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For:

Ok Tedi MiningLimited

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Ok Tedi Mining Limited

Acid Drainage and Metal
Leaching Potential of Waste
Rock, Tailings and River
Deposited Materials

PRELIMINARY REPORT

Contents

Tables

Figures

1.0 Introduction

This report present the preliminary findings of investigations carried out by Environmental Geochemistry International Pty Ltd to evaluate the acid drainage potential of mine waste rock and tailings and the implications for water quality and mine operations at Ok Tedi.

The information presented in this report is based the results of the available acid–base data, waste rock and ore production schedules provided by OTML, preliminary geochemical modelling and a site visit conducted by Stuart Miller of EGi from June 2 to June 8, 1999.

The overall purpose of this report is to evaluate the risk of acid generation and metal leaching from deposited materials and implication for the mine operation to minimise or eliminate these risks. The specific objectives are as follows:

2 Evaluate the acid-base and acid forming potential of waste rock and tailings to be discharged from the mine from 1999 to the end of mine life;
3 Evaluate the acid base and acid forming potential of materials deposited in the Ok Mani, Ok Gilor, Ok Tedi and Fly River.
4 Determine the likely sulphide oxidation and acid generation rate from deposited materials.
5 Determine the risk of developing acid drainage from the mine and river deposited materials.
6 Evaluate the implications for copper solubility within the Ok Tedi and Fly River.
7 Identify potential management options for controlling or eliminating the risk of adverse impacts from sulphide oxidation in mine waste materials.

This report is based on preliminary information only and best estimates from OTML and EGi on the likely nature and behaviour of material types. The results have identified the need for additional investigations to confirm the assumption used and refine the management needs for controlling the risk of potential problems associated with sulphide oxidation and copper release from deposited materials in the Ok Mani, Ok Gilor, Ok Tedi and Fly River catchments. The specific data requirements and investigations are outlined in Appendix A.

2.0 Factors Influencing the Potential for Acid Generation and Copper Leaching at Ok Tedi

2.1 Production Schedules

The waste rock currently being mined at Ok Tedi comprises a number of rock types including limestone, siltstone, monzonite, monzodiorite, endoskarn, skarn and oxide porphyry.

The available data indicates that siltstone, monzonite, monzodiorite, endoskarn and skarn all contain reactive sulphides and some units are significantly deficient in acid neutralising capacity (ANC) and are potentially acid forming (PAF). Limestone is the main source of ANC in the bulk waste rock and although the current production is adequate to buffer the potential acidity from the other rock types, on a short term basis, the limestone production is variable and periods of low production are likely to occur. However due to the nature of waste rock disposal at Ok Tedi, short periods of low production have not been a concern due to the remobilisation and mixing that occurs in the failing waste rock dumps.

The production schedule provided by OTML indicates that the quantity of limestone mined from 1999 to the end of the current mine life will decrease significantly from around 33 % of the total waste rock production in 1999 to less than 5% from 2006 to the end of 2009. The limestone production schedule as a percentage of total production from 1999 to 2009 is shown on Figure 1. The reduction in limestone production implies a significant reduction in the total ANC load to the river system with potential consequences for the acid potential of deposited materials.

Monitoring data provided by OTML indicates that the current ex-mill tailings are potentially acid forming containing about 2 to 3% total S and a low ANC of about 10 to 20 kg H_2SO_4/t. The net acid producing potential (NAPP) ranges from about +40 to +80 kg H_2SO_4/t indicating an excess of acid potential over inherent neutralising capacity. Net acid generation (NAG) test have been conducted on site and confirm the NAPP results. The current ex-mill tailings are therefore classified as potentially acid forming (PAF).

The ore type production schedule indicates that the ex-mill tailings will continue to be PAF throughout the remaining years of the operations with a potential shift towards higher total S and lower ANC contents. Hence the NAPP of the tailings may increase with time due to increased processing of higher sulphide ore types.

The production schedules provided by OTML for waste rock and ore/tailings for the remaining years of the operation identify a potential risk that areas of PAF materials may deposit within the failings waste rock dumps and within the river systems.

2.2 Other Sediment Input

In addition to the mined waste rock, valley wall erosion occurs within Harvey Creek and contributes to the total sediment load entering the river system. Also, natural sediments from the surrounding limestone catchments enter the river system. The mix of these material types with the mine waste rock and tailings will impact the potential for acid generation in waste dumps and river deposited materials.

2.3 Deposition Environment and Material Geochemistry

The potential for acid generation in the mix of deposited tailings, waste rock, eroded sediments and natural sediment within the Ok Mani, Ok Gilor, Ok Tedi and Fly River depends on the presence of reactive sulphides, primarily pyrite but also chalcopyrite, and the acid neutralising capacity (ANC) at the deposition site. When the ANC of the material is significantly higher than the potential for acid generation then it is likely that the deposited material will remain non-acid forming (NAF). On the other hand, if the acid potential is significantly higher than the ANC then the material should be considered to be potentially acid forming (PAF), unless proved other wise (by investigations comprising NAG tests, kinetic leach test and mineralogical evaluation). If there is prolonged exposure of PAF material to atmospheric conditions then it is likely that acid conditions will eventually develop.

Provided the deposited materials are fully water saturated this potential acid formation will not be realised. However, whenever the materials are deposited above the water table and some drying takes place then sulphide oxidation may occur. There is visual evidence of oxidation within the failings dumps and along the Ok Tedi but no apparent evidence within the Fly River.

Since the acid forming potential of the deposited material is determined by the balance of sulphide and carbonate minerals, any differential sorting and settlement of different particle sizes within the river system may lead to changes in the acid forming potential down the catchment.

The results of recent sediment sampling of deposited materials from Tabubil to Ogwa (immediately below the confluence with the Strickland River) highlight the potential for sorting and preferential deposition of sulphides. The results of the NAPP and NAG testing to date of samples collected within the Ok Tedi and Fly River in April 1999 are shown on Table 1. The sampling locations listed on Table 1 are shown on Figure 2.

The results show that the sulphur content of deposited materials in the Ok Tedi is relatively high ranging from values of about 6%S at Ningerum to about 1%S at the last point bar near the confluence with the Fly River (site: 500m U/S Ok Tedi). At Tabubil (LOB: Lower Ok Tedi Bridge) and at Haidowogam the S content is about 2 to 4%S. The higher S content of deposited material at Ningerum indicates possible segregation and preferential deposition of pyrite in this reach.

The ANC of deposited material in the Ok Tedi is relatively high at about 100 kgH_2SO_4/t for material deposited from Tabubil to Ningerum and even higher, ranging up to 200 kgH_2SO_4/t, near the confluence with the Fly river.

The acid base data indicates that all samples collected at Ningerum were NAPP positive with ANC/MPA ratios less than 1. In addition a number of samples at LOB and Haidowogam were also NAPP positive. However, near the confluence with the Fly River, the NAPP values are strongly negative with a significant excess of ANC (ANC/MPA 3.4 to 7.1). These results indicate that at the present time, NAPP positive material is exposed to atmospheric conditions in the failing dumps and upper/middle Ok Tedi.

However, the results of the NAG test work conducted to date indicate that the NAPP positive samples with high ANC are only likely to develop acid conditions if exposed to atmospheric oxygen for a very long period of time. Table 1 shows that the NAGpH values are all significantly greater than 4.5 for the Ningerum samples. Only 1 sequential NAG test has been conducted to date and the results show that the NAGpH did not drop below 4.5 until the third peroxide addition. The NAGpH of 2.7 from the sequential NAG test confirms that this sample is PAF but with a very long lag period (at least 5 years and possibly more than 20 years). Column leach test will be conducted to determine the relative rates of sulphide oxidation and ANC consumption/dissolution so that a better estimate of the lag period for NAPP positive samples can be determined (see Appendix A).

Table 1 also shows that natural sediments within the Fly river (sampling sites Kiunga and KO, both upstream of the confluence with the Ok Tedi) have a low S content (0.15%S) and a high ANC (75 to 85 kgH_2SO_4/t). These natural sediments are therefore a source of additional ANC for deposited materials in the middle and lower Fly. The data shows that sediments in the Strickland River have similar high ANC but slightly higher total sulphur (0.3%S). The background sulphur content in the Fly and Strickland Rivers is elevated compared to the average crustal abundance and typical soils. This possibly reflects drainage from mineralised catchments.

Sediments collected from the middle Fly River at Kuambit, Wygerin, Mabadaun and Manda have very similar acid-base characteristics with about 1 to 1.5% S and ANC values ranging from about 75 to 165 kgH_2SO_4/t. All samples collected from these sites are NAPP negative. Sediments represented by these samples are classified as non-acid forming (NAF).

At Bossett and Obo the sulphur content is about 0.3 to 0.5%S and the ANC content is about 30 to 80 kgH_2SO_4/t. The NAPP remains strongly negative and the materials are classified as NAF.

Overall, the results of this 'snap shot' sampling event are summarised as follows:

- Zones of NAPP positive sediments occur in the Ok Tedi.
- Sulphide segregation is occurring with S preferentially deposited in the upper reaches of the Ok Tedi.
- Deposited materials in the Ok Tedi have a high ANC (100 to 200 kgH_2SO_4/t).
- NAG test indicate that PAF deposits are likely to have a very long lag period due to the high ANC (many years of exposure would be required before acid conditions develop).
- Background sediments have a high ANC (approximately 80 kgH_2SO_4/t) and provide additional buffering.
- Sediments in the Fly River down to Manda contain about 1% S but have excess ANC and are NAPP negative. These sediments are NAF.

As noted above, provided PAF materials remain water-saturated they should remain geochemically stable and eventually will become permanently buried beneath the water table and therefore should not constitute any additional risk to the river system and its biological systems.

Even short term exposure of PAF materials may not necessarily be a concern if there is significant ANC and/or there is periodic inundation by alkaline river water which will supplement the buffering provided by the inherent ANC of the solids.

However, in the event that areas of PAF sediments are deposited above the water table and are subject to long-term exposure to evaporative drying then there will be potential for both acid and metals release which could have an additional impact on the river system. It is therefore important that the capacity of the Ok Tedi and the downstream environments to assimilate any acid and/or metals released from PAF zones as a consequence of sulphide oxidation is understood and, to the extent possible, quantified so that potential impacts from changes in the mine plan and/or tailings management can be assessed.

3.0 Approach

The approach adopted for this preliminary assessment of the potential for ARD and metal leaching from the mine derived sediments is based on a site specific geochemical model comprising linked modules which are described below. The model has been prepared in Excel workbook format with each module comprising a single work sheet. The model has been set up to allow for updates and refinements as additional data and information become available.

Because of the limited data set in a number of areas, the preliminary model has been run in a deterministic mode (i.e. using single value estimates for the model variables). As data becomes available from the proposed investigation program (as outlined in Appendix A), statistical distributions will be used as inputs rather than single values so that probablistic outputs will be generated allowing the risk of ARD under various management options to be better evaluated.

Module 1: Solids Production

This data input module includes the waste rock and tailings annual production schedule by rock type, annual valley wall erosion input, and the natural sediment inputs.

The annual waste rock production schedule is entered by waste rock types (i.e. limestone, siltstone, monzonite, monzodiorite, endoskarn, skarn, oxide porphyry and other). For the initial model runs the data provided by OTML is preliminary and is currently being updated on site.

The annual tailings production is also entered by ore types (i.e. mineralised siltstone, sulphide monzonite, sulphide monzodiorite, sulphide endoskarn, sulphide skarn, oxide porphyry, oxide skarn). Again, the data provide by OTML is preliminary and will be updated when available.

The annual valley wall erosion rates has been taken from Gary Parker's sediment model.

Module 2: Material Geochemistry

Total sulphur, ANC and NAPP data are entered for each rock type, ore type, valley wall material and natural sediments. The values used for the preliminary model are mean values based on a limited data set and are as follows.

WASTE ROCK - ROCK TYPE	%S	ANC kgH_2SO_4/t	NAPP kgH_2SO_4/t
Limestone	0	850	-850
Siltstone Waste	2	3	58
Monzonite Waste	1	39	-8.4
Monzodiorite Waste	1.4	9	34
Endo. Skarn Waste	3.4	10	94
Skarn Waste	8.9	5	267
Other Waste	2	10	51
Oxide porphyry	0.05	10	-8.5
TAILINGS ORE TYPE			
Sulphide monzonite	1	20	11
Sulphide monzodiorite	1.4	9	34
Oxide Porphyry	0.05	10	-8.5
Mineralised Siltstone	2	3	58
Sulphide Endoskarn	3.5	10	97
Sulphide skarn	4.5	5	133
Oxide Skarn	0.1	10	-7
SLIDE AND NATURAL SEDIMENTS			
Natural Sediments	0.1	80	-77
Harvey Valley Erosion	0.5	20	-4.7

These input data are considered conservative for the preliminary modelling tending towards higher NAPP values that are likely to occur. Additional test work is proposed to expand the geochemical data base and refine these input data.

Module 3: Solids, Sulphur and ANC Deposition

This input module includes an estimate of the fraction of the total annual waste rock, tailings, valley wall erosion and natural sediment load depositing in the waste rock dumps and river sections. The locations selected for modelling are as follows:

Ok Mani;
Ok Gilor/Sulphide Creek;

Upper Ok Tedi (Tabubil to Bige);
Lower Ok Tedi (Bige to D'Albertis);
Upper Fly (D'Albertis to Manda); and
Middle Fly (Manda to Obo).

The estimates entered in this module are based on the output from Gary Parker's sediment model. The values can be varied to evaluate the sensitivity of the model to different deposition patterns and post mining erosion rates.

This module also includes estimates of the fraction of the total sulphur load from rock (waste rock and valley wall erosion) and tailings depositing in each of the above sections. In addition, estimates of the fraction of the total ANC from rock, tailings and natural sediments depositing are entered.

For the initial model runs, the ANC deposition pattern is assumed to be the same as the sediment solids. For sulphur, sorting and preferential deposition is assumed to occur in the upper and middle Ok Tedi as indicated by the results of the recent sediment survey.

Module 4: Solids Deposition

This module calculates the annual deposition rates (in Mt/a) for each location from modules 1 and 3

Module 5: Sulphur Content and Load

The sulphur content for waste rock, tailings, valley wall erosion and natural sediments from Module 2 are used to calculate the annual sulphur load (tonne S). The annual sulphur deposition (in tonnes) and average sulphur content (in %S) at each location is then calculated using Module 4.

Sulphides within the reactive zone of deposited materials become less reactive with time due to the build up of various types of coatings, loss of the more reactive component and shrinking surface area of the contained sulphides. For modelling purposes an exponential decay characteristic is applied to the post mining period with a decay coefficient (k) of -0.02 with time in years.

Module 6: ANC Content and Load

The ANC content for waste rock, tailings, valley wall erosion, slide material and natural sediments from Module 2 are used to calculate the annual ANC load (tonne ANC). The annual ANC deposition (in tonnes) and the average ANC content (in kgH_2SO_4/t) at each location is then calculated using Module 4.

Module 7: Acid-Base Balance (NAPP)

This module calculates the annual average NAPP values (in kgH_2SO_4/t) for waste rock and tailings discharged from the site as well as the NAPP of material in the failings waste dumps and river deposits.

Module 8: Exposed Area

This module estimates the exposed area (in hectares) of deposited material at each location on an annual basis from 1999 to 2050. The areas have been estimated from information provided by OTML.

The exposed surface areas (in hectares) used in the model for the waste rock dumps and river deposits for the remaining years of operation are as follows:

Waste Rock Dumps	
Ok Mani:	300 ha
Ok Gilor	200 ha
Ok Tedi Deposits	
Tabubil to Bige	1,000 ha
Bige to D'Albertis	200 ha
Fly River Deposits	
D'Albertis to Manda	40 ha
Manda to Obo	20 ha

After mining and processing cease, on-going erosion will result in a progressive reduction in the exposed surface area. Figure 3 shows the estimated trend in surface area exposed on waste rock dumps and on the Ok Tedi and Fly River deposits. These surface areas have been used for the preliminary modelling. The rate of area reduction shown on Figure 3 is based on the sediment erosion rates extracted from Gary Parker's sediment transport model (Gary Parker to confirm). For modelling purposes, the sediment erosion rate is assumed to be directly proportional to the rate of reduction of the surface area exposed.

Module 9: Constant Intrinsic Oxidation Rate model (CIOR)

This module calculates the oxidation rate and sulphate generation rate (in $tSO_4/ha/year$) in deposited material. For the Ok Tedi model, 3 geochemical deposit types have been defined as follows:

- NAF: non-acid forming
- PAF–lag: potentially acid forming (i.e. NAPP positive) during the lag phase.
- PAF-acid: potentially acid forming after the lag period.

The CIOR module requires estimates of the reactive sulphur content, intrinsic oxidation rate of the material as well as an estimate of the oxygen diffusion coefficient of the deposited material. In addition, an estimate of the lag period (in years) is required.

The reactive sulphur content is assumed to be equivalent to the sulphur content predicted from Module 5. This will be revised as mineralogical data and the results of NAG tests and column leach tests become available (see Appendix A).

The intrinsic oxidation rates (IOR) is the rate the material will consume oxygen when oxygen is not limiting and is in the units of $kgO_2/m^3/s$. The assumed IOR values for each deposit type are as follows:

Non Acid Forming
IOR = 1×10^{-9} $kgO_2/m^3/s$

Potentially Acid Forming -lag
IOR = 5×10^{-8} $kgO_2/m^3/s$

Potentially Acid Forming - acid
IOR= 2×10^{-7} $kgO_2/m^3/s$

These oxidation rate are typical of similar material from other mine sites and have been used for the preliminary modelling. The IOR values will be refined when the results of the column leach test are available (see Appendix A).

The oxidation rate and sulphate generation rate (both acid sulphate and neutral sulphate) in deposited materials is very sensitive to the oxygen diffusion coefficient at the deposition environment. The diffusion coefficient is a function of the degree of saturation or moisture content. At a moisture content above about 75% of maximum saturation, the diffusion coefficient drops dramatically. The oxygen diffusion coefficient for dry soil is almost 4 orders of magnitude higher than for a saturated soil.

The depth to the water table (or depth to saturation) is also entered. This defines the maximum potential oxidation depth in the deposited material. If this depth is less than the theoretical oxidation depth predicted by the CIOR model, than the sulphate generation rate is reduced to account for the restricted depth.

For the preliminary model runs, the water content of exposed material and depth to water table for each location have been estimated and are presented in Section 4.

The CIOR model also provides an estimate of the minimum time to oxidise all the reactive sulphide in the oxidation zone.

Module 10: Sulphate, Acid and Metal Loads

This module estimates the annual total sulphate and potential acid load from exposed material in the dumps and within the Ok Tedi and Fly River. The module uses the NAPP values predicted by Module 7 to define the geochemistry of the deposit type (i.e. either NAF, PAF-lag or PAF-acid). An estimate is also required of the fraction of the exposed area (from Module 8) assigned to each material type and then the total sulphate and acid loads are calculated. The acid load is calculated from the area of PAF-acid material exposed and the total sulphate load is calculated from the areas of NAF, PAF-lag and PAF material.

The following criteria are used to estimate the fraction of the total exposed area comprising PAF material:

NAPP Value kgH_2SO_4/t	Percentage of Area comprising PAF material
Less than -100	0
-50 to -100	2
0 to -50	5
0 to 10	20
10 to 20	40
Greater than 20	80

A 5 year lag period has been used for modelling. This is likely to be conservatively short for deposited material at Ok Tedi.

This module will be expanded to estimate the total copper load released from these material types based on relationships developed between copper release and sulphate generation rates. Results from the proposed column leach test outlined in Appendix A will provide the necessary data. At this stage, no estimate of total copper released from the oxidising material is predicted.

Module 11: Alkalinity Load

This module calculates the annual alkalinity load from background water inputs based on the water quality and flow data provided by OTML.

Flow data for Ningerum, Konkonda, Kiunga, Kuambit, Manda and Obo and background alkalinity concentrations for the Ok Tedi and Fly River have been included in the model.

For preliminary model runs, the median and low flow conditions (defined as the 10th percentile flow) have been modelled. The flow and alklainity concentrations used are as follows:

Location	Median flow m^3/sec	Low Flow m^3/sec	Alkalinity $mgCaCO_3/l$
Ningerum	231	100	60
Konkonda	743	197	60
Kiunga	1200	285	80
Kuambit	2041	610	60
Manada	2351	622	60
Obo	2559	1011	60

For later probabilistic modelling, statistical distributions will be entered rather than these single values as addition data is received.

Module 12: Acidity-Alkalinity Balance and Water Quality Predictions

This module generates annual alkalinity/acidity ratios and predicts the pH and potential dissolved copper concentration at key locations in the Ok Tedi and Fly River.

Output from Modules 10 and 11 are used to calculate the alkalinity/acidity ratio. This ratio is then used to estimate the pH and potential dissolved copper concentration at various location in the Ok Tedi and Fly River.

Relationships between the alkalinity/acidity ratio, pH and dissolved copper specifically for Ok Tedi water types are not yet available. Therefore, for preliminary modelling, data from other mine sites have been used. Figures 4 and 5 show the relationships used for the alkalinity/acidity ratio verses pH and dissolved copper, respectively. These plots are from the results of mixing experiments conducted using acid drainage and river water from Bougainville in PNG. A similar test program is proposed for Ok Tedi and is outlined in Appendix A.

The power functions shown on Figures 4 and 5 are used up to an alkalinity/acidity ratio of 50. When the ratio is greater than 50, the dissolved copper concentration is assumed to be controlled by the complexing capacity of the water. For the preliminary modelling, a copper complexing capacity of 10 μg/L is assumed. For pH predictions, a maximum value of 8.5 is assumed.

Module 12: Limestone Requirement

This module calculates the limestone production required (in Mt/a) to maintain a NAF mine waste blend with sufficient excess ANC to ensure long term control of acid generation. Where the required production is less than the mine plan, an estimate for the shortfall is calculated on an annual basis.

The design target NAPP for the bulk waste rock on an annual basis is assumed to be –150 kgH_2SO_4/t. This target is based on limestone blending trials currently being conducted by EGi at another mine site using similar materials and in a similar climatic zone.

Note: the mine pit will be included in the model when final wall rock types have been defined. It is expected that the final wall rocks will comprise both limestone and PAF rock types. Therefore the pit module will produce a net acidity or alkalinity load that will be link to Modules 10 and 11. The surface area of the final pit is understood to be about 150 ha.

4.0 Preliminary Model Output

Although the model described above is not fully completed it is sufficiently developed for preliminary runs to provide output for the current risk assessment program. As indicted previously, there is a high degree of uncertainty with much of the input data and for the current simulations many of the assumptions, although realistic, are biased towards generating more negative outcomes.

The model output for median flow conditions and low flow conditions (i.e. the 10th percentile) with limestone addition and without limestone addition are presented on Table 2, 3, 4 and 5. The predictions are based on the assumptions outlined in previous sections of this report and the following in situ moisture conditions for deposited materials:

Flow Conditions and Location	Moisture content in oxidising zone m^3/m^3	Degree of Saturation in oxidising zone (%)	Depth of Potential Oxidation Zone (m)
Median Flows			
Waste Dumps	0.2	50	3
Ok Tedi Deposits	0.2	50	2
Fly River Deposits	0.3	86	0.1
Low Flows			
Waste Dumps	0.15	38	5
Ok Tedi Deposits	0.15	38	3
Fly River Deposits	0.3	75	0.3

The moisture content and degree of saturation values presented above are for the potential oxidation zone. As indicated previously, the theoretically oxidation depth is calculated in Module 9 of the model and is based on the diffusion coefficient and intrinsic oxidation rate of the deposited material. Were the potential depth is greater than the theoretical depth, the oxidation rate and acid generation rate of the deposited material are reduced in proportion to the ratio of the 2 depths.

Tables 2, 3, 4 and 5 show the predicted acid-base status, as NAPP values[1], for the mine rock (i.e. waste rock and valley wall erosion) and tailings for the period 1999 to 2009 and the predicted pH and dissolved copper concentrations at Konkonda, Kuambit, Manda and Obo.

The model runs assume the flow conditions specified apply to all years from 1999 to 2053. The low flow simulation is obviously worst case but could be relevant to an El

[1] NAPP positive indicates that the material is potentially acid forming and NAPP negative indicates that the material is non-acid forming.

Nino period. As discussed previously, variables will be entered as distributions to provide probabilistic outputs when sufficient data is available.

4.1 Acid-Base (NAPP) Trends and Recommended Limestone Addition Rate

The model output indicates that the ex-mill tailings are currently potentially acid forming (PAF) and will continue to be PAF for the remaining years of the operation. The NAPP of the tailings will range from about +34 to +67 kgH_2SO_4/t.

The mine rock (waste rock plus valley wall erosion) currently has a NAPP value of about –180 kgH_2SO_4/t and is classified as non-acid forming (NAF). However, as indicated on tables 2 to 5, the NAPP value will increase steadily from 1999 and will be positive from year 2005. The bulk waste rock from about 2005 will then be PAF. The increasing NAPP of the waste rock is due to the decreasing production of the limestone component.

Based on the waste rock production schedule used for the preliminary modelling, the recommended annual limestone requirement for the remaining years of operation required to meet the NAPP design target for waste rock are as follows:

Year	Addition Rate Mt/a
2000	0.04
2001	0
2002	0.85
2003	3.33
2004	6.16
2005	8.47
2006	7.89
2007	7.01
2008	5.55
2009	1.89

The limestone will need to be co-dumped with potentially acid forming (PAF) waste rock during each year. It will be necessary to evaluate the waste rock type production schedules for each of these years so that limestone addition can be scheduled with the PAF rock.

Without the additional limestone, it is expected that PAF material will begin to be deposited in waste rock dumps and accumulate in the Ok Tedi and Fly River deposits from about year 2003 until the end of mining at year 2009. With the additional limestone it is expected that the deposited material will be NAPP negative and therefore likely to be non-acid forming (NAF).

4.2 Predicted pH and Dissolved Cu in the Ok Tedi and Fly River

pH and the potential dissolved copper concentrations have been estimated for a number of locations in the Ok Tedi and Fly River under median and low flow conditions for the run-of-mine waste rock production schedule and with additional limestone production at the rates recommended in the previous section. The results are summarised below:

Run-of–Mine Waste Rock Production

Median flow conditions

- The pH is predicted to decrease slightly at all locations for varying periods of time. At Konkonda the minimum pH is predicted to be 7.6 at year 2013 returning to background values by year 2045. At Kuambit, Manda and Obo, the pH will only decrease slightly (about 0.5 of a pH unit) returning to background values by about 2030.

- The model predicts a current dissolved Cu concentration at all locations of 10 μg/l (equivalent to the entered Cu complexing capacity). At Konkonda, the dissolved Cu concentration is predicted to increase to between 140 to 400 μg/l during the period from 2009 to 2044. After 2044, the concentration will return to background values.

- At Kuambit, Manda and Obo, the dissolved copper concentration could increase to about 120 to 200 μg/l from 2013 returning to background values by about 2025.

Low Flow Conditions

- The model predicts that if annual low flow conditions occur for any year from 2009 to 2044 and there has been sufficient prior exposure to overcome the inherent lag period, then the dissolved Cu concentration will be a major concern at all locations within the Ok Tedi and Fly River down to Obo. At Konkonda, Kuambit and Manda low flows continue to be a concern beyond year 2053. The dissolved Cu concentrations could be greater than 1,000 μg/l at Konkonda and 500 μg/l at Obo if annual low flows occur during the years 2013 to 2020.

- Under low flows, the pH at Konkonda could decrease to a minimum of 6.8 and about 7.1 to 7.4 at the Kuambit, Manda and Obo.

With Additional Limestone Production

2 The pH at all locations will remain at background values under both median and low flow conditions.

3 The dissolved copper concentration is predicted to be controlled by the complexing capacity of the water since there is sufficient excess alkalinity to limit the solubility of dissolved copper.

5.0 Conclusion

The results of the acid drainage investigations and geochemical modelling work conducted to date indicate that it is highly unlikely that classical low pH acid drainage conditions will ever develop in the Ok Tedi or Fly Rivers. However, there is a high risk that elevated dissolved copper concentrations (significantly exceeding the complexing capacity of the water) could occur through out the Ok Tedi and downstream in the Fly if mining continues in accordance with the waste rock production schedule used in the current simulation. However, with additional production of limestone at the recommended rates and with a high level of diligence to ensure the timely co-dumping with potentially acid forming waste rock, the risk of elevated dissolved copper concentrations will be significantly reduced or eliminated. It is understood that alternate mine plans are currently being evaluated by OTML that will significantly increase the run-of -mine limestone production.

It will also be necessary to manage the production and disposal of limestone for the remaining years of the operation to ensure that sorting and preferential deposition of sulphides does not result in any significant areas of NAPP positive material in the Ok Tedi.

Overall, the findings of these preliminary investigations demonstrate that the risk of acid drainage and copper leaching from the failings waste rock dumps and river deposited materials can be minimised or eliminated by appropriate management at the mine and mill. Investigations are now commencing with the aim of refining the model predictions and developing operating specifications for managing the potential risks identified in this report.

The findings of the current investigations indicate that the ex-mill tailings will be potentially acid forming for the remaining years of the operation. This has implications for land disposal options since the tailings will need to be stored or covered in a manner that permanently isolates the contained sulphides from atmospheric oxygen or sufficient crushed limestone will need to be added to provide excess acid neutralising capacity to produce a non-acid forming blend for safe disposal. In-river disposal at Ok Tedi appears to provide both a permanent water cover in the Fly River deposits and the opportunity for mine derived limestone and natural sediments to provide the necessary acid neutralising capacity.

Modelling indicates that acid generation and copper leaching can be controlled in river deposited materials through simple management options. A similar level of geochemical security for a land based tailings disposal system in the Lower Ok Tedi will require careful planning and operational control as well as an on-going commitment to management and maintenance.

APPENDIX A

Work tasks, investigation programs and data needs

(These tasks and programs have been presented to OTML and are currently being progressed on site)

1.0 Waste Rock

4 Acid potential of waste rock

The sulphur data base within the waste zones will need to be expanded. In addition, the acid potential of waste rock types needs to be confirmed. It is recommended that blast hole samples are selected and analysed for total S. (Note: prepared samples should be split with 1 split analysed for total S at the mine and the other dispatched to the environmental laboratory for analyses of ANC and the net acid generating capacity, NAG). Where available, exploration drill hole samples should also be analysed. The rock types must be recorded for each sample tested.

5 Waste rock production schedule by rock type and sulphur grade.

Waste rock production schedules by rock type and sulphur grade are required to confirm the timing and magnitude of periods when limestone production maybe inadequate to buffer the potential acidity from the other waste rock types. The sulphur categories for the production schedule will need to be confirmed based on the statistical distribution modelled but possible categories would be:

- $<0.5\%S$,
- 0.5 to 1.0 %S,
- 1.0 to 2.0 %S,
- 2.0 to 3.0 %S,
- 3.0 to 4.0 %S,
- 4.0 to 5.0%S, and
- $>5.0\ \%S$.

6 Oxidation kinetics, lag period and copper leaching

Representative samples of waste rock types by sulphur grade will be required for leach column test work to determine the oxidation kinetics and copper leaching characteristics. The samples should represent waste rock as well as final wall rocks. Column test will be conducted on individual rock types and blends (including limestone blends). The blended test will be conducted on samples from a range of size categories to refine the blending requirement for scale up to field operations. These samples will be selected after the sulphur model and production schedule (Task 2 above) have been completed.

It is recommended that EGi assist OTML in designing, setting up and training site personnel in the operation and monitoring of the leach tests. This training would also involve procedures for performing routine ANC and NAG test and interpretation of the data.

2.0 Tailings

It is understood that the current bulk tailings contains a sulphur content of approximately 3 %S. Although most of this occurs as pyrite, some copper sulphide forms (mainly chalcopyrite) also occur. Data on the expected total and pyritic sulphide content of the tailings for the remaining years of the operation is critical for the overall geochemical assessment. The tailings at the present time are NAPP positive and NAG testing confirms the potentially acid forming (PAF) nature.

The following information is required:

- Annual ore type production schedules.
- Residual sulphur content of tailings and pyritic sulphur content from each ore type.
- Residual sulphur content of tailings and pyritic sulphur content from the main composite ore types and tailings.
- Lime consumption rate and trends.
- It is also recommended that monthly ore feed and tailings composites are analysed for total sulphur, ANC and NAG. In addition, density separation products of the tailings composites should be analysed for total S, ANC and NAG. Total S assays can be conducted at the mill with splits forwarded to the environmental laboratory for ANC and NAG determinations.

3.0 Mine Planning

Annual waste rock production schedules by rock type and sulphur grade are required. This information is required to evaluate the NAPP of the bulk waste rock production from the mine. It is understood that it may take 4 to 6 months to generate these schedules. Therefore for our preliminary work and while the geochemical data on all rock types is being confirmed, schedules which identify limestone separately from other waste rock types should be provided as soon as possible.

4.0 River Deposited samples

As discussed previously, the current assessment indicates that ROM tailings will be PAF for the remaining years of the operation. In addition, sampling within the Ok Tedi deposition areas indicates that zones of NAPP positive materials are depositing. It is therefore important to evaluate the acid base distribution across the various size fractions within these deposition areas and to confirm the acid potential (by NAG testing) to evaluate the need to control the particle size rage of limestone addition to the waste rock and/or tailings stream.

It is recommended that up to about 5 locations along the Ok Tedi are sampled and the various size fractions separated and analysed for NAPP, NAG and total copper. The sample size and size fractions required at each location will vary down river. However, it is expected that bulk samples ranging up to about 0.25 m^3 in size will be required from the upper reach of the Ok Tedi whereas in the lower Ok Tedi the sample size may only need to be about 20 litres (depending on the size distribution).

The main purpose of this sampling is to identify the acid-base (i.e. the sulphur and ANC) distribution across size fractions. This will assist in defining the limestone size fraction required to deposit with the sulphides within the river system. The strategy will be to collect samples from across the various deposition environments on point bars and river bank deposits and prepare composite samples for size fractionation back at Tabubil. Assistance will be required from OTML geology personnel in designing and carrying out this sampling program. If possible, the program should extend into the Ok Mani dump area.

The size fractions to be analysed will vary down river but possible ranges are as follows:

>40 mm (the effective surface area of particles greater than 40 mm will be negligible)
20 to 40 mm
10 to 20 mm
5 to 10 mm
2 to 5 mm
<2 mm

Bulk samples of some size fractions from selected locations will be included in the column leach test program that will be set up on site. EGi will assist OTML in setting up these columns to follow procedures already established at EGi.

5.0 Copper Solubility in Ok Tedi and Fly River water

The column leach test outlined in the items above will provide data on the copper load leached from different material types and the relationship between the acid generation rate and copper leaching rate. Within the Ok Tedi and Fly River, water quality monitoring and preliminary modelling indicates that a substantial alkalinity load also enters the rivers from background catchments including the Fly River upstream of D'Albertis junction. As indicated previously, the alkalinity/acidity balance will determine the dissolved copper carrying capacity of the river water. Hence the balance between any acid and copper load from oxidising deposits in the Ok Mani, Ok Gilor and Ok Tedi and the total alkalinity inputs is an important consideration.

The preliminary model uses relationships between the alkalinity/acidity ratio and pH and dissolved copper that have been developed for other sites. There are differences between sites depending on the overall water chemistry and therefore it is necessary to determine these relationships specifically for acid drainage from the pit and river water from the Ok Tedi and Fly River.

EGi will prepared a detailed test protocol and assist OTML in carrying out this work on site. The program simply involves collecting acid drainage from the mine pit and mixing this at set ratios with water collected from the Ok Tedi and Fly rivers. The water source samples and mixed samples are analysed for a range of parameters including acidity, alkalinity, pH and dissolved Cu, SO_4, Ca, Mg, Al, Zn and Fe.