molybdenum sulphide normally floats with the copper sulphides and is generally separated from the copper minerals in a further flotation circuit.

The flotation process is both water and chemical intensive and these systems are designed to work on anything between 10 and 50% solids. Volumes of cells range between 14 and 100 cubic metres. Chemical reagents are used to enhance hydrophobicity, control selectivity, enhance recovery and grade and modify the kinetics of the process. Collectors are chemicals which render the target particles hydrophobic. The flotation of copper sulphide minerals from an ore containing > 95% siliceous gangue is usually carried out using a xanthate (alkyl-dithiocarbonate) collector. Dithiophosphates are also commonly used, while yet other agents are increasingly finding acceptance in the industry. A transiently stable froth is maintained by a frothing agent. This may be a long chain alcohol or more complex natural plant oils such as eucalyptus oil or pine oil. Quantities of collectors used range between 1-100g per tonne of ore treated depending upon metal mineral content. Frothers are applied at between 5-100g per tonne of ore treated. The published reserve figures for Namosi suggest that around 2-5g collector per tonne and 20-25g/tonne ore of frother will be applied. A typical copper ore flotation plant uses around 3800 litres of water per tonne of ore treated.

Modifier chemicals are used as auxiliary reagents. Lime is commonly used in copper mineral flotation to control pH and to suppress the flotation of pyrite. Sodium silicate may be used as a dispersant/depressant for siliceous gangue and clays. Sodium cyanide is used as a depressant for metal sulphides while Nokes reagent, a complex mixture which includes arsenic and antimony compounds is used as a selective depressant in molybdenite circuits. When properly designed and operated a froth flotation circuit can concentrate an ore originally assaying 0.5% copper to in excess of 35% and recover 85% of the copper present in the ore. Materials not recovered are discharged with the gangue as tailings. In the case of porphyry copper ores, tailings will comprise up to 99% of the total mass of the material processed in a mixture with water and containing unspent process chemicals.

The concentrate stream is then dried and in the Namosi operation will be stored prior to shipment in a covered stockpile. It is not clear to what extent water reuse will be practised in the operation. In the majority of mines, tailings are discharged into a tailings pond. This is an operation of considerable environmental significance, requiring extensive design and planning. Tailings are usually thickened before discharge to the pond and the major purpose of the tailings pond in many plants is for water management. Many plants in the United States recycle all of the process water and achieve zero discharge. In addition, tailings management of this kind facilitates the use of the rejected materials in the overall reclamation of the mine site after closure as backfill of the excavated site.

WASTE MANAGEMENT AT THE NAMOSI MINE

There is little doubt that tailings and waste rock management is a primary concern at copper mine sites. At Namosi, it is proposed that the waste rock arising would be contained at constructed dumpsites and eventually as backfill of the excavated site. Provision would be made in the design to prevent leachate and acid drainage formation. The tailings generated by processing also constitute a waste management problem.

The practice of direct discharge to local watercourses is now deemed unacceptable due to the considerable environmental impacts which result upon both physical and chemical environmental quality. Nonetheless the practice still persists in a number of developing countries and has caused severe environmental impacts. The Ok Tedi mine in Papua New Guinea discharges around 80,000 tonnes ore processing residues and a similar volume of waste rock and overburden daily into the headwaters of the Fly River. This amounts to about 58 million tonnes of sediment per year and has led to high accumulations of metal rich sediments in the floodplain of the river, reaching to the deltaic region. It is difficult to see how this practice can be justified in environmental terms and indeed has led to a number of legal challenges being made (Hettler & Lehmann 1995). The report also notes that the lack of public accountability by the mine operators for environmental performance is unacceptable.

Interestingly, the same arguments advanced by the Ok Tedi operators against the use of a tailings impoundment are used by Placer Pacific (Placer Pacific 1992) in relation to the Namosi prospect. They argue that land disposal would involve the construction of one or more very large impoundments to permanently store the tailings with a land-take of around 49 square kilometres. The high rainfall in the area would necessitate that the water surplus would need to be continuously discharged from the impoundment and the discharge systems would need to accommodate cyclonic rainfall to prevent overtopping and possible failure of the system. Seismic events also pose a risk to structural integrity. The point is made that the necessary earth filled impoundments would be expensive to construct.

Accordingly, the preferred option on the part of the operators is submarine tailing disposal which is described as a "safe and permanent" method of tailing disposal. The technique is described as a proven and safe method and the example of the Island Copper Mine in Canada is cited together with the submarine tailings disposal operation carried out at the Misima Gold mine in Papua New Guinea operated by a subsidiary of the Placer Company. Essentially, submarine tailings disposal involves the discharge of tailings slurry via a mix/deaeration tank, where it is mixed with seawater. The slurry is discharged below a depth of 100m where it would fall as a density current to the bottom of the Suva Basin at around 2000m depth.

As an incidental point, this solution, in the case of the Namosi prospect is inconsistent with the possible problems of water availability. On the one hand, impoundment is ruled out because of water management problems, yet there is little doubt that recycle of process water would alleviate the water availability problems alluded to in the Inception Report. It is noted that the flow in the Waiosi Creek diversion channel would be insufficient to provide process water except under conditions of heavy flow. Given that recycled water quality can be controlled, the rationale for not maximising reuse and achieving zero discharge from the development seems predicated upon cost conditions alone. Full recycle of water would unquestionably be more expensive in terms of the infrastructure required.

MINE TAILINGS: CONTAINMENT AND SUBMARINE DISPOSAL

a) Tailings impoundment

There is little doubt that improperly designed and maintained tailings impoundments represent a significant environmental hazard. Recent reports in the media have documented the collapse of a tailings dam at the Omai mine in Guyana releasing some four billion litres of cyanide containing wastes into the Essequibo River (Chatterjee 1996). At the Marcopper Mine in the Marinduque Islands in the Phillipines, 1.5 million tonnes of waste materials were released from a storage pit into a local River. In the first case, Placer originally owned the mine, in the second case, Placer maintains a 40% interest. Other tailings dams have also failed, in some cases with substantial environmental impacts.

Barbour (1994) notes that tailings management is a subject of major environmental importance and that it is required to provide acceptable solutions with respect to several issues:

1) The site must not infringe areas of historical or ethnic interest and value nor affect the livelihoods of local inhabitants. It must be acceptable in engineering, environmental and aesthetic terms.

2) The dam must be stable and acceptably designed and constructed and include safe systems for handling exceptional rainfall.

3) The tailings must be stable when located in areas prone to seismic events

4) Supernatant or runoff water should be of acceptable standard

for recycle or discharge.

5) Deleterious effects of supernatant water on adjacent streams or on groundwater should be accounted for.

6) Revegetation should be carried out to avoid windage losses and improve appearance.

Tailings are inhomogenous and differ markedly between operations and hence tailing handling is a highly site specific process. The Namosi tailings are predicted to be a mixture of sand, silt and clay which should not prove difficult to handle as a pumpable slurry in practice. The real difficulty is likely to arise as a result of the substantial land-take coupled with construction costs and long term engineering stability issues.

Overall, the limited analysis contained in the Final Inception Report is correct to point out the substantial costs and risks involved in conventional tailing ponding in the Namosi project and to consider some of the site specific aspects of this. The considerable costs of constructing an adequate impoundment in an area of high rainfall, coupled with the problems of ensuring long term stability of the impoundment in structural and chemical terms require that a detailed assessment of the potential environmental impacts be produced if this method of tailings management is to be pursued.

b) Submarine discharge

The statement that submarine tailings disposal (STD) is "a proven method for the safe and permanent disposal of tailing" is highly questionable. In particular, the facts pertaining to the cited example of the Island Copper Mine in Canada appear to be somewhat misrepresented. It should be recognised at the outset that this proposal represents the cheapest option and therefore the option which by externalising disposal costs increases the operational viability and economics of exploitation of the prospect. Indeed, given the highly marginal nature of the prospect and the associated difficulties of operating under the prevailing climatic and terrain conditions it is arguable that it would be economic to exploit the deposit if this method of disposal were not to be used. Hence, this decision appears to be largely predicated upon economics rather than environmental protection interests.

The costs of constructing a pipeline to convey the tailings to sea coupled with the relatively low costs of retrospective monitoring would be a fraction of those associated with a land based option. In order to evaluate the full comparative aspects a cost analysis of the respective operations should be performed as part of the overall environmental impact assessment process. If this has been done, the details do not yet appear to be in the public domain.

Direct discharge of tailings to coastal waters has been practised at a number of mine sites. Current opinions in the literature as to the acceptability of this practice are divided. On the one hand, Barbour (1994) notes that tailings disposal to sea is generally out of favour with regulatory authorities. On the other hand Ellis (1988) considers that coastal mines have the option of discharging wastes to sea. Of the mines listed in this reference, the majority are non-ferrous metal operations and in many cases these appear to have exploited relatively marginal resources.

There also appears to be some confusion in the literature of definition. For example, (SAML 1994) it is stated that STD has been used at around 20 mine sites around the world. The quoted authority in this article has described these operations (Ellis 1988). In fact, STD where tailings are discharged to deep water has been practised at relatively few sites and in most cases disposal has been to shallow coastal waters. Moreover, (Jones & Ellis 1995) the Misima mine is described as "the pioneer of deep water tailings disposal".

As pointed out by Golder Associates (1996), of the mines in Canada which have historically discharged tailings to the sea, only Island Copper conforms to a true STD operation. Britannia Mine (Howe Sound), Jordan River Mine (Jordan River), Yreka Mine (Neurotsos Inlet) and Anyox (Granby Bay) were all operational before contemporary STD principles evolved. Moreover, the Polaris Mine and Nanisivik Mine discharge tailings to discrete water bodies where the tailings settle out. Since only the liquid decant is discharged to the marine environment, these operations cannot be regarded as true STD operations. Finally, the "Black Angel" lead-zinc mine in Greenland has discharged tailings into an adjacent fjord of 40m depth. This has produced marked elevations of dissolved lead (Muir *et al.* 1992). On this basis it would seem that the supposed wide data base upon which the acceptability of STD is predicated, is in fact limited to the operational experience at the Island Copper Mine and the scant data obtained at the Misima mine over the initial 5 years of operation.

It should be noted too, that in the case of many of the marine discharges, volumes of material discharged have been less than the amount projected at Namosi. The Namosi prospect is predicted to generate 600 million tonnes of tailing over the lifetime of the mine at a nominal process throughput of 60,000 tonnes per day of ore. The Island Copper Mine generated around half this quantity of tailings over the lifetime of the mine at 300 million tonnes, while the Misima Mine generates 18,000 tonnes of tailings per day (Jones & Ellis 1995). Hence, there is a considerable difference of scale between the Namosi operation and those being used as benchmark data sources for STD operations. Accordingly, the value of predictions for Namosi based on these examples is subject to considerable doubt.

In the case of the Island Copper Mine, four primary impacts have been identified. These are increases in water turbidity, smothering of benthic environments, and trace metal bioaccumulation. Only the fourth, shoreline habitat loss resulting from waste rock disposal, is not relevant to the Namosi proposals. The Island Mine tailings disposal operation is probably one of the best documented in the scientific literature as a result of Government and public interest in the environmental impacts.

While the degree of environmental monitoring has been comparatively extensive, this should not be confused with adequacy. Moreover, as with any operation of this kind monitoring activities provide a retrospective evaluation of the impact. In the case of the Island Mine development, it is of interest to compare the predictive assessments with retrospective monitoring results and also to compare the situation with the proposed development of the Namosi prospect.

At the Island Copper mine (Ellis 1988) around 40,000 tonnes per day of ore were processed, most of which was discharged via submarine outfall to form a density current into a fjord system. The discharge took place below the pycnocline. This method of discharge of tailings which depends upon density differentials to allow the tailings plume to sink to the bottom of the receiving water differs in concept from simple discharge to surficial coastal waters. The discharge ceased in 1995 at which stage the daily process volume was recorded as 50,000 tonnes per day. This translated to an average discharge volume of 85,000 cubic metres daily. Around 60% of the particulates were below 63 micrometers in diameter in the form of aluminosilicates (Golder Associates 1996).

The licence to discharge was granted to the operators on the basis that the tailings discharge would form a confined density current which would come to rest in the deepest portion of the inlet. Secondly, that the material would be isolated from the tidal effects arising from adjacent narrows. Thirdly, that over the 25 year lifetime of the mine, deposits would be restricted to 1,600 acres of seabed; and that finally, the fine tailings would not enter the surface waters of the inlet.

In practice, the seabed area impacted in the first few years of operation extended over some 9,500 acres of seabed. Moreover, surface turbidity levels were primarily increased due to the waste rock disposal operation, but also due to "boils" of tailings reaching the surface in an area of high tidal energy. This increased turbidity rapidly developed to extend over a wide area. A large sub-surface turbidity field also developed within two years of operation commencement. Unsurprisingly, bottom deposition affected most of the area overlain by water showing increased turbidity and ranged from very light deposition to very heavy deposits. High rates of sedimentation were observed in intertidal and shallow sub-tidal zone.

In retrospect the failure of the predictions on which the licence was originally granted flowed from a number of inadequacies in the baseline environmental data on local tidal and current regimes coupled with misapplication of models designed to predict sediment behaviour in freshwater systems to the saline conditions in the receiving environment. Additional complexities were introduced by the interactions in the recipient between freshwater and saline water bodies.

The statement in the Final Inception Report to the effect that STD represents a proven safe method is, therefore, incorrect. What has been proven in the case of Island Copper Mine is that the predictive models failed comprehensively to predict the extent of the physical impact. Moreover, there is no way in which these predictive models can have any relevance to the Namosi proposal, dealing as they do with the highly specific conditions pertaining to the Canadian operation.

The statement that "no bioaccumulation of any significant heavy metals has occurred in marine organisms and the general health of the marine ecosystem has not been adversely affected" can be criticised on a number of grounds. Firstly, the term "ecosystem health" has been criticised on the basis that it is essentially meaningless (Suter 1993) and that more precise terminology in this context would be ecosystem "quality" as an expression of "the abstract property that encompasses the specific goals of environmental management". If this term is used, then it is quite clear that environmental quality has been degraded in the vicinity of the mine. Golder Associates (1996) point out that while it is not an objective of STD operations to smother or obliterate bottom fauna in the receiving zone, it is an expected outcome of the practice. Indeed this report considers it "a foregone conclusion that habitat and fauna in the pathway will be smothered". The issue is therefore what area will be affected.

In relation to significant metal bioaccumulation, the assertion in the Inception Report that this has not occurred is contradicted by both Ellis (1988) and Golder Associates (1996). Ellis (1988) presents tabulated data suggesting uptake by *Fucus* spp. Although it is noted that this may be due to attached metal rich particles, this point is questioned in the later report. In addition *Mytilus edulis* also contained consistently higher levels of copper and zinc when sampled at the loading dock in comparison to reference sites. This of course raises the issue that dock operations will inevitably be accompanied by spillage during loading operations and there is a need in the case of Namosi to investigate the potential impacts of such spillages.

Golder Associates (1996) note that the collected data for marine macrophytes show an increase in metal concentrations over time, with higher concentrations of metals occurring closer to the mine. Moreover, arsenic in species of benthic bivalves and prawn exceeded US Food and Drug Administration tolerance limits for seafood by a factor of up to three times. Arsenic levels in commercially fished species of crab also exceeded FDA limits from 1971 through to 1994 over a wide geographical area.

More seriously, the above report documents a number of failings of the biomonitoring programme. In particular it notes that he inconsistent way in which data were obtained in relation to location and time seriously limited the utility of the whole dataset in determining trends. In addition, testable hypotheses were not formulated at the monitoring programme design stage and this compromised the sampling design in terms of conducting power analysis and determining replicate sample requirements. Lack of replicates fatally compromised time trend analysis. In essence, the frequency and intensity of sampling was insufficient to detect elevation of crab (or other organismal) tissue metal levels to an acceptable level of statistical probability and at a useful accumulation threshold. It was also the case that due to the greater than expected spatial impact of the tailings discharge some of the reference sites were also impacted, thus diminishing the power of controls and references within the programme. Finally, of the great body of data generated, potential toxic effects at the organismal level were not evaluated.

Hence the statements made in the Final Inception Report need to be carefully evaluated in relation to the documented deficiencies in the environmental programme design at the Island Copper Mine. Similar considerations apply to the Misima Mine operated by a subsidiary of Placer. It is stated that the Misima Mine has been safely disposing of its tailing since operations commenced. As pointed out earlier, published evaluations have been based on only the first five years of operation (Jones & Ellis 1995). This operation discharges at 112m depth into a submerged mixing zone of 1200m radius. Tailings are apparently confined to the sloping floor of a basin at 1000-1500m depth. Visual inspection by ROV has taken place to a depth of only 160m. Sampling of ocean floor sediment has been used to ascertain the disposition of the tailings in deep water. The operation has been regarded as a success since no tailings have been observed to date in the productive surface waters. The findings have not been confirmed by direct visual observation at depth. This is of concern since in the case of the Island Copper Mine, the full areal extent of deposition did not become clear through sediment sampling but only after visual inspections were made by divers.

More pertinent are observations made on the Misima site (Huber 1994). This development has in fact caused extensive destruction of reefs. Soft rock waste is dumped from trucks directly onto the reefs in addition to the pipeline discharge. Approximately 9km of fringing reef have been affected, with impacts becoming progressively more severe near the discharge point. These impacts, however, were predicted by the environmental plan for the project and deemed acceptable by government. In addition, sediment levels in north flowing creeks have been higher than predicted owing to mine development taking place in areas not envisaged by the environmental plan. In addition, it is recognised that there is little baseline information on the northern reefs of Misima Island. The response has been to increase the elements of retrospective monitoring in this area.

Overall, therefore, the Final Inception Report quite correctly identifies in simple terms the potential difficulties associated with land based tailings disposal in impoundments. The overview of STD operations, however, does not appear to be an accurate representation of the available data from Island Copper and fails to objectively describe the limited experiences at the Misima Mine. Moreover, the experience with STD as projected for Namosi is not comparable with the situation at most mines which have historically discharged tailings to marine systems. It is, therefore, totally unjustified to claim that the practice is proven or safe given that in the best documented case the dataset is demonstrably deficient. Moreover, comparison of the two sites cannot be justified given a number of other site specific considerations.

NAMOSI: SITE SPECIFIC CONSIDERATIONS

As discussed above, the technique of submarine tailings disposal has been poorly validated as an acceptable environmental option and indeed the literature provides a conflicting view with that found in the Final Inception Report. Essentially, the technique has only been employed at one mine for which reasonable production lifetime records exist and, in this case, there was widespread failure of the predictive models used and failure to anticipate the effects of local conditions.

A further important consideration is the degree to which comparison of the Island Copper Mine with the Namosi prospect is actually relevant. The Namosi Prospect is located in a tropical region with high rainfall. It will be developed in a coastal region with fringing coral reefs and mangroves and an offshore barrier reef. This environment differs markedly from that in which Island Copper was situated: a temperate, tidally influenced fjord system with variable bottom substrate, natural turbidity extremes and seasonal productivity cycles. Namosi is more directly comparable with Misima, but as yet the data extend over a rather limited time frame.

Coralline environments are notoriously sensitive to changes in environmental quality as is evident from the progressive deterioration in the Arabian Gulf (Sheppard *et al.* 1992).
As noted by Bell *et al.* (1989), corals have a narrow physiological tolerance range for key environmental variables, the interactions of key reef species e.g. algal-coral competition are susceptible to pollutant stresses and finally, the effects of toxic substances may be enhanced by the high water temperatures common in coral reef environments.

Despite efforts on the part of the University of the South Pacific at Suva, the Fijian marine environment is not well described. Nonetheless it is acknowledged that Fiji has one of the largest and best developed coral reef systems in the South West Pacific with all reef types represented. The largest fringing reef is the Coral Coast reef of Viti Levu. The reef environment is essential to the subsistence of the indigenous population in rural areas. The economic value of Fiji's reefs is estimated at an annual figure of 196 million dollars US. Reefs in the Suva area have been deteriorating since early this century due to clearing of the watershed, while major flood events cause occasional massive mortality of corals on fringing and barrier reefs (Zann 1994).

Suva Harbour itself is acutely disturbed. The presence of a rubbish dump and a battery factory have led to serious contamination of sediment and biota. Contamination is of such seriousness that in other countries a hazardous site designation could be applied (Naidu & Morrison 1994). Accordingly, the impact of a new port and concentration facility with significant bulk handling commitments for coal must be viewed not only in terms of the impact that it will itself cause, but in relation to potential additive effects. It is inevitable that any bulk cargo operation dealing with uncontained minerals and concentrates will have losses due to spillage and dust blow. The impacts are potentially severe both for reef organisms and the mangrove environments.

The STD operation depends upon the tailings being deaerated and mixed with seawater to adjust density. The tailings are then discharged below the density discontinuity plane (pycnocline). The resultant turbidity flows of the negatively buoyant plume are described extensively in Golder Associates (1996). A key difference between the Island Copper mine recipient and Fijian waters is the intensity of the discontinuity. In the Canadian example, salinities varied between approximately 22 an 30 parts per thousand, hence the density discontinuity is due to differentials between fresh and saltwater and to a lesser extent, water temperature. In the case of the proposed Namosi operation, the stratification of the recipient waters is much less marked and supported by much smaller salinity and temperature differences.

Significantly, it is noted by NSR (1995) that the definition of the discontinuity as the depth where density gradient exceeds 1.5kg per cubic metre per 100m depth does not readily describe the Fijian situation in many cases. This has led to the need to estimate the depth of the pycnocline rather than basing it upon empirical data. In many of the water column profiles presented, the density discontinuities appear to be weak or non-existent. On the basis of these data, NSR (1995) suggest that base of the surface mixed layer varied between 15-155m while the euphotic zone ranged from 30-110m. In the case of the first range, it is acknowledged that difficulties exist in defining mixed layer depth. The measurements were taken during periods when no extreme weather events were recorded. Cyclonic weather could extend the surface mixed layer depth substantially. As would be expected, oceanic turbidity was found to be consistently low. This variable and generally weak stratification contrasts also with the situation at Misima where apparently ocean stratification is permanent. In addition the euphotic zone at Misima appears to be generally shallower in extent than is the case at Namosi.

It should be appreciated that the oceanographic survey data is extremely limited in extent. It is not clear on which basis the survey stations were derived and therefore which particular questions such a sampling distribution was designed to address. The major survey campaign appears to be related to an offshore transect some 15 km in extent. No reference sites appear to have been selected to control for post operational impacts. A further site some distance away from the transect does not act as a control, but has been selected to investigate changes in water physico-chemical properties related to the Beqa passage. Hence, the mass water flow in the vicinity remains uncharacterised and, in particular, lack of upwelling can only be unreliably and indirectly inferred. This is an issue of considerable potential importance in the dispersion of fine tailings particles.

Taken together, these observations suggest that the conditions relating to STD and the associated data for Island Copper and Misima cannot be readily extrapolated to fit the Namosi Prospect. It is highly likely that the control of the tailings slurry density would be critical in ensuring that the discharged plume would be negatively buoyant under all conditions. The discharge pipeline and seawater intake pipeline would need to be situated at a depth of at least 200m but with this provision there is no guarantee that a discrete density discontinuity would be a permanent feature. Hence, the scheme cannot be relied upon to operate in the same way as at the operations used as exemplars.

Miscalculation or poor management of the waste stream density could result in the ready formation of an upper plume of tailings. The restriction of the fine particulate plume to deep water cannot be assured. The variations in the depth of the mixed layer and the weak density discontinuity imply that there would be no physical barrier to the free movement of particulates in the water column. In this regard, the possible generation of threshold slope instability followed by slumping of the tailings could generate a significant turbidity cloud at periodic intervals. In turn, this could be transported considerable distances and impact coralline environments over a wide area.

BIOLOGICAL ASPECTS

As described earlier, the Island Copper mine discharge was made into a fjord environment whose flora and fauna were typical of a temperate shallow water northern Pacific Assemblage. Deep water tropical species assemblages have not been well characterised. Implicit in the Final Inception Report and in Jones and Ellis (1995) is the assumption that if tailings are discharged below the euphotic zone, then biological impacts will be minimal. This depth at Namosi is given as in excess of 100m. Such an assumption is unwarranted. The euphotic zone in coralline Pacific areas may extend to in excess of 100m also. Indeed, the euphotic zone depths at the survey sites ranged from 30-110m. Hermatypic corals may be found at depths of 140m in parts of the Pacific, contrasting with a depth limit of around 50m in Papua New Guinea where the Misima mine operates. The green alga *Halimeda* may be found at up to 145m. These facts comprise relatively elementary knowledge (Bosscher 1992). Hence this is further evidence that comparison of the Misima operation with that proposed at Namosi is ill founded.

The above facts also serve to highlight a further deficiency of the oceanographic data in that these are not related to the underlying ecosystems. Coralline environments are characterised by biocoenoses which include most of the invertebrate taxa with the exception of insects. Without data on the communities living at the depth of proposed discharge, any prediction concerning potential impact is at best extremely speculative. It is also unwarranted to assume that the deep water communities are sparse. In the limited areas where deep sea survey work has been carried out the communities are found to be very species rich. Their wider interactions remain poorly understood. While deep sea survey work is highly specialist, the information has been widely published in the popular scientific press (see: Pain 1996).

Hence, as matters stand, it is proposed to discharge tailings from

In addition to the documented problems at the exemplar sites, the environment differed markedly from that of Fiji. Hence, extrapolation of data from the Canadian operation to Fiji is simply not possible. Differences exist too in the nature of the environment at the tropically located Misima mine in Papua New Guinea with respect to Fiji. In addition the Misima operation has only produced data for the first five years of operation. This operation has also been documented in the scientific literature as causing extensive destruction of coral reefs in the vicinity of the discharge. Far, therefore from being a proven safe method for the disposal of tailings, STD is largely an experimental method which has not yet been fully validated in the field for either temperate or tropical waters. It should be recognised that validation is a retrospective exercise. If damage is done through using STD, then it will not be possible to reverse the discharge

Various site specific aspects of the Fijian operation suggest that STD will not be simple to operate in this location. The apparently weak, seasonally variable density discontinuity imply that management of the discharge to confine tailings to deep water will be highly demanding with the potential to prove impossible on a consistent basis. The lack of any baseline data concerning the recipient deep water ecosystems is also of concern. The oceanographic profiling carried out in support of the proposal has been limited in extent and not related either to shallow or deep water environments.

Accordingly, before STD is approved as the method of choice for the Namosi operation, extensive baseline studies and assessments need to be carried out. These should include as elements *inter alia*.

1) Full characterisation of the fringing and barrier reef communities and the identification of sensitive organisms.

2) Full characterisation of the communities in the deep water ecosystems

3) Determination of the principal local and regional water currents, including a component directed at determining upwelling currents in the area.

4) Establishment of a markedly extended oceanographic programme to determine the full variability of the depth of the euphotic zone and surface mixed layer.

5) Comparative characterisation of the bottom sediments in the recipient with the properties of the tailings

6) Evaluation of potential modifying effects of the process chemicals present in the discharge to toxic and other effects of the discharge.

7) Realistic evaluation of the area of seafloor likely to be smothered by the discharged tailings.

8) Evaluation of likely impacts of cyclonic weather

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the Namosi operation in uncharacterised ecosystems for which there is a complete lack of baseline information. The environment differs markedly from the environment into which tailings were discharged by the Island Copper facility. Substantial differences also exist between Namosi and the example of Misima. Extrapolation of toxicological observations made on fauna from temperate regions is not acceptable. It is likely that tropical organisms will differ markedly in their responses to environmental toxicants.

The lack of knowledge about the communities and ecosystems in the recipient also raises questions about the behaviour of metals introduced into the system via the tailings. The tailings will also contain unused process chemicals and the effect of these upon metal speciation and mobilisation is largely unknown. Significantly, although metal sulphides themselves are considered to be insoluble, this assumption proved simplistic in the case of the Black Angel discharge. Here, soluble hydroxide, carbonate and sulphates of metals formed during the milling process were quickly released to seawater. Hence, a good understanding of the nature of the process effluents is critical. Some information is available concerning the diagenetic processes taking place in metal rich tailings discharged to sea. In the case of Island Copper it appears that the tailings inhibit the benthic regeneration of phosphate. In these receiving waters, this does not constitute a major part of the phosphate cycle (Pedersen & Losher 1988). This may not be the case for the Namosi receiving water.

Studies of metal mobilisation into the overlying water at the Canadian site have shown that this does not appear to be highly significant. Nonetheless, a proportion of the metals contained in the tailings can undoubtedly be mobilised as reflected in the elevated levels of heavy metals found in members of the biota sampled as part of routine retrospective monitoring. The significance of this for tropical areas is not known.

OVERVIEW

The Namosi Prospect if developed will number among the 20 largest open-pit mines in the world. Mining a low grade resource, concentrate will be produced at the site and shipped for further refining elsewhere. The development is projected to include a new port facility, road and power station and the port will handle both concentrate exports and imports of coal to fuel the proposed power station.

Environmental impacts are likely to be substantial. In the case of the marine environment these are likely to accrue primarily from the disposal via submarine pipelines. It is highly probable that the the port facilities will also cause degradation of the inshore coralline environment. The major concerns undoubtedly stem from the proposal to use submarine tailings disposal. This waste disposal methodology has been documented extensively at a mine operating in Canada. Numerous failures of predictive models took place, such that the overall area of impact was substantially greater than anticipated.