Orebodies 29, 30 and 35: Preliminary Acid and Metalliferous Drainage Risk Assessment

Report Prepared for

BHP Billiton Iron Ore

Report Prepared by

srk consulting

SRK Consulting (Australasia) Pty Ltd

BHP107

August 2013

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Executive Summary

Orebodies 29, 30 and 35 (OB29/30/35) are satellite projects located on the southern side of the BHP Billiton Iron Ore (BHPBIO) Mt Whaleback mining operation, west of Newman, WA. Iron ore produced from OB29/30/35 forms the main Marra Mamba feed to the Newman Joint Venture blend. Mining is by conventional open cut method.

This report presents a preliminary acid and metalliferous drainage (AMD) risk assessment for OB29/30/35 and includes current and proposed mining operations.

The propensity for mined materials to generate acid is a balance between their acid forming (e.g. sulfides) and acid neutralising constituent minerals (e.g. carbonates). This balance can be determined quantitatively using acid base accounting (ABA) methods. Materials are classified as potentially acid forming (PAF) when the acid forming potential (AP) is greater than the neutralising potential (NP). Acid and metalliferous drainage (AMD) is the term used collectively to describe drainage that combine attributes such as an acidic pH (below pH 4.5) or high concentrations of dissolved metals and sulfate.

The preliminary AMD assessment incorporated information supplied by BHPBIO including chemical analyses, geological and mine planning information, surface water and groundwater investigations and ecological studies. The mined lithologies, present above and below the water table, were separated into waste and ore volumes by the relevant orebody cut-off criteria, and assessed in terms of their potential to generate acid using sulfur thresholds values of 0.2% (in line with the current BHPBIO criteria for PAF classification) and a more conservative threshold of 0.1% (in recognition of the limited nature of geochemical data currently available for OB29, 30 and 35).

The preliminary AMD assessment has identified the potential presence of some PAF material within mined volumes for OB29, 30 and 35. However, the majority of materials have a low to negligible potential to generate acidic conditions, supporting current BHPBIO management strategies. In the case of ore grade materials, the proportion of PAF rock was very low, with less than 2% of the volume containing sulfur values in excess of 0.1 %. Based on the low volumetric proportion of PAF materials, combined with the short residence times within stockpiles, the ore materials are considered to represent a low to negligible risk of AMD.

Within the overburden, the estimated proportion of PAF classed materials was around 5% for OB35 and 11% for OB29 using a 0.1 % sulfur threshold. (Assessment of the proportion of PAF material within the mined volume of OB30 was outside the scope of this study as the overburden will be managed within the Mt Whaleback operation). The form in which the sulfur is present is not known, and since some of the sulfur may be present as sulfate, it is likely that the acid potential inferred from total sulfur has been overestimated.

The lithological units with the highest proportions of PAF classified materials comprised the:

- Detrital, Paraburdoo Member (Wittenoom Formation) (PBD), West Angela Member – A1 (Shale waste) (Wittenoom Formation) (WA1) and West Angela Member – A2 (Wittenoom Formation) (WA2) units at OB29; and
- Marra Mamba Iron Formation, MacLeod Member (MM) and Marra Mamba Iron Formation, Nammuldi Member (MU) units at OB35.

Most of the other lithological units contained only a small number of sulfur analyses in excess of the 0.1% threshold; usually outliers representing between 1 and 5% of the assays.

In general, material mined from below the water table was found to contain less sulfur than the equivalent materials from above the water table.

A source-pathway-receptor risk assessment was completed to assess the magnitude of potential contaminant loading represented by each source (OSAs, stockpiles, exposed pit walls, pit lakes) via potential contaminant transport pathways (surface water, groundwater) to the identified potential environmental receptors (including surface water bodies, groundwater, and ecology).

The potential for AMD from the OSAs is considered to be low, but cannot be discounted. Similarly, the potential for AMD in pit wall runoff is considered to be low. The overall proportion of high sulfur material exposed on the pit walls is low (less than 5%). It is however, noted that the sulfur-bearing materials form isolated ‘hot-spots’, generally located near the crest of the pit walls. As these locations lie above the expected level of the final pit lake, it is possible they could represent a source of ongoing solute release in pit wall runoff.

The overall potential for AMD from the OSAs and pit walls however cannot be quantified accurately without additional geochemical assessments. Similarly it has not been possible to assess the potential for saline drainage from the materials. It is likely that soluble salts are present, particularly in materials mined from near-surface, which could leach readily resulting in short-term pulses of salinity in contact waters.

Potential pathways comprising surface and groundwater flow paths, and receptors for AMD from OB29/30/35 have been identified; however, impacts on receptors were difficult to quantify based on available information.

Pits remaining as open voids post closure would act as groundwater sinks and would capture some seepage and runoff from the OSAs. Under this scenario, although the pit lake would be anticipated to salinise over time due to evapo-concentration, the risk of any impacts on the key environmental receptors is considered negligible.

Pits partially backfilled to above the regional groundwater table, or completely backfilled, would allow the regional groundwater flow would to be re-established and flows would pass through the backfill. Solutes contained in the backfill would be released to the groundwater and ongoing solute loadings may occur from the waste above the water table and the wall rocks. Whilst BHPBIO is currently only considering the placement of NAF as backfill, the risk of impacts on groundwater quality would depend on the specific properties of the materials backfilled. Partial backfilling to below the predicted long term steady state lake elevation would result in an indefinite groundwater sink and the risk of any impacts on the key environmental receptors would be considered negligible.

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Disclaimer

The opinions expressed in this Report have been based on the information supplied to SRK Consulting (Australasia) Pty Ltd (SRK) by BHP Billiton Iron Ore (BHPBIO). The opinions in this Report are provided in response to a specific request from BHPBIO to do so. SRK has exercised all due care in reviewing the supplied information. Whilst SRK has compared key supplied data with expected values, the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information and does not accept any consequential liability arising from commercial decisions or actions resulting from them. Opinions presented in this Report apply to the site conditions and features as they existed at the time of SRK's investigations, and those reasonably foreseeable. These opinions do not necessarily apply to conditions and features that may arise after the date of this Report, about which SRK had no prior knowledge nor had the opportunity to evaluate.

List of Abbreviations

Abbreviation	Meaning
Acid-base account (ABA)	An Acid Base Account (ABA) calculates the balance between acid generation processes (oxidation of sulfide minerals) and acid neutralising processes. It involves determination of the maximum potential acidity (MPA) and the inherent acid neutralising capacity (ANC), both defined below.
Acid drainage	A form of Acid and Metalliferous Drainage (AMD), characterised by low pH, elevated toxic metal concentrations, high sulfate concentrations and high salinity.
Acidity	A measure of hydrogen ion (H+) concentration and mineral (latent) A measure of hydrogen ion (H+) concentration and mineral (latent) acidity; generally expressed as mg/L CaCO3 equivalent. Measured by titration in a laboratory or estimated from pH and water quality data.
AER	Annual Environmental Report
Alkalinity	A measure of the capacity of a solution to neutralise an acid.
AMD	Acid Mine Drainage or Acid and Metalliferous Drainage also known as Acid Rock Drainage (ARD) or Acid Mine Drainage.
ANZECC	Australian and New Zealand Environment Conservation Council
AP	Acidification Potential, calculated from sulfide-sulfur content
ARD	Acid Rock Drainage
Ave	average
AWT	Above water table
BHPBIO	BHP Billiton Iron Ore
BIF	Banded Iron Formation
BOM	Bureau of Meteorology
BWT	Below water table
cm	centimetre(s)
DEC	Department of Environment and Conservation
Detritals	Tertiary Detritals
DITR	Department of Industry Tourism and Resources
EC	Electrical Conductivity
EPA	Environmental Protection Authority
GARD	Global and Metalliferous Drainage (Guide)
H_2SO_4/t	sulfuric acid per metric ton
INAP	International Network of Acid Prevention
kg	kilogram(s)
kg H_2SO_4/t	kilogram(s) of sulfuric acid per ton
kL/day	Kilolitre(s) per day
km	Kilometre(s)
L	litre(s)
LOI	Loss On Ignition
LOM	Life of Mine

Abbreviation	Meaning
m	Metre(s)
m^2	Metre(s) squared (area)
m^2/d	Metre(s) squared per day
Max	maximum
MEND	Mine Environmental Neutral Drainage (Program)
meq/L	Milli-equivalents per litre
Metalliferous Drainage	Mine drainage with elevated heavy metal concentrations, high sulfate salinity.
mg	milligram(s)
mg/L	milligram(s) per litre
Min	minimum
ML	Metal Leaching
ml	millilitre(s)
MM	Marra Mamba Iron Formation, MacLeod Member
MMIF	Marra Mamba Iron Formation
mRL	Metres above reference level
Mt (text)	Mount
Mt (units)	Mega tonne
MU	Marra Mamba Iron Formation, Nammuldi Member
n	Number of samples
N1	Marra Mamba Iron Formation, Mount Newman Member
N2	Marra Mamba Iron Formation, Mount Newman Member, N2 (Shale bearing)
N3	Marra Mamba Iron Formation, Mount Newman Member, N3
Na	Sodium
NAF	Non-acid forming waste is unlikely to generate acid. NAF waste is designated as having a NPR > 4.
NE	North east
NJV	Newman Joint Venture
NP	Neutralisation Potential
NPR	Neutralisation Potential Ratio
OB	Orebody
OB29	Orebody 29
OB30	Orebody 30
OB35	Orebody 35
OSA	Overburden Storage Area
P1	Priority 1 (Drinking water source protection zone)
P3	Priority 3 (Drinking water source protection zone)
PAF	Potentially acid forming waste is likely to generate acid. PAF waste is designated as having a NPR > 1 and < 1.5.
PBD	Paraburdoo Member (Wittenoom Formation)

Abbreviation	Meaning
pers. comm.	Personal communication
QA	Quality Assurance
QC	Quality Control
SE	South east
SRK	SRK Consulting (Australasia) Pty Ltd.
T	Tertiary Detritals
TD1	Tertiary Detritals 1
TD2	Tertiary Detritals 2
TD3	Tertiary Detritals 3
TDS	Total Dissolved Solids
TEC	Threatened Ecological Community
TS	Total Sulfur
TSS	Total Suspended Solids
UC	Uncertain acid forming potential
μg	microgram(s)
μS	Micro-Siemen(s)
μS/cm	Micro-Siemen(s) per centimetre
WA	Western Australia
WA1	West Angela Member – A1 (Shale waste) (Wittenoom Formation)
WA2	West Angela Member – A2 (Wittenoom Formation)
WT	Water table

1 Introduction

1.1 Project Background

Orebodies 29, 30 and 35 (OB29/30/35) are satellite projects located on the southern side of the BHPBIO Mt Whaleback mining operation (Figure 1). Ore produced from OB29/30/35 forms the main Marra Mamba iron ore feed to the Newman Joint Venture blend. The mining methods employed are conventional open cut.

The Mt Whaleback Deposit occurs in a faulted outlier of the Brockman Iron Formation. The general stratigraphic sequence encountered at OB29/30/35 comprises older Jeerinah Formation, overlain by the Marra Mamba Iron Formation (ore host) and then the Wittenoom Formation. Tertiary detrital units lie unconformably over the bedrock.

Development of the Marra Mamba (goethite-hematite) resource at OB29 began in 1974. Ore was originally sold as a direct shipping product and as a blend with Mt Whaleback fines (BHP Billiton, 2012). Approval for above water table mining at OB30 and OB35 was granted in 1999. Mining commenced at OB30 in November 1999 and at OB35 in October 2000.

BHPBIO proposes to proceed with operations, including mining below the water table, at OB29/30/35 and is currently preparing documentation for the projects, pursuant to gaining mining and environmental approvals.

1.2 Scope of Work

BHPBIO commissioned SRK Consulting (SRK) to prepare a preliminary acid and metalliferous drainage (AMD) risk assessment for OB29/30/35 which was to include current and proposed mining operations. Current operations include above water table mining at OB29 and OB30 only. The AMD risk assessment was requested to comply with relevant Australian and International guidelines, including:

- Managing Acid and Metalliferous Drainage, February 2007, developed by the Australian Government, Department of Industry Tourism and Resource;
- The Global Acid and Metalliferous Drainage (GARD) Guide, May 2012, developed by the International Network of Acid Prevention (INAP); and
- The Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand 2000, Australian Water Guidelines for Fresh and Marine Waters and its updates.

The primary objectives of this preliminary AMD risk assessment are to:

- Review available information to determine the risk of AMD generation by the materials that have been mined, or are to be mined;
- Provide a desktop assessment based on a source-pathway-receptor model; and
- Identify potential risk associated with mining activities, mine waste and pit void management and impacts on potential environmental receptors.

The scope of the required work programme does not include the Mt Whaleback mining operation or wastes, or the waste material generated from OB30, which will be accommodated at Mt Whaleback in Overburden Storage Area (OSA) W13.

This AMD risk assessment is intended to provide information in support of the environmental approvals process for mining at OB29/30/35.

1.3 Report Structure

The report comprises an introductory section (Section 1) which outlines the OB29/30/35 project background and the scope of work for this Preliminary AMD Risk Assessment. A summary of the OB29/30/35 environmental setting is detailed in Section 2, which incorporates a review of existing information collates all data relevant to the Source-Pathway-Receptor (S-P-R) analysis given in Section 4. The assessment of acid and metalliferous drainage potential from materials to be mined at OB29/30/35 is presented in Section 3, with a subsequent preliminary risk evaluation (incorporating the S-P-R analysis) (Section 4) and conclusions (Section 5).

2 Background

2.1 Climate

The East Pilbara region has an arid climate characterised by hot summers with periodic heavy rain and mild winters with occasional rain. The region experiences highly variable rainfall, with tropical cyclones predominantly occurring between January and March which bring sporadic high rainfall tropical storms from the north.

The annual average rainfall recorded between 1965 and 2003 at the Newman weather station is 310.2 mm (BOM, 2013). Newman experiences high variability in recorded annual rainfall, with a maximum of 537.8 mm (1997), and a minimum of 135.2 mm (1976), recorded between 1965 and 2003.

The average monthly rainfall and evaporation rates for the Newman Airport weather station are shown in Table 2-1.

Table 2-1: Average Monthly Precipitation and Evaporation

Average Rainfall / Evaporation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Rainfall (mm)	57.3	78.8	40.3	19.9	18.1	14.2	14.9	8.0	4.6	4.9	10.3	37.6
Evaporation (mm)	461	369	343	290	174	173	199	193	264	377	424	466

Notes: Averages measured at Newman Airport weather station as cited as (BOM, 2011) - RPS Aquaterra, *Orebody 35: Surface Water Impact Assessment*, 2011, (page 2, Table 2.1)

2.2 Geological Setting

The Mt Whaleback Deposit occurs in a faulted outlier of the Brockman Iron Formation. The general stratigraphic sequence encountered at OB29/30/35 comprises older Jeerinah Formation, overlain by the Marra Mamba Iron Formation and then the Wittenoom Formation. Tertiary detrital units lie unconformably over the bedrock.

The orebodies are hosted predominantly in the upper members of the Marra Mamba Iron Formation, with some mineralisation occurring in the lower Marra Mamba (Nammuldi Member) and the overlying West Angela Member of the Wittenoom Formation. The overlying detritals, where present, may also be mineralised.

OB29

OB29 is located within a large northwest plunging open syncline resulting in the existing pit having a horse shoe shape. The orebody is predominantly located in the Marra Mamba Iron Formation and is underlain by the Jeerinah Formation of the Fortescue Group (which outcrops to the immediate east and south of the deposit). The stratigraphically younger Brockman Iron Formation (which is mined in the Mt Whaleback Pit) outcrops to the north and northwest of OB29. The Paraburdoo Member of the Wittenoom Formation is also present within the proposed pit shell.

OB30

OB30 is located to the west of OB29, on the steeply dipping southern limb of the Whaleback South Syncline. Strata are overturned and are generally dipping at approximately 50° to the south.

The general stratigraphic sequence intersected in the area consists of the older Jeerinah Formation (Fortescue group) overlain by the younger Marra Mamba Iron Formation, in turn overlain by the

Wittenoom Formation.

The Wittenoom Formation occurs immediately to the north of the current mine pit, including the ‘Wittenoom Dolomite’ which is interpreted to be the Paraburdoo Member of the Wittenoom Formation. The Mount Sylvia and Mount McRae Formations outcrop further to the north, in the southern wall of the Mt Whaleback Pit. Lower members of the Marra Mamba Iron Formation (MacLeod and Nammuldi) and the Jeerinah Formation outcrop to the south of the OB30 pit.

OB35

OB35 is located approximately 1km to the south of OB30 and is situated in the next (structurally higher) syncline from OB30, and is part of the Western Ridge Syncline (Kneeshaw, 2008).

The strata present at OB35, from youngest to oldest are:

- Paraburdoo Member (Wittenoom Formation);
- West Angela Member (Wittenoom Formation);
- Mount Newman Member (MMIF);
- MacLeod Member (MMIF);
- Dolerite sill (Jeerinah Formation); and
- Nammuldi Member (Marra Mamba Iron Formation, MMIF).

Thrust faulting is a predominant feature in the centre and west of the deposit. A dolerite dyke is present in the east of the deposit, exclusively intrudes the Nammuldi Member, and is interpreted as being younger than the Nammuldi Member, but older than the MacLeod Member.

Tertiary detrital units lie unconformably over the bedrock, and are subdivided as TD1, TD2 and TD3. The detritals occur predominantly in the western part of the project area and along the valley present between two ridges (trending NW-SE) overlying the eastern part of the deposit.

Geological cross-sections of OB29, OB30 and OB35 are presented in the RPS Aquaterra *Preliminary Hydrogeological Review OB29, OB30 and OB35* (2012).

2.3 Hydrogeological Setting

2.3.1 Regional Hydrogeology

Three major aquifer groups have been identified in the Central Pilbara (Water and Rivers Commission, 2001). These include unconsolidated sedimentary aquifers (alluvium and colluvium valley fill), chemically-deposited aquifers (calcrete and pisolitic limonite) and fractured-rock aquifers (dolomite and banded iron-formation (BIF)).

Orebodies 29, 30 & 35 (and Mt Whaleback) are located within the Hamersley (Fractured Rock) Aquifer (Western Australia Department of Water, Hydrogeological Atlas), within the Precambrian rocks of the Hamersley basin, principally comprising volcanics, shales and iron formation (Forrest and Coleman, 1996).

Groundwater within fractured rock aquifers occurs where secondary porosity has developed in fractured and weathered zones or along bedding plane partings or joints. The Hamersley Fractured Rock Aquifer is an unconfined aquifer comprising three main aquifer bearing lithologies – Banded Iron Formation (BIF), dolomite and sandstone.

BIF aquifers exist in the Brockman and Marra Mamba Iron Formations, and permeability is typically associated with fractures and ore mineralisation, or locally (i.e. local aquifers), within weathered and fractured chert within the BIF (AGC Woodward-Clyde, 1997b - Water and Rivers Commission, 2001). BIF aquifers are not considered regional aquifers although they do have potential as local aquifers.

Dolomitic aquifers in the Wittenoom Formation are the primary groundwater supply target for mining (and town) water supplies in the Central Pilbara (Water and Rivers Commission, 2001). The Wittenoom Formation is an extensive carbonate, shale and minor epiclastic unit that overlies the Marra Mamba Iron Formation, and has some hydraulic continuity with the overlying sedimentary units. Aquifers within the Wittenoom Formation are present within the calcrete and underlying sands and gravel, which are generally separated by a sequence of clays that act as aquitards. Fractured or cavernous dolomitic zones may extend to a depth of 100m in the Central Pilbara. Borehole yields are variable (up to 1600 kL/day), with higher yields typically in the valley centres (where the dolomite is more fractured and cavern dense) and to a lesser degree near valley sides (where dolomite is more massive). There is potential for each of the orebodies to be in hydraulic connection with permeable dolomite of the Wittenoom Formation (RPS Aquaterra, 2013).

2.3.2 Orebody Hydrogeology

The Marra Mamba orebodies are typically permeable and are likely to form localised aquifers where situated below the water table. Sub-grade Marra Mamba, West Angela (stratigraphically higher) and Jeerinah (stratigraphically lower) typically have a much lower permeability.

As highlighted in previous hydrogeological assessments (RPS Aquaterra, 2012) the Paraburdoo Member (Wittenoom Formation), along with saturated alluvium and detritals in the Whaleback Creek valley, have the potential to be local aquifers, hydraulically connected to the orebody aquifers. Based on more recent mine planning information (i.e. the projected materials to be mined as detailed in this assessment) the Paraburdoo Formation is expected to be mined at all three orebodies, however it is considered unlikely that karstic aquifer conditions will be encountered, rather the formation is likely to comprise tight crystalline basement (BHPBIO, pers. comm. 2013).

Ore moisture content investigations were undertaken at OB29 (Aquaterra, 2009) and the assessed hydrogeological properties are summarised in Table 2-2. It was noted in this investigation that thin bands/layers have higher silt/clay fractions and lower permeability, causing heterogeneous vertical permeability (however, this effect may be reduced on larger scale pit dewatering compared to single bore scale study).

Table 2-2: Hydrogeological parameters for Marra Mamba (OB29)

Parameter	Minimum Value	Maximum Value
Transmissivity (m^2/d)	77	88
Storativity	6.3×10^{-5}	1.5×10^{-3}
Specific Yield (%)	4 (ave. = 5)	15

Note: Taken from the Aquaterra, 2009 – Orebody 29 Moisture Content Investigation, 740/OB29/600/504a

The degree of inter-orebody connectivity has not yet been determined; however, the hydraulic connection between the OB29/30/35 and the Whaleback Pit (via the Mt Sylvia and Mt McRae Shale Formations) is considered to be limited. This is corroborated by minimal drawdown effects being experienced in the vicinity of OB29/30/35 in response to the Whaleback pit dewatering to date.

The geology of the OB29/30/35 area is known to be structurally complex and there is potential for connectivity along zones of secondary permeability (faults and fractures), through stratigraphic units which are known to be of lower permeability (e.g. the Macleod and Nammuldi Members of the Marra Mamba Formation).

Groundwater flow is described as generally mimicking the direction of surface water flow (Department of Water, 2009), and locally to OB29, 30 and 35 as occurring from south and west towards the north and east (RPS Aquaterra, 2013).

Groundwater analyses were undertaken on groundwater samples collected from three bores at OB29, screening the Marra Mamba Iron Formation. The results are shown in Table 2-3.

Table 2-3: Groundwater chemistry from boreholes at OB29 screening Marra Mamba

Sample Date	**Units**	**8-Mar-13**	**11-Apr-13**	**30-Apr-13**
Borehole		**HWHB0051**	**HWHB0052**	**HWHB0057**
pH	-	8.1	8.3	8.1
Conductivity	µS/cm	960	920	760
TDS	mg/L	580	550	460
Total Alkalinity as $CaCO_3$	mg/L	360	310	260
Bicarbonate Alkalinity as HCO_3	mg/L	440	380	320
Carbonate Alkalinity as CO_3	mg/L	<1	<1	<1
Chloride	mg/L	77	85	74
Sulfate	mg/L	61	65	38
Nitrate	mg/L	0.08	<0.05	1.1
Calcium	mg/L	61	53	46
Iron	mg/L	0.18	0.03	<0.02
Magnesium	mg/L	61	49	42
Potassium	mg/L	5	4.2	4.9
Sodium	mg/L	66	64	44
Anion-Cation Balance	%	2	-2	-2
Sum of Anion Milliequivalents	meq/L	11	10	8
Sum of Cation Milliequivalent	meq/L	11	10	8
Sum of Ions	mg/L	691	630	513

It is anticipated that OB29, 30 and 35 respectively will be mined to approximately 110 m, 80 m and 25 m below the water table. This approximates to depths of 420 mRL (OB29), 450 mRL (OB30) and 505 mRL (OB35), assuming a pre-mining water level in the range 525-535 mRL.

2.4 Hydrology and Surface Water Management

The Pilbara region is typically subjected to localised thunderstorm and cyclonic rainfall events, generally occurring during the period of December to April, which can generate large runoff events during which watercourses in the area are generally flowing. From May to November, rainfall is relatively low and significant runoff events are uncommon.

The OB29, 30 and 35 orebodies, along with Mt Whaleback, are located within the Whaleback Creek catchment area (Figure 2). Whaleback Creek flows in an easterly direction, between Mt Whaleback and the orebodies to the south, until it turns northeast and flows into the Fortescue River upstream of Ophthalmia Dam. Whaleback Creek is ephemeral, and typically has between one to three short-lived flow events per year.

2.4.1 OB29 Hydrology

Surface water studies identified that owing to its higher elevation, OB29 should not be subjected to flooding from Whaleback Creek. The catchment area directly intercepted by the mine workings and associated runoff volume are not considered significant (Aquaterra, 2006). Two small runoff flowpaths were identified to drain into the southwest area of the site, although these appear to be dammed by the existing OSAs (Figure 3). Two additional drainage lines were identified to drain in a southwest direction, and were assessed to require bunding to prevent water from entering the pit.

2.4.2 OB30 Hydrology

Whaleback Creek flows approximately 40 to 50 m south of OB30, leaving the pit potentially exposed to inundation during a large flood. An initial phase of flood protection bunding between the pit and Whaleback Creek was constructed, with further pit flood defences assessed to be required as a result of expansion of the pit and downstream stockyard areas (Aquaterra, 2005) (Figure 4). More recently, as part of the NJV Hub works, a diversion of the Whaleback Creek has been constructed at the eastern end of the Orebody 30 pit and a revised flood protection bund has been designed (BHP Billiton, 2009).

2.4.3 OB35 Hydrology

OB35 is located to the south of the Whaleback Creek, and the proposed pit development intercepts a tributary referred to as Southern Creek, which flows from south to north. The Southern Creek currently cuts across the locations of the proposed OB35 pit, the OB35 OSA and the topsoil stockpile (Figure 5). A diversion of the Southern Creek is proposed around the western edge of the OB35 pit development, discharging into Whaleback Creek approximately 1.1 km upstream of the existing confluence (Figure 6) (RPS Aquaterra, 2011).

Bunding has also been proposed around the perimeter of the OB35 OSA, located to the north of the pit, adjacent to Whaleback Creek. The bunding has been designed to capture internal runoff and divert external runoff, with sediment basins to be installed at low points along the perimeter to treat the internal runoff prior to discharge to the natural drainage systems. Sump pumping is proposed to be used to remove internal and external stormwater runoff that would collect at the OB35 pit base (RPS Aquaterra, 2011).

2.4.4 Surface Water Quality

Surface water quality collected from two monitoring sites in the vicinity of Mt Whaleback area are summarised in Table 2-4 and provided in full in Appendix A. BHPBIO has advised that these surface water monitoring sites, WBSW042 (Whaleback Creek – upstream of the greater Whaleback site) and WBSW043 (Whaleback Creek – downstream of Power Station) are considered representative of general surface water conditions for OB29/30/35.

Table 2-4: Surface water chemistry

Location	**Units**	**Whaleback Creek (upstream)**			**Whaleback Creek downstream of Power Station**			**ANZECC Freshwater Trigger Levels (95%)**
Site No.		**WBSW042**			**WBSW043**			
Sample Count		2			7			
		Min	**Ave**	**Max**	**Min**	**Ave**	**Max**	
pH		7.22	7.48	7.74	7.23	7.48	7.83	-
EC	uS/cm	104	169	234	30	177	407	-
TDS	mg/L	95	144	192	34	124	245	-
TSS	mg/L	29	675	1320	4	143	620	-
SO_4	mg/L	2	3	4	6	28	70	-
Na	mg/L	5	6	6	2	11	24	-
K	mg/L	4	4	4	2	4	7	-
Ca	mg/L	8	21	33	3	12	25	-
Mg	mg/L	4	7	9	2	6	12	-
Fe	mg/L	0.06	0.65	1.23	0.05	0.18	0.37	-

Location	**Units**	**Whaleback Creek (upstream)**			**Whaleback Creek downstream of Power Station**			**ANZECC Freshwater Trigger Levels (95%)**
Site No.		**WBSW042**			**WBSW043**			
Sample Count		2			7			
		Min	**Ave**	**Max**	**Min**	**Ave**	**Max**	
Mn	mg/L	0.001	0.641	1.280	0.001	0.002	0.008	1.9
Zn	mg/L	<0.005	<0.005	<0.005	<0.005	0.053	0.34	0.008
Cu	mg/L	<0.001	0.0013	0.002	<0.001	0.002	0.004	0.0014
Al	mg/L	0.02	0.03	0.04	<0.01	0.13	0.34	0.055[a]
Cd	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
Pb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0034
As	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.024[b] 0.013[c]
Hg	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0006[d]
Cr	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001[e]
Mo	mg/L	<0.001	<0.001	<0.001	<0.001	0.001	0.002	-

Notes: Surface water analyses results from the BHP Billiton Annual Environmental Report Mt Whaleback, OB29, 30 and 35 (July 2011-June 2012).

[a] Aluminium trigger if pH > 6.5; [b] Arsenic trigger for As (III); [c] Arsenic trigger for As (V); [d] Mercury trigger for inorganic Hg; and [e] Chromium trigger for Cr (VI).

Upon screening the available surface water quality data, one copper analysis result (0.002 mg/L) from the upstream monitoring location (WBSW042) was identified as exceeding the ANZECC Freshwater Trigger (95%) guideline value. At the downstream monitoring location (WBSW043), one zinc (0.34 mg/L) and three copper (0.003-0.004 mg/L) results were higher than the Freshwater 95% Trigger guideline values.

2.5 Environmental Receptors

A clear understanding of the environmental receptors is required in order to support a Source-Pathway-Receptor assessment. This section therefore incorporates a review of existing information and collates all data relevant to the description of the receptors in the receiving environment.

2.5.1 Key Environmental Receptors

Two key environmental receptors have been identified within the Newman / Whaleback area (Figure 1), Cathedral Gorge and Ethel Gorge (RPS Aquaterra, 2013).

Cathedral Gorge, located approximately 12 km to the northwest of OB30 (Figure 1) is an environmental receptor on the basis of its surface water pools and associated vegetation.

Ethel Gorge, located approximately 19 km to the northeast of OB29 (Figure 1) is a regional outflow zone for the upper reaches of the Fortescue Rive Catchment. The Homestead, Whaleback, Shovellanna and Warrawanda Creeks all converge with the Fortescue River upstream of Ethel Gorge. A stygofauna community has been identified in the Ethel Gorge area, with an expected habitat related to the saturated shallow calcretes and gravels of an extensive Tertiary overburden sequence (RPS Aquaterra, 2013).

2.5.2 Flora and Fauna

No Priority Flora or Declared Rare Fauna have been identified within the OB29/30/35 area. The nearest Threatened Ecological Community (TEC) is the Ethel Gorge Aquifer Stygobiont Community located approximately 18 km north east of OB29 on the Fortescue River (Figure 7).

Groundwater Dependant Vegetation

Assessment of groundwater dependant vegetation (GDV) in the vicinity of OB29/30/35 concluded that the predicted drawdown of the water table was unlikely to have an impact on native vegetation (Onshore Environmental, 2013), as the majority of vegetation in this area has no interaction with groundwater. The assessment highlighted that vegetation associations, found along the main drainage line, previously defined as being at moderate risk from groundwater drawdown, are not considered to be groundwater dependant based on the current water table level (RPS Aquaterra, 2013).

Marginal increases in surface water salinity resulting from excess water discharges are not anticipated to have a significant impact on the vegetation in the Ethel Gorge area (RPS 2013).

Stygofauna

Stygofauna generally inhabit groundwater habitats with substantial fissures or voids, which in the vicinity of the area of study includes saturated Tertiary alluvium, along with orebody, dolomite and fractured rock aquifers. A stygofauna assessment of the study area (Bennelongia, 2013) concluded that the proposed dewatering at OB29, 30 and 35 does not pose a significant threat to the conservation status of the stygofauna species within the potential drawdown zone of influence.

The nearest TEC to the study sites is the Ethel Gorge Aquifer Stygobiont Community, which has been classified as a TEC B (ii) community. This classification is based on the community being of "*limited distribution, with few occurrences, each of which is small and/or isolated and all or most occurrences are very vulnerable to known threatening processes"* (DEC, 2010). The community is located at Ethel Gorge, approximately 18.5 km to the north east of OB29 (Figure 7).

The potential increase in groundwater salinity downstream of the Ophthalmia Dam (as a result of periodic discharges of excess dewater from OB29/30/35 to Ophthalmia Dam) is not anticipated to have a significant impact on the stygofauna communities in the Ethel Gorge area (RPS Aquaterra, 2013).

2.5.3 Water Supply and Drinking Water Source Protection

The Ophthalmia Borefield, located approximately 15km to the east of the study area, provides potable quality water to Newman and the nearby mining operations. The borefield abstracts groundwater from alluvial and chemical sediments that have in-filled paleovalleys associated with the Fortescue River and its tributaries. Some of the bores within the Ophthalmia Borefield also draw water from the Wittenoom Formation (Department of Water, 2009).

Groundwater recharge in the vicinity of Newman occurs mostly by leakage from stream beds during runoff and to a lesser extent by direct infiltration of rain over the surface. The potable water supply bores are drawing from a superficial aquifer system, and therefore the water quality and quantity is heavily influenced by the quality and quantity of surface water.

The surface water catchment of Whaleback Creek contributes a significant proportion of the recharge of the superficial aquifer from which the Ophthalmia Borefield draws water (Department of Water, 2009).

The Ophthalmia Dam is located on the Fortescue River and was installed to capture surface water runoff for subsequent slow release to replenish the downstream aquifers which support the

Ophthalmia Borefield. An aquifer recharge system has been constructed below the dam, comprising four excavated recharge ponds, two river basin and an open-earth canal, which can be flooded as required from the dam. The aquifer recharge scheme can be activated if monitoring data indicates that groundwater abstracted from the Ophthalmia Borefield is projected to exceed the sustainable yield of the aquifer (Department of Water, 2009).

The Newman Water Reserve, covering an area of 840 km^2, was proclaimed in 1983 under the Country Areas Water Supply Act 1947 (WA) for public drinking water source protection.

All Crown land (with the exception of the land within the gazetted town site) in the Newman Water Reserve is classified as Priority 1 (P1), which are areas defined as having the fundamental water quality objective of risk avoidance (the most stringent of the P1-P3 risk-based classifications).

BHPBIO owns and operates the water supply headworks at the Ophthalmia Borefield, and treats dewatering supply which is provided to the Water Corporation, subsequently reticulating the water to the town of Newman.

2.6 Mine Planning

2.6.1 OB29

The proposed pit shell covers an area of approximately 173.5 ha, and is proposed to be mined to a depth of 435 mRL, approximately 110 m below the pre-mining water table. The OB29 pit development includes the pit, North OSA, South OSA, historic OSA (partly rehabilitated), low-grade stockpile and a historic run of mine (rom) pad with some stockpiling (Figure 1).

The assumed life of mine is eight years (RPS Aquaterra, 2012).

2.6.2 OB30

The proposed pit shell covers an area of approximately 58.3 ha, and is proposed to be mined to a depth of 465 mRL, approximately 80 m below the pre-mining water table.

Waste rock from OB30 will be stored in facilities located within the Whaleback operation (W13 OSA, as detailed in BHP Billiton, 2009). Overburden storage areas containing OB30 waste rock were excluded from the scope of the current preliminary AMD risk assessment.

The assumed life of mine is seven years (RPS Aquaterra, 2012).

2.6.3 OB35

The proposed pit shell covers an area of approximately 120.2 ha, and is proposed to be mined to a depth of up to 25 m below the pre-mining water table (approximately 455 mRL). The OB35 pit development also includes an OSA to the north of the pit, a low grade ore stockpile and two topsoil stockpiles (Figure 1).

3 Assessment of Acid / Metalliferous Drainage Potential

3.1 Background and Methodology

The propensity for mined materials to generate acid is a balance between their acid forming constituents (e.g. sulfides) and acid neutralising constituent minerals (e.g. carbonates). This balance can be determined quantitatively using acid base accounting (ABA). Materials are classified as potentially acid forming (PAF) when the acid forming potential (AP) is greater than the neutralising potential (NP). Acid and metalliferous drainage (AMD) is the term used collectively to drainage that may display one or more of the following chemical characteristics (DITR, 2007):

- Low pH (typically below pH 4.5);
- High soluble metal concentrations (e.g. iron, aluminium, manganese, cadmium, copper, lead, zinc, arsenic and mercury);
- Elevated acidity values;
- High sulfate salinity (typically 500 – 10,000 mg/L);
- Low concentrations of dissolved oxygen (< 6 mg/L); and
- Low turbidity or suspended solids (combined with one or more of the above characteristics).

As no acid base accounting or leaching data are available for materials from the pits in question, the assessment of acid/metalliferous drainage potential has relied principally upon the chemical assay information contained within the BHPBIO drill-hole database. The drill-hole database contained results for the following parameters: Al_2O_3, CaO, Fe, K_2O, MgO, MnO, P, S, SiO_2, TiO_2. These results are understood to be based on XRF analyses.

Leapfrog 3D modelling software was used to process the drill-hole database. The following information was also imported into Leapfrog for 3D modelling purposes:

- Geological wireframes;
- Water table contours;
- Pre-mining topography; and
- Pit shells.

The 3D modelling allowed separation of all chemical assay values for samples within the final pit shell. Additionally, assay values were separated into categories based on lithology and location either above or below the pre-mining water table. Construction of the geological models enabled assignation of a lithology to those drill-hole database entries that did not already include a lithological code. The lithologies considered in the current assessment are presented in Table 3-1.

Table 3-1: Summary of lithological categories addressed in the assessment

Lithological Category	Abbreviation	Comment/Description
Tertiary Detritals	Detritals	Includes Tertiary units: T, TD1, TD2 and TD3. This material comprises a range of material types including calcrete, clays, lignite
Wittenoom Formation, Paraburdoo Member	PDB	This formation contains carbonate-bearing material such as dolomite, and shales
Wittenoom Formation, West Angela Member - A2 (Shale Waste)	WA2	
Wittenoom Formation, West Angela Member - A1	WA1	

Lithological Category	Abbreviation	Comment/Description
Marra Mamba Iron Formation, Mount Newman Member - N3	N3	These units are highly mineralised and are important ore hosts
Marra Mamba Iron Formation, Mount Newman Member - N2 (Shaley)	N2	
Marra Mamba Iron Formation, Mount Newman Member - N1	N1	
Marra Mamba Iron Formation, MacLeod Member	MM	
Marra Mamba Iron Formation, Nammuldi Member	MU	

Note: Other lithologies were encountered in the database (e.g. dolerite, alluvials, fault zone material), but were volumetrically insignificant and were therefore excluded from the analysis.

Within each pit, the dataset was further subdivided according to whether the materials were ore grade or waste. Ore grade was defined at 58% Fe for OB30 and OB35, corresponding to the cut off value currently in use by BHPBIO. For OB29, a cut-off grade of 54% Fe was used, for consistency with historic OB29 modelling carried out by BHPBIO. For the purposes of the assessment, all material with lower iron contents was categorised as waste. There were large differences in sample numbers available for statistical interrogation depending on orebody and whether ore or waste was being considered. Table 3-2 presents the numbers of analytical values available, within each pit shell, for ore and waste grade material. Sample numbers were generally considered adequate for the purposes of the preliminary AMD risk investigation. However, it should be noted that the smallest data-set available is for waste grade material from OB30.

Table 3-2: Numbers of analytical values available within each pit shell

Analyte	Number of assay samples within pit shell					
	OB29		OB30		OB35	
	Waste	Ore	Waste	Ore	Waste	Ore
S	5,314	10,355	432	4,035	2,252	3,314
CaO	7,429	13,880	519	4,746	2,471	3,586
MgO	6,793	12,289	458	4,208	2,294	3,338
MnO	7,125	13,322	479	4,628	429	925
Al_2O_3	7,452	13,974	535	4,859	2,477	3,612
Fe	7,452	13,974	537	4,859	2,477	3,612
K_2O	6,300	11,500	432	4,035	2,252	3,314
P	7,452	13,974	300	3,062	2,477	3,612
SiO_2	1,504	13,974	432	4,035	2,477	3,612
TiO_2	5,314	11,549	505	4,552	2,277	3,346

At the current time, limited scheduling information is available for future material movements. Historically, there has been no selective placement of different material types at OB29 or OB30. For the purposes of the current assessment, it is assumed that different mined lithologies are randomly mixed, and will continue to be randomly mixed, in the relevant OSAs and stockpiles.

With respect to assessing the characteristics of the pit walls, Leapfrog software has been used to generate 'maps' of the pit wall lithological distributions, allowing quantification of the areal extent of exposure of different lithological types. Additionally, a 3D sulfur model was constructed to investigate of the distribution of sulfur concentrations on the pit walls.

3.1.1 Assessing Acid Drainage Potential

Data for total sulfur (S) were used to infer maximum acid potential (AP) based on the assumption that all sulfur present is in the form of reactive sulfide. This is a conservative approach, as some proportion of the sulfur may be present as sulfate in the form of gypsum or other non-acid forming minerals.

As already mentioned no acid base accounting results are available for the OB29, 30 and 35 materials. Therefore, there have been no measurements of neutralisation potential (NP). In most rocks, the most effective neutralising potential is contributed by carbonate-based minerals, e.g. calcite ($CaCO_3$) and dolomite ($Ca_{0.5}Mg_{0.5}CO_3$). In the current assessment, the data for calcium oxide (CaO) and magnesium oxide (MgO) were used as a crude surrogate for carbonate-based neutralising potential. This was considered crude because both Ca and Mg can be present in alternative minerals such as silicates. Nevertheless, in many Pilbara lithologies, silicate mineralogy is dominated by quartz, kaolinite, illite and muscovite – none of which are expected to contain significant concentrations of Ca or Mg.

Comparison of acid and neutralisation potentials based on surrogates allows an initial assessment of the acid-base account and calculation of a neutralisation potential ratio (NPR) – or the ratio NP/AP. Using the NPR, waste rock or overburden materials can be classified as follows (MEND, 2009):

- NPR < 1 - Potentially acid forming, PAF;
- 1 < NPR < 3 – Uncertain potential to generate acid, UC; and
- NPR >3 – Non-acid forming, NAF.

Note that because there is a low degree of confidence in the estimated NP values, low confidence can be assigned to the material classifications using this method.

An alternative approach to classify materials is to identify a sulfur cut-off threshold. Materials with a sulfur content below the threshold are considered to represent a low risk of acid generation. According to BHPBIO general practice a 0.2% sulfur cut-off value is often utilised for differentiation of PAF waste material. Identification of a defendable sulfur cut-off should be supported by site-specific assessment of the availability in NP in the materials of concern. Given the lack of site-specific NP data for OB29/30/35, the most conservative approach would be to assume no NP. For materials that contain little or no NP, then a lower sulfur cut-off value of 0.1% is often used (e.g. Green and Borden, 2011). In the assessment that follows, the lower, more conservative, cut-off value has been adopted for most discussions. However, where appropriate, discussion has been extended to include a higher sulfur cut-off value.

Of the two approaches to material classification described above, the sulfur cut-off approach is considered to be most conservative as this approach takes no credit for neutralising potential that may be present within the materials.

3.1.2 Assessing Metal Leaching Potential

Data for examining the distribution of metals and other potential contaminants are very limited indeed, a few analytes only (Al_2O_3, Fe, K_2O, MnO, P, SiO_2, TiO_2). Furthermore, because no leach testing has been conducted, there are no data available with which to assess the potential for contaminant leaching from these materials.

In the assessments that follow, the following approach has been adopted in order to inform a ‘first pass’ assessment regarding the potential for metalliferous leaching:

- The distribution of potential acid forming materials is considered linked to the potential for metalliferous leaching on the basis that many elements are more soluble and leachable under acidic conditions. Also, the distribution of many trace elements is known to be coincident with the distribution of sulfides and sulfide weathering products. For example, elements such as Se are chemically analogous to sulfur and often substitute in sulfur-bearing minerals.
- Available Fe data is examined in detail to gain a more detailed understanding of the distribution of iron oxides in the waste materials. In many samples, iron is a major component and a high proportion of iron is probably in the form of iron oxides such as magnetite (Fe_3O_4), hematite (Fe_2O_3) and goethite (FeOOH). Many minor and trace components could be present as impurities within these iron oxides (e.g. positive correlations between arsenic and iron have been noted elsewhere in the Pilbara, and have been attributed to incorporation in iron oxides). Iron oxides and oxy-hydroxides are also known to be strong adsorbents, and could be coincident with high adsorbed trace element loads.
- The distribution of Mn was examined as a possible indicator of the distribution of transition metals in the mined materials.

The other analytes contained within the database are considered of limited value with respect to assessing the potential for acid or metalliferous drainage. SiO_2, Al_2O_3 and K_2O are major components of silicates – a mineral group that is considered unlikely to be reactive under the geochemical conditions expected within most overburden storage areas or stockpiles (unless strongly acidic conditions are encountered). TiO_2 is most likely hosted by similarly unreactive minerals such as ilmenite ($FeTiO_3$) or rutile (TiO_2). Phosphorus (P) is likely to be present either as an impurity in the iron oxides or the silicates, or possibly in the form of minor phosphates (also likely to be relatively unreactive).

3.2 Orebody 29

3.2.1 Data Coverage

The numbers of Orebody 29 (OB29) analytical values available for interrogation are presented in Table 3-3. Figure 8 presents the spatial distribution of drill holes containing sulfur data and indicates that there is generally good spatial coverage for the majority of the OB29 pit.

3.2.2 Mined Volumes

OB29 is the largest of the ore bodies to be assessed. Around 52 million cubic metres of waste rock could be produced (Table 3-3), and 59 million cubic metres of ore (Table 3-4).

More than 50% of the waste rock volume comprises the Detritals, PBD and WA2 units. A relatively small proportion (approximately 20%) of the volume is sourced from below the pre-mining water table.

For this pit, the ore grade zones were modelled on the basis of a 54% Fe threshold. The ore is dominated by Mount Newman Member units, N1, N2 and N3 (80% of ore volume). Around 30% of the ore volume is sourced from below the pre-mining water table.

Table 3-3: Volumetric quantities of waste rock to be mined, by lithology (OB29)

Lithological Unit	Above WT (m^3)	Below WT (m^3)	Total (m^3)	% of volume
Detritals	14,156,000	456,380	14,612,380	28%
PBD + WA2[1]	14,290,000	5,686,300	19,976,300	39%
WA1	3,417,200	2,100,900	5,518,100	11%
N3	1,615,700	1,013,000	2,628,700	5%
N2	1,894,900	331,130	2,226,030	4%
N1	3,185,100	274,590	3,459,690	7%
MM	3,004,000	291,150	3,295,150	6%
MU	75,210	452	75,662	0.1%
Total	**41,638,110**	**10,153,902**	**51,792,012**	**100%**

Note: WT – Water table (pre-mining); [1] PBD and WA2 units were combined because the mine model did not define the top surface of the WA2 unit.

Table 3-4: Volumetric quantities of ore to be mined, by lithology (OB29)

Lithological Unit	Above WT (m^3)	Below WT (m^3)	Total (m^3)	% of volume
Detritals	1,210,500	48,074	1,258,574	2%
PBD + WA2[1]	28,094	28,094	56,188	0%
WA1	1,587,700	485,870	2,073,570	4%
N3	8,383,000	4,057,200	12,440,200	21%
N2	8,692,300	4,721,500	13,413,800	23%
N1	13,750,000	7,225,200	20,975,200	36%
MM	6,738,800	1,625,600	8,364,400	14%
MU	328,670	3,976	332,646	1%
Total	**40,719,064**	**18,195,514**	**58,914,578**	**100%**

Note: WT – Water table (pre-mining); [1] PBD and WA2 units were combined because the mine model did not define the top surface of the WA2 unit.

3.2.3 Pit Wall Composition

The lithological composition of the exposed final pit wall is summarised in Table 3-5, and illustrated in Figure 9. Almost half of the exposed surface area comprises the MM unit. Around 40% of the exposed pit wall area comprises rock that was located below the pre-mining water table. Lithological exposure above (AWT) and below (BWT) the pre-mining water table are also shown in Figure 9.

Table 3-5: Areas exposed on pit walls, by lithology (OB29)

Lithological Unit	Above WT (m^2)	Below WT (m^2)	Total (m^2)	% of exposed surface
Detritals	85,676	16,146	101,822	5%
PBD + WA2[1]	61,278	95,100	156,378	7%
WA1	16,620	37,340	53,960	2%
N3	43,761	64,227	107,988	5%
N2	84,816	70,500	155,316	7%
N1	253,690	289,940	543,630	25%
MM	703,990	336,800	1,040,790	47%
MU	54,590	2,011	56,601	3%
Total	**1,304,421**	**912,064**	**2,216,485**	**100%**

Note: WT – Water table (pre-mining); [1] PBD and WA2 units were combined because the mine model did not define the top surface of the WA2 unit.

3.2.4 Geochemical Characteristics of Mined Lithologies

Figure 10 illustrates sulfur statistics for materials from OB29. Pink highlighting has been used in the figure to indicate regions where the total sulfur content lies above a 0.1% sulfur cut-off (i.e. could be considered as potentially acid forming, PAF).

The following comments can be made:

- All materials (waste rock and ore) show similarly low ranges of sulfur values. Median sulfur values lie below 0.1% for all materials, suggesting a low potential for acid generation.
- High maximum sulfur values are observed for many lithologies, but these often represent outliers. For most lithologies, sulfur values greater than 0.1% are not encountered until above the 95th percentile of the dataset (i.e. represents less than 5% of the data). A notable exception is waste rock from the Detrital unit (from above the water table). This unit gave the highest maximum sulfur content (7.6%) and sulfur values greater than 0.1% were encountered at around the 80th percentile.
- Material sourced from below the pre-mining water table shows lower ranges of sulfur values. (Note, however, that the datasets are smaller for this material category).

Summary statistics for acid potential (AP), neutralising potential (NP), and Fe and Mn content are shown in Table 3-6 (above water table (AWT) material) and Table 3-7 (below water table (BWT) material).

Table 3-6: Summary statistics for OB29 above water table materials: Acid-base accounting surrogates and selected metals (Fe, Mn)

	Acid-Base Accounting Surrogates									Distribution of Selected Contaminants							
	AP, kgH_2SO_4/t[1]				NP, kgH_2SO_4/t[2]				NPR[3]	Fe, %				Mn, %			
Lithology	**n**	**Min**	**Ave**	**Max**	**n**	**Min**	**Ave**	**Max**		**n**	**Min**	**Ave**	**Max**	**n**	**Min**	**Ave**	**Max**
Waste Materials																	
Detritals	1258	0.09	4.9	234.4	1615	0.1	3.5	48.7	0.7	1748	1.1	43.1	65.3	1693	0.001	0.43	13.52
PBD + WA2	1944	0.09	2.3	132.5	2567	0.09	2.6	42.3	1.2	2689	1.8	32.0	63.9	2655	0.001	2.66	63.13[4]
WA1	490	0.09	2.1	60.7	684	0.2	2.5	29.9	1.2	776	8.1	45.3	63.6	754	0.02	1.92	15.92
N3	117	0.09	1.2	13.8	159	0.2	2.6	26.6	2.2	221	19.1	50.1	64.4	195	0.02	0.43	8.13
N2	93	0.09	1.5	26.5	118	0.1	3.7	29.8	2.5	168	21.6	51.0	64.3	146	0.008	0.09	0.62
N1	222	0.09	1.4	26.6	269	0.07	1.6	18.3	1.2	337	24.4	49.0	62.1	301	0.004	0.07	6.51
MM	212	0.06	0.8	11.5	242	0.06	2.1	31.1	2.5	298	18.0	49.0	62.2	277	0.002	0.03	0.27
MU	12	0.09	0.2	0.3	12	0.06	0.2	0.3	0.9	12	17.0	33.9	61.0	12	0.008	0.04	0.19
Ore																	
Detritals	116	0.09	1.2	29.6	185	0.1	1.1	12.1	0.9	216	22.6	57.1	65.2	213	0.01	0.2	7.6
PBD + WA2	5	0.09	0.5	1.5	7	0.3	1.4	5.8	2.7	7	37.2	55.3	64.3	7	0.09	0.5	1.0
WA1	268	0.03	1.7	52.0	353	0.2	1.1	15.1	0.7	419	19.3	57.6	66.4	408	0.008	0.5	8.0
N3	1458	0.03	0.8	55.4	1792	0.1	0.8	14.7	1.1	2140	22.7	62.3	67.6	2055	0.008	0.2	6.1
N2	1539	0.03	0.6	31.5	1799	0.04	0.9	33.6	1.4	2143	14.1	61.2	67.2	2019	0.007	0.1	6.8
N1	2613	0.03	0.5	30.6	2943	0.04	0.6	19.7	1.1	3442	27.9	61.7	67.5	3250	0.004	0.1	3.2
MM	829	0.03	0.7	15.3	984	0.04	0.6	19.5	1.0	1140	16.3	58.0	65.9	1068	0.005	0.04	1.7
MU	30	0.1	0.8	3.0	185	0.09	0.4	0.5	0.5	43	47.9	59.2	61.9	43	0.008	0.02	0.1

Notes:

[1] Total S has been used to calculate maximum acid potential - total S (%) multiplied by 30.6 gives units of kgH_2SO_4/t.

[2] Neutralisation potential is inferred on the basis of the sum of the CaO and MgO content, following a conversion to units of kgH_2SO_4/t as follows – CaO (%) multiplied by 17.5 and MgO multiplied by 24.5. A further reduction factor, 0.1, was applied to account for the fact that (i) some proportion of Ca and Mg will be present in non-neutralising minerals, and (ii) based on experience elsewhere in the Pilbara, only a small proportion of neutralisation potential is readily available.

[3] Neutralisation potential ratio (NP/AP) is inferred from the average MPA and inferred ANC values.

[4] This maximum is an outlier within the dataset (all other values were less than 20%) - and possibly represents an error within the raw dataset.

Table 3-7: Summary statistics for OB29 below water table materials: Acid-base accounting surrogates and selected metals (Fe, Mn)

	Acid-Base Accounting Surrogates									Distribution of Selected Contaminants							
	AP, kgH_2SO_4/t[1]				NP, kgH_2SO_4/t[2]				NPR[3]	Fe, %				Mn, %			
Lithology	**n**	**Min**	**Ave**	**Max**	**n**	**Min**	**Ave**	**Max**		**n**	**Min**	**Ave**	**Max**	**n**	**Min**	**Ave**	**Max**
Waste Materials																	
Detritals	19	0.4	0.7	1.1	26	0.2	1.2	4.2	1.6	27	26.0	52.2	61.5	26	0.03	2.2	19.7
PBD + WA2	498	0.09	1.84	85.7[4]	585	0.1	1.9	4.5	1.0	642	5.2	36.5	66.1	558	0.002	3.9	40.3
WA1	233	0.03	1.01	85.7[4]	279	0.1	1.2	4.2	1.2	288	6.6	45.0	66.3	284	0.04	2.5	11.9
N3	111	0.06	0.4	3.7	123	0.1	0.8	3.8	2.2	124	11.4	48.2	66.3	124	0.02	2.0	9.7
N2	43	0.12	0.3	0.4	43	0.2	0.3	0.5	1.3	43	33.5	59.6	65.7	43	0.01	0.1	0.4
N1	23	0.06	0.1	0.3	26	0.1	0.3	0.7	2.0	34	31.2	46.6	62.9	12	0.005	0.08	0.4
MM	39	0.09	0.50	3.1	45	0.1	0.3	0.8	0.6	45	25.3	48.1	64.7	45	0.008	0.06	0.4
MU	No data available for this unit (represents a very low volumetric proportion of mined volumes)																
Ore																	
Detritals	2	0.6	0.6	0.6	12	0.4	1.0	2.5	1.7	12	45.9	56.4	62.9	12	0.1	1.7	7.4
PBD + WA2	3	0.2	0.2	0.3	5	0.3	1.1	2.9	4.5	5	32.2	47.3	58.2	213	0.4	0.7	1.2
WA1	85	0.06	9.6	85.7[4]	108	0.1	0.6	1.7	0.1	122	43.9	59.7	67.0	115	0.0	0.6	3.9
N3	628	0.03	1.2	85.7[4]	802	0.09	0.5	5.1	0.4	861	21.2	62.7	68.3	818	0.0	0.3	10.3
N2	835	0.03	1.0	85.7[4]	1015	0.08	0.4	6.0	0.4	1087	31.9	62.1	67.5	1034	0.0	0.2	5.4
N1	1513	0.03	0.8	85.7[4]	1757	0.04	0.4	4.9	0.5	1835	21.4	61.8	67.9	1787	0.0	0.1	15.2
MM	431	0.03	0.40	4.7	484	0.04	0.3	1.5	0.8	502	28.7	59.0	66.8	488	0.0	0.0	0.4
MU	No data available for this unit (represents a very low volumetric proportion of mined volumes)																

Notes:

[1] Total S has been used to calculate maximum acid potential - total S (%) multiplied by 30.6 gives units of kgH_2SO_4/t.

[2] Neutralisation potential is inferred on the basis of the sum of the CaO and MgO content, following a conversion to units of kgH_2SO_4/t as follows – CaO (%) multiplied by 17.5 and MgO multiplied by 24.5. A further reduction factor, 0.1, was applied to account for the fact that (i) some proportion of Ca and Mg will be present in non-neutralising minerals, and (ii) based on experience elsewhere in the Pilbara, only a small proportion of neutralisation potential is readily available.

[3] Neutralisation potential ratio (NP/AP) is inferred from the average MPA and inferred ANC values.

[4] These maximum values are based on a repeated high sulfur value (2.8%) encountered in one particular drill-hole (EEG0341) – believed to be a possible data entry error.

In Table 3-6 and Table 3-7, the acid potential has been calculated based on the conservative assumption that all sulfur present is sulfidic. No information is available to describe sulfur speciation and it is possible that some portion of the sulfur present comprises sulfates or hydroxy-sulfates rather than sulfides – particularly in the case of materials located above the water table.

The highest average and maximum total sulfur (and therefore AP) values are associated with the AWT Detritals. For this particular unit, around 20% of the available data were at sulfur values above 0.1% (around 10% of the data were at sulfur values above 0.2% - the higher sulfur cut-off often used by BHPBIO). It is not known if the higher sulfur values are indicative of sulfide-bearing material within this unit. Sulfidic materials, such as lignites, have been recorded in detrital units elsewhere within the Pilbara (Green and Borden, 2011). It is also possible that the high sulfur values reflect higher sulfate contents within this unit, e.g. gypsum.

Average NP is low, less than 5 kgH_2SO_4/t. Notably, the highest maximum NP values are coincident with the Detritals, PDB and WA2 units. This would be consistent with the expected presence of carbonate-bearing materials within these lithologies. For example, the Detritals are known to include calcretes, whilst the PDB and WA2 units may contain dolomitic materials.

Average AP and NP were used to calculate neutralisation potential ratios (NPRs). The NPRs are generally less than 1 (indicative of PAF material) or between 1 and 3 (of uncertain potential to generate acid). However, as already mentioned, based on the low sulfur contents, the majority of the materials would be classed as NAF based on a sulfur cut-off approach.

The average and maximum Fe content of the materials is uniformly high – as would be expected for the geological setting represented. The range of Fe contents extend to lower minima in the Detritals, PBD, WA2 and WA1 units. It is expected that Fe is hosted by iron oxides such as hematite, magnetite and goethite – and therefore is unlikely to be readily leachable. The widespread distribution of Fe as iron oxides could be beneficial in that these minerals represent strong adsorbents. Contaminant sorption can reduce dissolved contaminant levels in contacting waters, and attenuate contaminant transport. The lower minimum Fe contents observed for some units may be of significance if this is coincident with a lower sorptive capacity.

Average and maximum Mn content is greatest in the Detritals, PBD, WA2 and WA1. These units also gave higher average and maximum NP values, introducing the possibility that Mn distribution is correlated with NP (i.e. CaO and MgO) and reflects incorporation of Mn in carbonates. Examination of the datasets in more detail showed that any such correlations, if present, were not strong. For example, within the larger AWT datasets, correlation coefficients were less than 0.3 for all units. The lack of strong correlations does not preclude incorporation of Mn in carbonate minerals – but does suggest that other mineral hosts are present, e.g. the iron oxides. Note that Mn (and by analogy other transition metals) present within carbonates could be readily leachable if exposed to acidic conditions.

3.2.5 Potential for Acid / Metalliferous Drainage

Estimates of the overall proportion of PAF material present in overburden storage areas (OSAs) and within ore stockpiles are shown in Table 3-8 and Table 3-9, respectively. These estimates combine the volumes of material to be mined (Section 3.2.2), with the geochemical characteristics of the materials as described in Section 3.2.4. The following assumptions apply:

- There is no selective placement of materials, i.e. OSAs and stockpiles are random mixtures of the mined lithologies.
- The proportion of PAF-classed material can be estimated on the basis of sulfur statistics generated for the AWT datasets. These are the larger datasets and are therefore considered more statistically robust. This is considered a conservative approach as the AWT materials were found to give higher ranges of sulfur contents than did BWT materials.

Table 3-8: Estimation of the proportion of mined PAF-classed material within overburden storage areas (OB29)

Lithological Unit	% of waste rock volume	0.1% sulfur cut-off		0.2% sulfur cut-off	
		Proportion of PAF material in unit[1]	% of PAF material	Proportion of PAF material in unit[1]	% of PAF material
Detritals	28%	20%	5.6%	12%	3.40%
PBD + WA2	39%	10%	3.9%	5%	1.90%
WA1	11%	10%	1.1%	5%	0.50%
N3	5%	5%	0.3%	1%	0.10%
N2	4%	3%	0.1%	1%	0.00%
N1	7%	3%	0.2%	1%	0.10%
MM	6%	1%	0.1%	1%	0.10%
MU	0.1%	0%	-	0%	-
Total	**100%**		**11.2%**		**6.10%**

Notes: [1] Proportion of PAF-classed material estimated on the basis of the percentile of the AWT dataset that lies above the sulfur cut-off (0.1% or 0.2%). The AWT dataset was used as this was the larger dataset.

Table 3-9: Estimation of the proportion of mined PAF-classed material within ore stockpiles (OB29)

Lithological Unit	% of ore volume	0.1% sulfur cut-off		0.2% sulfur cut-off	
		Proportion of PAF material in unit[1]	% of PAF material in stockpile	Proportion of PAF material in unit[1]	% of PAF material in stockpile
Detritals	2%	5%	0.1%	4%	0.1%
PBD + WA2	0%	0%	-	0%	0.0%
WA1	4%	10%	0.4%	5%	0.2%
N3	21%	3%	0.6%	1%	0.3%
N2	23%	1%	0.2%	1%	0.2%
N1	36%	1%	0.4%	0%	0.1%
MM	14%	1%	0.1%	0%	0.0%
MU	1%	0%	-	0%	0.0%
Total	**100%**	**-**	**1.8%**	**-**	**0.9%**

Notes: [1] Proportion of PAF-classed material estimated on the basis of the percentile of the AWT dataset that lies above the sulfur cut-off (0.1% or 0.2%). The AWT dataset was used as this was the larger dataset.

Table 3-8 suggests that OSAs may contain around 11% PAF material if a 0.1% sulfur cut-off is used, and around 6% PAF material if a 0.2% sulfur cut-off is assumed. Most of this PAF material is contributed by Detritals and PBD+WA2. Figure 11 is an image of the pit volume showing the distribution of waste rock that contains more than 0.1% sulfur.

Table 3-9 suggests that the proportion of PAF material in the ore stockpile will be very small, less than 2% if a 0.1% sulfur cut-off is used, and less than 1% if a 0.2% sulfur cut-off is assumed. The small proportion of PAF, combined with the expected short duration of ore storage, suggest that the potential for AMD from stockpiles will be low to negligible.

The PAF estimates are considered overestimates because (i) acid potential has been overestimated by assuming all sulfur is sulfidic and (ii) no credit has been taken for NP, which may be present in more significant quantities in the Detrital and PBD+WA2 units.

The presence of PAF materials within the OSA introduces the potential for generation of acid and metalliferous drainage within these facilities. The proportion of PAF materials is relatively low and it could be expected that acid generation be localised. Some of acid generated would be neutralised by interaction with neutralising potential (NP) encountered along flowpaths within the OSA – reducing the potential for acidic seepage from the base of the facility. However, it should be noted that available NP in most mined lithologies could be limited (based on surrogate data) and therefore insufficient to provide long-term neutralisation capacity.

In summary, there is potential for AMD from the OB29 OSA. Unfortunately the potential cannot be quantified accurately without more detailed geochemical data – for example sulfur speciation within the Detrital and PBD+WA2 units, and static and kinetic leach data to describe contaminant leachability and key reaction rates.

Estimates of the overall proportion of PAF material exposed on the pit walls are shown in Table 3-10. These estimates combine the surface areas of materials exposed (Section 3.2.3), with the geochemical characteristics of the materials as described in Section 3.2.4. The proportion of PAF material is low, with 3.5%. using the 0.1% sulfur cut-off, and 1.9% when the 0.2% sulfur cut-off is applied.

Figure 12 is an image of the OB29 pit shell showing the location of exposed rock with high sulfur values (i.e. above the 0.1% sulfur threshold). The sulfur-bearing material forms isolated ‘hot-spots’, generally located near the crest of the pit walls. These locations lie above the expected level of the final pit lake surface, which is assumed to be below the pre-mining water table as outlined in the RPS Aquaterra Hydrogeological Assessment (RPS, 2013). If these materials are sulfidic (sulfur speciation is not currently known), they could represent a source of AMD contributing to solute load in pit wall runoff.

Table 3-10: Estimation of the proportion of PAF-classed material exposed on pit walls (OB29)

Lithological Unit	% of exposed pit wall	0.1% sulfur cut-off		0.2% sulfur cut-off	
		Proportion of PAF material in unit[1]	% of PAF material exposed on pit wall	Proportion of PAF material in unit[1]	% of PAF material exposed on pit wall
Detritals	5%	20%	0.9%	12%	0.6%
PBD + WA2[1]	7%	10%	0.7%	5%	0.4%
WA1	2%	10%	0.2%	5%	0.1%
N3	5%	5%	0.2%	1%	0.0%
N2	7%	3%	0.2%	1%	0.1%
N1	25%	3%	0.7%	1%	0.2%
MM	47%	1%	0.5%	1%	0.5%
MU	2.55%	0%	-	0%	0.0%
Total	**100%**		**3.5%**		**1.9%**

Notes: [1] Proportion of PAF-classed material estimated on the basis of the percentile of the AWT dataset that lies above the sulfur cut-off (0.1% or 0.2%). The AWT dataset was used as this was the larger dataset.

3.3 Orebody 30

3.3.1 Data Coverage

The numbers of Orebody 30 (OB30) analytical values available for interrogation are presented in Table 3-2. Figure 13 presents the spatial distribution of drill holes containing sulfur data and indicates that there is generally good spatial coverage for the majority of the OB30 pit.

3.3.2 Mined Volumes

OB30 is smallest of the ore bodies to be assessed. A relatively small volume of waste rock could be produced, 4.4 million cubic metres (Table 3-11), and around 17.4 million cubic metres of ore (Table 3-12).

It is understood that waste rock from OB30 will be stored in a OSA located within the Mt Whaleback Operation. As was the case with OB29, a major proportion of the waste rock volume (68%) comprises the Detritals, PBD and WA2 units. Only around 10% of this volume is sourced from below the pre-mining water table.

For this pit the ore grade zones were modelled on the basis of a 58% Fe threshold. The majority of ore to be mined (90%) is sourced from Mount Newman Member units, N1, N2 and N3. Around 33% of the ore volume is sourced from below the pre-mining water table.

Table 3-11: Volumetric quantities of waste rock to be mined, by lithology (OB30)

Lithological Unit	Above WT (m^3)	Below WT (m^3)	Total (m^3)	% of volume mined
Detritals	741,720	0	741,720	17%
PBD	380,140	185,790	565,930	13%
WA2-	1,515,900	169,050	1,684,950	38%
WA1	406,520	5,715	412,235	9%
N3	314,650	16,395	331,045	7%
N2	175,000	2,251	177,251	4%
N1	267,360	15,657	283,017	6%
MM	112,580	46,619	159,199	4%
MU	74,422	84	74,506	2%
Total	**3,988,292**	**441,561**	**4,429,853**	**100%**

Note: WT – Water table (pre-mining)

Table 3-12: Volumetric quantities of ore to be mined, by lithology (OB30)

Lithological Unit	Above WT (m^3)	Below WT (m^3)	Total (m^3)	% of volume mined
Detritals	0	0	0	0%
PBD	0	0	0	0%
WA2	59,584	47454	107,038	0.6%
WA1	628,730	456900	1,085,630	6%
N3	2,989,700	1611800	4,601,500	26%
N2	3,847,500	2059900	5,907,400	34%
N1	3,715,700	1429000	5,144,700	30%
MM	456,010	63983	519,993	3%
MU	0	0	0	0%
Total	**11,697,224**	**5,669,037**	**17,366,261**	**100%**

Note: WT – Water table (pre-mining)

3.3.3 Pit Wall Composition

The lithological composition of the final exposed pit wall is summarised in Table 3-13, and illustrated in Figure 14.

Most lithological units are represented. The WA2 and N1 units each represent around 20% of the surface area, whilst the other units represent up to 13%.

Around 45% of the exposed pit wall comprises rock that was located below the pre-mining water table. Above (AWT) and below (BWT) pre-mining water table zones are also presented in Figure 14.

Table 3-13: Areas exposed on pit walls, by lithology (OB30)

Lithological Unit	Above WT (m^2)	Below WT (m^2)	Total (m^2)	% of exposed surface
Detritals	25,169		25,169	3%
PBD	56,510	37,367	93,877	10%
WA2	124,150	47,284	171,434	19%
WA1	35,424	70,332	105,756	12%
N3	36,443	78,256	114,699	13%
N2	56,703	63,864	120,567	13%
N1	111,120	72,338	183,458	20%
MM	36,862	31,968	68,830	8%
MU	18,844	491	19,335	2%
Total	**501,225**	**401,900**	**903,125**	**100%**

Note: WT – Water table (pre-mining)

3.3.4 Geochemical Characteristics of Mined Lithologies

Figure 15 illustrates sulfur statistics for materials from OB30. Note that the sample numbers for this pit are smaller than was the case for the OB29. The following comments can be made:

- Although there is variability between lithological units, all materials show low ranges of sulfur values. Median sulfur values invariably lie below 0.1%, suggesting a low potential for acid generation.
- For waste rock, a maximum sulfur value above 0.1% is only observed in the case of the N1 unit. For most lithologies, the maximum sulfur content was significantly lower than observed for the equivalent lithologies in OB29. Although this may suggest that sulfur is less abundant at OB30, it could also be a reflection of the smaller size of the available datasets for OB30.
- For ore, several units gave maximum values greater than 0.1%. In all cases the high sulfur values represent outliers lying above the 97th percentiles of the datasets.
- Material sourced from below the pre-mining water table shows lower ranges of sulfur values. (Note, however, that the datasets are very small for this material category).

Summary statistics for acid potential (AP), neutralising potential (NP), and Fe and Mn content are shown in Table 3-14 (above water table (AWT) material) and Table 3-15 (below water table (BWT) material).

Table 3-14: Summary statistics for OB30 above water table materials: Acid-base accounting surrogates and selected metals (Fe, Mn)

	Acid-Base Accounting Surrogates									**Distribution of Selected Contaminants**							
	AP, kgH_2SO_4/t[1]				**NP, kgH_2SO_4/t[2]**				**NPR[3]**	**Fe, %**				**Mn, %**			
Lithology	**n**	**Min**	**Ave**	**Max**	**n**	**Min**	**Ave**	**Max**		**n**	**Min**	**Ave**	**Max**	**n**	**Min**	**Ave**	**Max**
Waste Materials																	
Detritals	113	0.03	0.5	2.2	123	0.5	4.8	18.5	10.5	136	2.9	31.5	55.3	124	0.008	0.09	0.4
PBD	17	0.03	0.2	0.6	20	40.4	79.0	90.1	482.4	20	2.9	7.4	13.8	17	0.9	1.4	4.0
WA2	111	0.03	0.4	2.1	116	0.3	5.8	70.9	15.5	147	4.5	35.0	57.6	131	0.06	5.6	19.0
WA1	39	0.06	0.7	2.1	39	0.5	10.8	66.6	16.3	47	11.2	36.4	60.5	43	0.008	0.2	1.2
N3	35	0.03	1.0	2.0	37	0.09	4.3	24.2	4.3	20	7.7	36.5	50.6	37	0.008	0.1	1.3
N2	26	0.4	1.1	2.2	28	0.06	5.4	22.2	5.1	46	12.8	39.7	50.9	31	0.008	0.1	0.2
N1	39	0.03	0.9	10.8	42	0.08	2.9	26.6	3.1	51	14.4	34.8	47.8	43	0.008	0.1	0.9
MM	15	0.03	0.1	0.6	16	0.1	1.3	12.1	9.8	19	20.9	41.3	57.2	16	0.008	0.02	0.1
MU	No data available for this unit (represents a very low volumetric proportion of mined volumes)																
Ore																	
Detritals	11	0.2	1.1	2.9	11	0.8	2.1	4.3	1.8	12	50.5	53.0	56.3	11	0.008	0.1	0.3
PBD	No data available for this unit (not represented within mined volumes)																
WA2	161	0.03	0.4	9.5	162	0.3	2.0	17.7	5.3	178	21.9	52.7	63.4	169	0.05	2.4	15.5
WA1	414	0.03	0.4	4.2	414	0.2	1.4	13.6	3.4	468	32.7	55.8	63.8	444	0.008	0.8	11.7
N3	737	0.03	0.3	21.5	760	0.06	1.0	22.2	2.9	898	37.2	60.6	66.7	831	0.008	0.1	3.4
N2	849	0.03	0.3	8.5	856	0.1	1.1	19.1	3.5	1004	35.1	60.0	66.1	960	0.008	0.1	2.9
N1	888	0.03	0.3	3.6	893	0.04	0.8	34.2	2.8	1108	31.4	59.7	65.9	1061	0.004	0.1	6.5
MM	286	0.03	0.3	1.8	315	0.04	0.6	10.2	1.9	354	28.1	55.4	64.9	326	0.008	0.03	0.4
MU	2	0.03	0.05	0.06	6	0.2	1.2	1.8	25.2	7	48.2	53.2	56.7	6	0.02	0.03	0.04

Notes:

[1] Total S has been used to calculate maximum acid potential - total S (%) multiplied by 30.6 gives units of kgH_2SO_4/t.

[2] Neutralisation potential is inferred on the basis of the sum of the CaO and MgO content, following a conversion to units of kgH_2SO_4/t as follows – CaO (%) multiplied by 17.5 and MgO multiplied by 24.5. A further reduction factor, 0.1, was applied to account for the fact that (i) some proportion of Ca and Mg will be present in non-neutralising minerals, and (ii) based on experience elsewhere in the Pilbara, only a small proportion of neutralisation potential is readily available.

[3] Neutralisation potential ratio (NP/AP) is inferred from the average MPA and inferred ANC values.

Table 3-15: Summary statistics for OB30 below water table materials: Acid-base accounting surrogates and selected metals (Fe, Mn)

	Acid-Base Accounting Surrogates									Distribution of Selected Contaminants							
	AP, kgH_2SO_4/t[1]				NP, kgH_2SO_4/t[2]				NPR[3]	Fe, %				Mn, %			
Lithology	**n**	**Min**	**Ave**	**Max**	**n**	**Min**	**Ave**	**Max**		**n**	**Min**	**Ave**	**Max**	**n**	**Min**	**Ave**	**Max**
Waste Materials																	
Detritals	No data available for these units (not represented within mined volumes)																
PBD	No data available for these units (very small volumetric proportion of mined volumes)																
WA2	26	0.03	0.2	0.4	26	0.8	9.3	83.7	59.5	26	6.6	33.0	59.0	26	1.0	7.5	16.2
WA1	8	0.09	0.2	0.3	8	1.1	2.2	2.7	10.0	8	26.2	39.1	52.2	8	0.9	5.5	10.5
N3	3	0.06	0.08	0.09	3	0.1	0.2	0.2	2.3	3	33.2	37.9	46.6	3	0.02	0.04	0.08
N2	No data available for these units (very small volumetric proportion of mined volumes)																
N1																	
MM																	
MU																	
Ore																	
Detritals	No data available (not represented within mined volumes)																
PBD																	
WA2	33	0.03	0.1	0.2	33	0.7	1.8	20.1	15.9	33	33.4	53.5	61.2	11	0.1	3.3	10.6
WA1	43	0.03	0.2	1.1	46	0.2	0.9	1.9	3.9	48	33.8	57.8	63.9	48	0.02	1.1	8.4
N3	164	0.03	0.3	2.4	189	0.04	0.4	2.3	1.6	199	45.8	62.2	65.7	198	0.01	0.1	3.6
N2	240	0.03	0.2	0.8	276	0.2	0.5	8.4	2.9	284	39.8	59.9	63.6	282	0.01	0.1	1.2
N1	201	0.03	0.2	0.6	237	0.07	0.5	18.0	3.3	256	41.2	60.7	64.8	249	0.005	0.09	1.8
MM	6	0.06	0.1	0.2	8	0.1	0.5	1.5	5.3	8	52.3	56.2	59.9	8	0.008	0.02	0.04
MU	No data available				2	1.1	3.0	4.9	-	2	41.6	41.8	42.0	2	0.04	0.04	0.04

Notes:

[1] Total S has been used to calculate maximum acid potential - total S (%) multiplied by 30.6 gives units of kgH_2SO_4/t.

[2] Neutralisation potential is inferred on the basis of the sum of the CaO and MgO content, following a conversion to units of kgH_2SO_4/t as follows – CaO (%) multiplied by 17.5 and MgO multiplied by 24.5. A further reduction factor, 0.1, was applied to account for the fact that (i) some proportion of Ca and Mg will be present in non-neutralising minerals, and (ii) based on experience elsewhere in the Pilbara, only a small proportion of neutralisation potential is readily available.

[3] Neutralisation potential ratio (NP/AP) is inferred from the average MPA and inferred ANC values.

In Table 3-14 and Table 3-15 , it can be seen that average AP is uniformly low, often less than 1 kgH_2SO_4/t. Estimated NP values are generally low (averages are less than 5 kgH_2SO_4/t), although the PBD waste rock unit (above the water table) gives an average of 79 kgH_2SO_4/t – which would be consistent with the presence of dolomitic material within this unit.

For most of the materials the inferred neutralisation potential ratios (NPRs) are greater than 3, i.e. would be classed as on acid forming, NAF. There are no units giving NPRs below 1, i.e. PAF. Several units give NPRs between 1 and 3 and are therefore of uncertain acid potential.

Fe and Mn distribution between lithological units shows similar trends are were observed for OB29. Fe content is uniformly high, with lower mimima in the Detrital, PBD and WA2 waste rock units. Higher average and maximum Mn contents are calculated for the WA2 unit.

3.3.5 Potential for Acid/Metalliferous Drainage

It is understood that waste rock mined from this pit will be stored in facilities located within the Whaleback operation. Overburden storage areas were excluded from the scope of the assessment for this pit. Estimates of the overall proportion of PAF material present within ore stockpiles are shown in Table 3-16. These estimates combine the volumes of material to be mined (Section 3.3.2), with the geochemical characteristics of the materials as described in Section 3.3.4.

As was the case for OB29, the following assumptions apply:

- There is no selective placement of materials, i.e. the stockpiles are random mixtures of the mined lithologies.
- The proportion of PAF-classed material can be estimated (conservatively) on the basis of the sulfur statistics generated for the AWT datasets.

Table 3-16 suggests that the proportion of PAF material in the ore stockpile will be very small, less than 0.1% using the 0.1% sulfur cut-off, and 0.12% when the 0.2% sulfur cut-off is applied. The small proportion of PAF, combined with the expected short duration of ore storage, suggest that the potential for AMD from stockpiles will be low to negligible.

Table 3-16: Estimation of the proportion of PAF-classed material within ore stockpiles (OB30)

Lithological Unit	% of ore volume	0.1% sulfur cut-off		0.2% sulfur cut-off	
		Proportion of PAF material in unit[1]	% of PAF material in stockpile	Proportion of PAF material in unit[1]	% of PAF material in stockpile
Detritals	0%		0.00%	0.0%	0.00%
PBD	0%	-	0.00%	0.0%	0.00%
WA2	0.60%	1%	0.01%	0.6%	0.00%
WA1	6%	1%	0.06%	0.0%	0.00%
N3	26%	1%	0.26%	0.3%	0.07%
N2	34%	1%	0.34%	0.1%	0.04%
N1	30%	1%	0.30%	0.0%	0.00%
MM	3%	-	0.00%	0.0%	0.00%
MU	0%	-	0.00%	0.0%	0.00%
Total	**100%**		**0.97%**		**0.12%**

Notes: [1] Proportion of PAF-classed material estimated on the basis of the percentile of the AWT dataset that lies above the sulfur cut-off (0.1% or 0.2%). The AWT dataset was used as this was the larger dataset.

Estimates of the overall proportion of PAF material exposed on the pit walls are shown in Table 3-17. These estimates combine the surface areas of materials exposed (Section 3.3.3), with the geochemical characteristics of the materials as described in Section 3.3.4. The proportion of PAF material is very low, 0.6% using the 0.1% sulfur cut-off, and 0.2% when the 0.2% sulfur cut-off is applied.

Figure 16 is an image of the OB30 pit shell showing the location of exposed rock with high sulfur values (i.e. above the 0.1% sulfur threshold). Most of the pit wall is below the sulfur threshold; as was the case with OB29, those areas with higher sulfur values tend to be located near the crest of the pit walls.

Table 3-17: Estimation of the proportion of PAF-classed material exposed on pit walls (OB30)

Lithological Unit	% of Exposed Pit Wall	0.1% sulfur cut-off		0.2% sulfur cut-off	
		Proportion of PAF material in unit[1]	% of PAF material exposed on pit wall	Proportion of PAF material in unit[1]	% of PAF material exposed on pit wall
Detritals	3%	0.0%	0.00%	0.0%	0.00%
PBD	10%	0.0%	0.00%	0.0%	0.00%
WA2	19%	0.0%	0.00%	0.0%	0.00%
WA1	12%	0.0%	0.00%	0.0%	0.00%
N3	13%	0.0%	0.00%	0.0%	0.00%
N2	13%	0.0%	0.00%	0.0%	0.00%
N1	20%	3.0%	0.60%	1.0%	0.20%
MM	8%	0.0%	0.00%	0.0%	0.00%
MU	2%	No data	-	No data	-
Total	**100%**		**0.60%**		**0.20%**

Notes: [1] Classification based on sulfur cut-off threshold (0.1%). Proportion of PAF-classed material estimated on the basis of the percentile of the AWT dataset that lies above the sulfur cut-off (0.1% or 0.2%). The AWT dataset was used as this was the larger dataset.

3.4 Orebody 35

3.4.1 Data Coverage

The numbers of Orebody 35 (OB35) analytical values available for interrogation are presented in Table 3-2. Figure 17 presents the spatial distribution of drill holes containing sulfur data and indicates that there is generally good spatial coverage for the majority of the OB35 pit. There is a relatively small zone along the southern edge of the OB35 pit for which no drill-hole data were available for the current assessment. BHPBIO are currently performing modelling to complete the OB35 pit model along this southern limit. This zone has been omitted from the majority of modelling and analysis undertaken within this assessment.

3.4.2 Mined Volumes

The expected volumes of waste rock and ore that could be mined from OB35 are summarised in Table 3-18 and Table 3-19, respectively.

Unlike OB29 and OB30, the waste rock is not dominated by the Detrital, PBD and WA2 units; these units comprise around 23% of the OB35 waste rock volume. The MM unit contributes another 19% of volume, whilst the other units are present at percentages between 7 and 14%. Less than 1% of this volume is sourced from below the pre-mining water table.

For this pit the ore grade zones were modelled on the basis of a 58% Fe threshold. Like OB29 and OB30, the majority of ore to be mined is sourced from Mount Newman Member units, N1, N2 and N3 (81% of the ore volume). As was the case with waste rock, less than 1% of this volume is sourced from below the pre-mining water table.

Table 3-18: Volumetric quantities of waste rock to be mined, by lithology (OB35)

Lithological Unit	Above WT (m^3)	Below WT (m^3)	Total (m^3)	% of volume
Detritals	3,765,700	0	3,765,700	19%
PBD	7,139	0	7,139	0.04%
WA2	720,200	0	720,200	4%
WA1	1,417,400	0	1,417,400	7%
N3	2,404,600	3,385	2,407,985	12%
N2	2,761,000	20,457	2,781,457	14%
N1	2,543,500	2,826	2,546,326	13%
MM	3,740,700	0	3,740,700	19%
MU	2,077,000	0	2,077,000	11%
Total	19,437,239	26,668	19,463,907	100%

Note: WT – Water table (pre-mining)

Table 3-19: Volumetric quantities of ore to be mined, by lithology (OB35)

Lithological Unit	Above WT (m^3)	Below WT (m^3)	Total (m^3)	% of volume
Detritals	4,256	0	4,256	0.02%
PBD	5,264	0	5,264	0.02%
WA2-	64,660	0	64,660	0.3%
WA1	578,800	0	578,800	3%
N3	7,031,400	7,373	7,038,773	33%
N2	6,277,500	110,950	6,388,450	30%
N1	3,695,500	12,858	3,708,358	18%
MM	3,021,700	6	3,021,706	14%
MU	368,700	0	368,700	2%
Total	21,047,780	131,187	21,178,967	100%

Note: WT – Water table (pre-mining)

3.4.3 Pit Wall Composition

The lithological composition of the exposed pit wall is summarised in Table 3-20, and illustrated in Figure 18.

The most prominent unit exposed on the surface is N2 (30%). Other major units are N1 (19%), N3 (16%) and MM (13%).

Only around 2% of the exposed pit wall comprises rock that was located below the pre-mining water table.

Table 3-20: Areas exposed on pit walls, by lithology (OB35)

Lithological Unit	Above WT (m^2)	Below WT (m^2)	Total (m^2)	% of exposed surface
Detritals	86,234		86,234	6%
PBD	1,838		1,838	0.1%
WA2	50,699		50,699	4%
WA1	75,506		75,506	5%
N3	227,160	2,811	229,971	16%
N2	408,100	23,985	432,085	30%
N1	271,120	5,442	276,562	19%
MM	187,610		187,610	13%
MU	97,796		97,796	7%
Total	1,406,063	32,237	1,438,300	100%

3.4.4 Geochemical Characteristics of Mined Lithologies

Figure 19 illustrates sulfur statistics for materials from OB35. Note that the sample numbers for this pit are smaller than was the case for the OB29. The following comments can be made:

- All materials (waste rock and ore) show similarly low ranges of sulfur values. Median sulfur values lie below 0.1% for all materials, suggesting a low potential for acid generation.
- High maximum sulfur values are observed for many lithologies, but these often represent outliers. For most lithologies, sulfur values greater than 0.1% are not encountered until above the 99th percentile of the dataset (i.e. represents less than 1% of the data). Exceptions were the MM and MU units, where the sulfur cut-off was encountered at the 90th percentile.
- Material sourced from below the pre-mining water table shows lower ranges of sulfur values. (Note, however, that the datasets are smaller for this material category).

Summary statistics for acid potential (AP), neutralising potential (NP), and Fe and Mn content are shown in Table 3-21 (above water table (AWT) material) and Table 3-22 (below water table (BWT) material).

In Table 3-21 and Table 3-22, it can be seen that average AP is generally low, often less than 2 kgH_2SO_4/t. As was the case for OB29 and OB30, estimated NP values are generally low (averages are less than 5 kgH_2SO_4/t). The highest maximum NP is encountered in the Detrital waste rock unit (above the water table), possibly indicative of a calcrete material.

Inferred neutralisation potential ratios (NPRs) showed a trend toward lower values for older stratigraphical units. For example the Detrital waste rock unit (AWT) gave an NPR of 6.2 (i.e. NAF), whilst the MM and MU units gave NPR values less than 1 (i.e. PAF).

Fe and Mn distribution between lithological units shows similar trends to those observed for OB29 and OB30 – namely uniformly high Fe content (with a lower minimum in the Detrital unit), and higher average and maximum Mn contents in the WA2 unit.

Table 3-21: Summary statistics for OB35 above water table materials: Acid-base accounting surrogates and selected metals (Fe, Mn)

	Acid-Base Accounting Surrogates									Distribution of Selected Contaminants							
	AP, kgH_2SO_4/t[1]				NP, kgH_2SO_4/t[2]				NPR[3]	Fe, %				Mn, %			
Lithology	**n**	**Min**	**Ave**	**Max**	**n**	**Min**	**Ave**	**Max**		**n**	**Min**	**Ave**	**Max**	**n**	**Min**	**Ave**	**Max**
Waste Materials																	
Detritals	432	0.2	1.1	44.4	454	0.0	6.8	74.9	6.2	472	0.9	41.0	65.1	58	0.0	0.1	0.2
PBD	No data available for this unit (very small volumetric proportion of mined volumes)																
WA2	79	0.06	0.6	3.2	84	0.3	3.0	17.5	5.1	87	15.0	39.1	64.6	5	0.06	3.4	9.1
WA1	140	0.2	1.0	13.6	142	0.09	3.7	28.9	3.6	147	22.0	48.1	59.0	29	0.008	0.08	0.3
N3	201	0.03	0.7	7.8	213	0.04	2.3	42.1	3.1	239	25.6	51.0	66.0	76	0.008	0.08	0.8
N2	370	0.03	0.9	41.9	371	0.04	1.3	18.8	1.5	410	28.9	50.0	63.7	119	0.008	0.1	0.7
N1	286	0.03	1.2	27.7	286	0.04	1.1	21.1	1.0	306	17.8	49.8	64.4	40	0.008	0.05	0.3
MM	553	0.03	1.6	20.7	553	0.04	0.7	20.8	0.4	611	16.2	50.4	63.7	88	0.008	0.04	0.4
MU	185	0.06	2.0	50.6	185	0.03	0.2	5.5	0.1	199	8.5	47.9	60.1	14	0.02	0.05	0.08
Ore																	
Detritals	2	0.2	0.4	0.6	2	0.1	0.2	0.3	0.6	2	59.1	60.2	61.3	1	0.008	0.008	0.008
PBD	No data available for this unit (very small volumetric proportion of mined volumes)																
WA2	10	0.06	0.3	0.6	10	0.09	0.6	1.9	2.4	12	32.5	55.1	61.5	No data available			
WA1	89	0.06	0.3	1.8	89	0.09	1.1	8.6	3.3	92	29.8	59.0	65.7	14	0.008	0.05	0.1
N3	1161	0.03	0.4	3.4	1171	0.04	0.5	12.0	1.1	1289	33.2	62.7	67.2	419	0.008	0.06	2.2
N2	1009	0.06	0.6	9.4	1009	0.04	0.4	5.9	0.7	1092	39.6	61.7	66.2	324	0.008	0.08	1.3
N1	545	0.06	0.5	2.4	551	0.02	0.4	0.4	0.7	581	34.9	62.1	66.4	100	0.008	0.05	0.3
MM	428	0.03	0.7	5.7	436	0.04	0.5	6.8	0.8	469	44.3	59.7	65.6	63	0.008	0.09	0.4
MU	53	0.2	0.6	4.7	53	0.04	0.3	0.9	0.5	53	58.0	61.6	65.8	No data available			

Notes:

[1] Total S has been used to calculate maximum acid potential - total S (%) multiplied by 30.6 gives units of kgH_2SO_4/t.

[2] Neutralisation potential is inferred on the basis of the sum of the CaO and MgO content, following a conversion to units of kgH_2SO_4/t as follows – CaO (%) multiplied by 17.5 and MgO multiplied by 24.5. A further reduction factor, 0.1, was applied to account for the fact that (i) some proportion of Ca and Mg will be present in non-neutralising minerals, and (ii) based on experience elsewhere in the Pilbara, only a small proportion of neutralisation potential is readily available.

[3] Neutralisation potential ratio (NP/AP) is inferred from the average MPA and inferred ANC values.

Table 3-22: Summary statistics for OB35 below water table materials: Acid-base accounting surrogates and selected metals (Fe, Mn)

	Acid-Base Accounting Surrogates									Distribution of Selected Contaminants							
	AP, kgH_2SO_4/t[1]				NP, kgH_2SO_4/t[2]				NPR[3]	Fe, %				Mn, %			
Lithology	**n**	**Min**	**Ave**	**Max**	**n**	**Min**	**Ave**	**Max**		**n**	**Min**	**Ave**	**Max**	**n**	**Min**	**Ave**	**Max**
Waste Materials																	
Detritals	No data available (most of these lithological units not encountered below the water table. In the case of N3, the volumetric proportion in the mined materials is very low)																
PBD																	
WA2																	
WA1																	
N3																	
N2	5	0.09	0.1	0.2	5	0.2	0.4	0.5	3.5	5	39.3	51.4	57.5	No data available			
N1	1	0.2	0.2	0.2	2	0.5	0.5	0.5	3.0	1	52.1	52.1	52.1				
MM	No data available (these lithological units not encountered below the water table)																
MU																	
Ore																	
Detritals	No data available (these lithological units not encountered below the water table)																
PBD																	
WA2																	
WA1																	
N3	1	0.2	0.2	0.2	1	0.5	0.5	0.5	2.1	1	62.8	62.8	62.8	No data available			
N2	14	0.06	0.2	0.3	14	0.1	0.3	0.7	1.8	19	49.4	63.4	67.2				
N1	2	0.1	0.1	0.2	2	0.4	0.4	0.5	3.2	2	60.1	61.6	63.1				
MM	No data available (these lithological units not encountered below the water table)																
MU																	

Notes:

[1] Total S has been used to calculate maximum acid potential - total S (%) multiplied by 30.6 gives units of kgH_2SO_4/t.

[2] Neutralisation potential is inferred on the basis of the sum of the CaO and MgO content, following a conversion to units of kgH_2SO_4/t as follows – CaO (%) multiplied by 17.5 and MgO multiplied by 24.5. A further reduction factor, 0.1, was applied to account for the fact that (i) some proportion of Ca and Mg will be present in non-neutralising minerals, and (ii) based on experience elsewhere in the Pilbara, only a small proportion of neutralisation potential is readily available.

[3] Neutralisation potential ratio (NP/AP) is calculated from the average MPA and inferred ANC values.

3.4.5 Potential for Acid / Metalliferous Drainage

Estimates of the overall proportion of PAF material present in overburden storage areas (OSAs) and within ore stockpiles are shown in Table 3-23 and Table 3-24, respectively. These estimates combine the volumes of material to be mined (Section 3.4.2), with the geochemical characteristics of the mined lithologies (Section 3.4.4). As was the case for OB29 and OB30, the following assumptions apply:

- There is no selective placement of materials, i.e. the OSAs and stockpiles are random mixtures of the mined lithologies; and
- The proportion of PAF-classed material can be estimated (conservatively) on the basis of the sulfur statistics generated for the AWT datasets.

The distribution of waste zones with greater than 0.1% sulfur is shown in Figure 20.

Table 3-23: Estimation of the proportion of PAF-classed material within overburden storage areas (OB35)

Lithological Unit	% of waste rock volume mined	0.1% sulfur cut-off		0.2% sulfur cut-off	
		Proportion of PAF material in unit[1]	% of PAF material	Proportion of PAF material in unit[1]	% of PAF material
Detritals	19%	3%	0.6%	1%	0.2%
PBD	0.04%	No data		No data	
WA2	4%	1%	0.04%	1%	0.04%
WA1	7%	3%	0.2%	1%	0.1%
N3	12%	3%	0.4%	1%	0.1%
N2	14%	1%	0.1%	1%	0.1%
N1	13%	1%	0.1%	1%	0.1%
MM	19%	10%	1.9%	1%	0.2%
MU	11%	10%	1.1%	3%	0.3%
Total	**100%**		**4.5%**		**1.2%**

Notes: [1] Proportion of PAF-classed material estimated on the basis of the percentile of the AWT dataset that lies above the sulfur cut-off (0.1% or 0.2%). The AWT dataset was used as this was the larger dataset.

Table 3-24: Estimation of the proportion of PAF-classed material within ore stockpiles (OB35)

Lithological Unit	% of ore volume	0.1% sulfur cut-off		0.2% sulfur cut-off	
		Proportion of PAF material in unit[1]	% of PAF material in stockpile	Proportion of PAF material in unit[1]	% of PAF material in stockpile
Detritals	0.02%	0%	0%	0.0%	0.00%
PBD	0.02%	No data	-	No data	-
WA2	0.30%	0%	0%	0.0%	0.00%
WA1	3%	0%	0%	0.0%	0.00%
N3	33%	1%	0.33%	0.0%	0.00%
N2	30%	1%	0.30%	0.2%	0.06%
N1	18%	0%	0%	0.0%	0.00%
MM	14%	3%	0.43%	0.0%	0.00%
MU	2%	1%	0.02%	0.0%	0.00%
Total	**100%**		**1.10%**		**0.06%**

Notes: [1] Proportion of PAF-classed material estimated on the basis of the percentile of the AWT dataset that lies above the sulfur cut-off (0.1% or 0.2%). The AWT dataset was used as this was the larger dataset.

Table 3-23 suggests that OSAs may contain around 5% PAF material if a 0.1% sulfur cut-off is used, and around 1% PAF material if a 0.2% sulfur cut-off is assumed. Most of this PAF material is contributed by the MM and MU units. Figure 20 is an image of the pit volume showing the distribution of waste rock that contains more than 0.1% sulfur.

The PAF estimates are considered overestimates, because:

a) The datasets are relatively small (428 samples of MM and 53 samples of MU). Therefore, a small number of high sulfur values may be result in a disproportionately high estimate for PAF material volume. At OB29 and 30, fewer high sulfur values were observed.

b) Acid potential has been overestimated by assuming all sulfur is sulfidic.

c) No credit has been taken for NP that might be present within the mined rock.

As was the case with OB29, the presence of PAF materials within the OSA introduces the potential for generation of acid and metalliferous drainage within these facilities. The proportion of PAF material is lower than was the case for OB29, and so the potential for AMD is likely to be less. However, cannot be quantified accurately in the absence of more detailed geochemical data.

Table 3-24 suggests that the proportion of PAF material in ore stockpiles will be very low, around 1% if the 0.1% sulfur cut-off is used, and less than 0.1% if the 0.2% sulfur cut-off is applied. The small proportion of PAF, combined with the expected short duration of ore storage, suggest that the potential for AMD from stockpiles will be low to negligible.

Estimates of the overall proportion of PAF material exposed on the pit walls are shown in Table 3-25. These estimates combine the surface areas of materials exposed (Section 3.4.3), with the geochemical characteristics of the mined lithologies (Section 3.4.4). The proportion of PAF material is low, with estimates of 3.3% (0.1% cut-off) and 1.1% (0.2% cut-off).

Figure 21 is an image of the OB35 pit shell showing the location of exposed rock with high sulfur values (i.e. above the 0.1% sulfur threshold). As was the case with OB29, the sulfur-bearing material forms isolated ‘hot-spots’ located near the crest of the pit walls. As these locations lie above the expected level of the final pit lake surface (which is assumed to be below the pre-mined water level), they could represent a source of AMD contributing to solute load in pit wall runoff.

Table 3-25: Estimation of the proportion of PAF-classed material exposed on pit walls (OB35)

Lithological Unit	% of Exposed Pit Wall	0.1% sulfur cut-off		0.2% sulfur cut-off	
		Proportion of PAF material in unit[1]	% of PAF material exposed on pit wall	Proportion of PAF material in unit[1]	% of PAF material exposed on pit wall
Detritals	6%	3%	0.18%	1%	0.06%
PBD	0.10%	No data		No data	-
WA2	4%	1%	0.04%	1%	0.04%
WA1	5%	3%	0.16%	1%	0.05%
N3	16%	3%	0.48%	1%	0.16%
N2	30%	1%	0.30%	1%	0.30%
N1	19%	1%	0.19%	1%	0.19%
MM	13%	10%	1.30%	1%	0.13%
MU	7%	10%	0.68%	3%	0.20%
Total	**100%**		**3.30%**		**1.13%**

Notes: [1] Classification based on sulfur cut-off thresholds (0.1%and 0.2%). Proportion of PAF-classed material estimated on the basis of the percentile of the AWT dataset that lies above the sulfur cut-off. The AWT dataset was used as this was the larger dataset.

3.5 Comparison of the Orebodies

Based on the descriptions provided in the preceding sections there are some differences in the geochemical characteristics of key lithological units from pit to pit. The most significant of these relates to the sulfur characteristics of the Detritals, PBD and WA2 units. The range of sulfur content of these units was higher in the OB29 pit than in the other pits. These differences may reflect variability in the abundance of sulfur in the overburden sequences from east to west across the project area, or may simply be an artefact of the different sizes of the available datasets. For example, the OB29 AWT dataset included 1258 sulfur analyses for the Detrital unit whilst the OB30 and OB35 sulfur datasets for these units were only 113 and 432, respectively.

As shown in Figure 22, the lithological composition of waste rock in the OSA also differs from orebody to orebody. In OB29, the Detritals, PBD and WA2 units are the most abundant. These high volumetric quantities, combined with the higher sulfur ranges observed for these lithologies at this orebody, result in estimation of higher PAF quantities for the OB29 OSA (Table 3-26).

In the case of the OB35 OSA, most of the PAF material was sourced from the MM and MU units. These units each were found to contain up to 10% PAF material using the 0.1% sulfur cut-off. Using a 0.2 % sulfur cut-off the proportions of PAF materials decrease to about 3% for the MU and about 1% for the MM.

Table 3-26: Comparison of PAF contribution to Waste Rock

Orebody	Estimated Proportion of PAF in OSA	
	0.1% sulfur cut-off	0.2% sulfur cut-off
OB29	11.2%	6.1%
OB30	No OSA: waste reports to Mt Whaleback Operation	
OB35	4.5%	1.2%

Figure 23 is a comparison of the composition of the pit wall from pit to pit. In all the pits, exposed rock is dominated by iron formation units, e.g. MM, MU, N1, N2 and N3. High sulfur content materials (i.e. sulfur values above the 0.1% threshold) have been shown to form isolated ‘hot-spots’ on the pit wall, often located near the pit crests. This is the case for all three pits.

4 Preliminary Risk Evaluation

4.1 Source-Pathway-Receptor Analysis

4.1.1 Sources

The potential sources considered include:

- OSAs;
- Stockpile areas;
- Exposed pit walls; and,
- Pit lakes.

The potential for the first three of these sources to contribute AMD has been described in the preceding section (on a pit by pit basis). In summary, ore stockpiles are considered to represent a low to negligible source of generate AMD, whilst OSAs could represent a source of AMD due to the presence of small volumes of PAF-classed materials. The highest potential was associated with the OB29 OSA. On the pit walls (particularly in the case of OB29 and 35) there are isolated locations where the sulfur content is above the assessed 0.1% and 0.2% thresholds. As these locations lie above the expected level of the final pit lake surface, they could represent a source of AMD and contributing to solute loads in runoff.

Pit lakes in the Pilbara region, where evaporation is significantly higher than precipitation, are typically modelled as equilibrating with water levels well below the pre-mining water table, and the pits acting as indefinite groundwater sinks. This results in a long term cone of depression forming around a pit, and the pit water quality gradually becoming increasingly saline due to evapo-concentration.

The base case assumed in this AMD risk assessment is that the pit voids will not be backfilled. An alternative to the base case option is partial or complete backfilling of the final voids.

If the final pits remain as open voids, the resultant water level in the void will be controlled by the surrounding aquifers, local groundwater recharge, surface water runoff, direct precipitation and evaporation. Surface runoff and inflow will be restricted by bunding around the pits. As the pit water level rises, groundwater inflow rates will decrease as the hydraulic gradient towards the pit declines. Evaporative losses will increase due to the increased surface area of the lake as the water elevation rises. The equilibrium level of water in the pit will be determined by the net balance of inflow (groundwater, runoff/surface water) and evaporative losses.

For OB29/30/35, RPS Aquaterra (2013) assessed that final pit lake levels may be "*only several tens of metres*" below the pre-mining water table, and that the salinisation rate of pit water is considered to be slow (typically less than 5000 mg/L every 100 years), until hypersaline conditions develop. If density driven hypersaline plumes are formed, it is considered that the plumes would be contained within "*pods of sub-grade mineralisation beneath the pits*", and thus any impacts would be localised (RPS Aquaterra, 2013).

Following the AMD risk assessment (based on the available data) it is considered that the sulfate loading contributions to the pit lakes resulting from exposed pit walls and OSA seepage are likely to be small compared to the sulfate inputs from baseline (background) groundwater flow. Even without the influence of AMD from pit wall runoff or OSA seepage (should the location of the OSAs lie within the catchment for the pit lake), it is likely that the quality of water in the lake would deteriorate over time due to evapo-concentration.

As an indicator of initial pit lake conditions, the groundwater sulfate analyses from the OB29 boreholes, screening the Marra Mamba, ranged between 38-65 mg/L. Regional water quality results for raw (source) water from the greater Newman Water Reserve has sulfate concentrations of 50-110 mg/L (Department of Water, 2009).

Further to the base-case scenario, partial or completely backfilled pit scenarios have been considered, incorporating the following assumptions indicated by BHPBIO:

- All three pits could be backfilled (OB29/30/35);
- The pits could be backfilled to either the pre-mining water table level or to a level that does not result in development of a pit lake; and
- Backfill material would be non-acid forming (NAF), and would not include PAF classed material (i.e. S content in excess of 0.1%). Potentially acid forming material would be stored in OSAs.

It is acknowledged that in some instances storage of PAF materials below the water table provides environmental impact mitigation (when relatively rapid and permanent submersion of the material can be ensured, efficiently reducing the transport of oxygen to the material), however, placement of PAF as backfill is not currently being considered by BHPBIO.

Completely backfilled or partially backfilled scenarios where the voids are backfilled either to above the pre-mined water table level, or to a level that does not result in the development of a pit lake (i.e. above the predicted long term steady state lake elevation), evaporative losses would decrease and would result in a net positive water balance for the final void. RPS Aquaterra (2013) reported that evaporative losses may be overcome by a thickness of 3-5m of waste rock infill. Therefore, depending on the final elevation of the backfill, is possible that either a through-flow or a recharge pit would form (RPS Aquaterra, 2013). Where partial backfill remains below the predicted long term steady state water elevation, the final void would remain a net water sink, and would emulate the base case.

A through-flow pit occurs where the water table recovers to pre-mining levels and groundwater flows as per the pre-mined conditions from upgradient of the pit to downgradient. This is most likely to occur for a completely backfilled pit where pre-mining conditions may be re-established.

A recharge pit forms where infiltration is increased within the pit (e.g. due to surface water runoff from surrounding catchments entering the pit or due to the inherent higher permeability of the backfill materials compared with the country rock) and a localised water table mound may develop within the pit area. A water table mound within the pit area would result in localised radial flow from the pit.

Whether a through-flow or recharge pit develops, solute loads initially could be higher (compared with inflowing groundwater quality) due to contact with the backfill materials. As the pit water would be continually flushed, and the potential for evapo-concentration effects would be reduced, the resultant water quality within the pit is likely to improve over time as the readily soluble mineral phases are depleted and flushed away.

Selective placement of PAF material to below the long term water table elevation would prevent future oxidation of the sulfide minerals. As such the overall risk of acid generation would be mitigated. Short term release of solutes will however occur due to oxidation that would have occurred while the PAF remained unsaturated prior to the recovery of the water table. At the current time, BHPBIO do not plan to place PAF material in the pit voids – although they may consider back-filling using NAF material. Backfilled materials that are not acid generating (and not a source of potential acidity) may however represent a source of solutes in the short term (i.e. neutral drainage). The pit walls may also contribute AMD and/or solutes, as there are isolated locations where the sulfur content on the walls is above the assessed PAF thresholds (particularly in the case of OB29 and OB35).

At present, detailed geochemical information is not available (e.g. sulfur speciation, acid neutralising capacity, static and kinetic leach data to describe contaminant leachability and key reaction rates) to allow an assessment of the potential solute loads that could be expected in OSA seepage, pit wall runoff, or from backfilled materials. However, as the quantities of PAF materials are invariably low, it is considered that potential for AMD is similarly low – but cannot be discounted.

4.1.2 Pathways

The following potential pathways have been identified:

- Seepage from the OSAs/stockpiles surface water or percolate to groundwater;
- Transport of solutes in runoff from pit walls to the pit lake; and,
- Transport of solutes from the pit lake (or backfilled materials) to groundwater (or surface water for the completely backfilled scenario).

The main potential surface water pathways are:

- Whaleback Creek – the most proximal creek to which OB29, OB30 and OB35 drain;
- Southern Creek – cuts through the proposed OB35 pit shell and OSA (diversion proposed to the west of OB35, joining Whaleback Creek upstream of OB35);
- Fortescue River – to the east of OB29, 30, and 35, to which Whaleback Creek is a tributary; and
- Discharges of surplus dewatering water to the Ophthalmia Dam (located on the Fortescue River), in accordance with the current Part V licence.

Regional groundwater flow is generally toward the northeast. However with a post-closure open pit, acting as a groundwater sink, local groundwater flow would be towards the pit lake. Therefore environmentally deleterious water would be contained within the pit, and would not present a significant risk to the key environmental receptors (i.e. Ophthalmia Borefield and Ethel Gorge located over 10 km from the proposed pits).

The Whaleback deposit and the OB29, 30 and 35 locations appear to occur within two separate hydrogeological regimes (e.g. Whaleback groundwater drawdown effects are not observed in the OB29/30/35 area). For this reason it is anticipated that groundwater pathways will not represent a means for solute transport between these distinct regions.

The current and proposed surface water management infrastructure for OB29, 30 and 35 has been reviewed (Aquaterra, 2005; Aquaterra, 2006; and RPS Aquaterra, 2011) to identify pathways for surface water drainage (that may potentially be impacted by AMD) to nearby surface water receptors (i.e. Whaleback Creek, Southern Creek). This review identified that:

- Potential pathways exist with surface runoff from the OB29 South OSA in the southwestern corner of the OB29 catchment flowing towards Whaleback Creek, and surface water flow from the ROM pad flowing towards Whaleback Creek via natural drainage, or into the OB29 pit (Figure 3).
- Flood protection bunding is present in two sections between the OB30 pit and Whaleback Creek, and as a result there is limited potential for surface water drainage pathways towards the creek at these locations, however a section which does not appear to have bunding is present to the south of the central section of the pit (Figure 4). It is noted that there are no (current or proposed) OSAs adjacent to OB30, and waste materials from OB30 are being accommodated by Mt Whaleback waste facilities.

- Perimeter bunding is proposed around the northern edge of the OB35 OSA, which would prevent surface water runoff from the OSA draining directly to Whaleback Creek. Shallow channelling with sediment traps are proposed to capture the runoff from the OSA (Figure 5 and Figure 6).

Surface water will be appropriately managed, in line with current BHPBIO management practice, to prevent significant surface water inflow to the pits.

4.1.3 Receptors

The potential receptor areas, as described in Section 2.5, include:

- Cathedral Gorge;
- Fortescue River (incorporating Ophthalmia Dam and Ethel Gorge);
- Whaleback Creek;
- Southern Creek;
- Ophthalmia Dam (amenity and human health); and
- Newman Water Reserve public drinking water source protection zones (Priority 1 and Priority 3) (human health).

In terms of flora and fauna, no high risk groundwater dependant vegetation species have been identified in the study area (Onshore Environmental, 2013). The closest Threatened Ecological Community (TEC) is the Ethel Gorge Aquifer Stygobiont Community, located on the Fortescue River.

The following sections outline a preliminary assessment of the risk posed to these receptors / flora and fauna by the proposed above and below water table mining at OB29, 30 and 35.

Surface water accounts for a large contribution to groundwater recharge, and therefore, any potential risks posed by AMD from mining activities to surface water quality should be considered in relation to being protective of both surface water ecology and drinking water quality.

As detailed in Section 5.1.1, relatively small volumes of PAF-classed materials have been identified within the waste materials to be mined and on the exposed pit walls, and therefore there is limited potential for AMD generation from OB29, 30 and 35.

Very few metal analyses were available for review, and the distribution of environmentally significant elements of concern within the mined materials (e.g. Cu, Cd, Zn, As and Se) could not be determined. Similarly, no leach testing has been conducted to date, and the potential metal concentrations and loadings in runoff (from OSAs, pit walls or pit backfill materials) could not be determined. Therefore, potential impacts from site drainage to surface water bodies and groundwater cannot be ruled out.

Potential pathways from the OB29/30/35 sites to proximal surface water receptors (i.e. Whaleback Creek, Southern Creek), including potential surface water runoff and shallow groundwater flowpaths from OSAs should be further assessed in order to determine if these pathways are active and have the potential to impact the surface water receptors. Further surface water management mitigation engineering may be required if significant AMD pathways are identified, in order to reduce the risk of AMD release and impacts on receptors.

During the operational phase, pit dewatering discharge is proposed to be fed into the Whaleback process water supply system, with excess water directed via the Newman Joint Venture water infrastructure to the existing approved discharge locations at Ophthalmia Dam and the nearby Aquifer Recharge Scheme infiltration ponds. These discharges should be protective of aquatic ecology sensitivity and drinking water requirements.

Standard BHPBIO rehabilitation and closure protocol, in construction of landform structures would be anticipated to minimise contact of water with OSA material, and therefore reduce AMD risk to environmental receptors (i.e. Whaleback Creek and Southern Creek).

Due to the limited availability of geochemical data, specifically in relation to metal contents and leaching potential, a detailed assessment of risks posed to individual flora and fauna species from the potential generation of AMD at OB29, 30 and 35 is not possible.

As an indicator of current conditions, it is noted that screening of the available surface water quality monitoring results from Whaleback Creek against ANZECC Freshwater Trigger (95%) guideline values identified that copper has been elevated both upstream (WBSW042) and downstream (WBSW043) of the OB29/30/35 (and Mt Whaleback) locations, and zinc exceedances were identified at the downstream monitoring location. BHPBIO advise that these surface water monitoring locations are representative of the OB29/30/35 and Whaleback area.

5 Conclusions

BHPBIO has not yet classed any mined materials from the OB29, 30 and 35 pits as PAF. This is largely because no stratigraphic units previously recognised to pose a risk of acid generation have been intersected by mining. For example, the Mount McRae Shale is not represented within the mined volumes, nor is the Jeerinah formation.

The AMD assessment evaluated the potential for the mined lithologies from OB29, 30 and 35, present above and below the water table, to generate acid. Material was assessed as potentially acid forming (PAF) using two sulfur thresholds. A threshold of 0.2% sulfur was applied in line with the current BHPBIO practice for PAF classification, and a more conservative threshold of 0.1% (in recognition of the limited nature of geochemical data currently available) was also assessed.

Based on the AMD assessment, the majority of materials represented in the mined volumes for OB29, 30 and 35 have a low to negligible potential to generate acid, supporting current BHPBIO management strategies. However, the assessment has identified the potential presence of some PAF material. In the case of ore grade materials, the proportion of PAF rock was very low, with less than 2% of the volume classed as PAF using the 0.1% S threshold (and less than 1% of the volume using the 0.2% S threshold). These materials were considered to represent a low to negligible risk of AMD based on the low volumetric proportion combined with expected short duration of storage within stockpiles.

Within the OSA waste rock volumes, the estimated proportions of PAF classed materials increased to around 5% for OB35 and 11% for OB29 based on a 0.1% S threshold, and around 1% for OB35 and 6% for OB29 based on a 0.2% S threshold. [Mined waste rock from OB30 will report to the Mt Whaleback operation and was therefore outside the scope of this AMD assessment].

The lithological units that contributed most toward the PAF content of the OSAs were:

- The Detrital, PBD, WA2 and WA1 units at OB29: These units were found to contain significant concentrations of sulfur; between 10 and 20% of the sulfur analyses were above a 0.1% sulfur threshold (5-12% analyses were above 0.2% sulfur). The equivalent units at OB30 and OB35 did not include such a high proportion of high sulfur values, introducing the possibility that some kind of sulfur mineralisation is exclusive to the OB29 location. Since it is not known whether the sulfur is present in sulfidic form, it is possible that the acid potential has been overestimated.
- The MM and MU units at OB35: For these units, up to 10% of the S analyses were above a 0.1% (and up to 3% were above 0.2%). There is some uncertainty as to accuracy of this assessment due to the small number of analyses available. At OB29 and 30, these units did not contain significant sulfur concentrations.

Most of the other lithological units contained only a small number of sulfur analyses in excess of a 0.1% threshold – usually outliers within the dataset, representing between 1 and 5% of total number of analyses (and only up to 1% of the S analyses were above 0.2%).

In general, material mined from below the water table was found to contain less sulfur than the equivalent materials from above the water table. Note however that the below water table datasets were smaller.

The potential for AMD generation cannot be quantified accurately without more detailed geochemical data. For example, no information was available to assess sulfur speciation and to determine the available neutralising potential. Similarly, with respect to metal leaching, very little information is available. As a result the distribution of many elements of interest within the mined materials (e.g. Cu, Cd, Zn, As and Se) could not be assessed and no leach testing has been conducted to determine the mobility and release rates of these contaminants.

Standard BHPBIO rehabilitation and closure protocol, in construction of landform structures would be anticipated to minimise contact of water with OSA material, and therefore reduce any potential AMD risk to environmental receptors. Nevertheless, the potential for AMD from the OSAs is considered to be low, but cannot be discounted completely. This conclusion is based on calculated MPA values and inferred ANC values. Whilst it is probable that the MPA based on total sulfur results in and overestimation of the acid generation, the basis for estimating the ANC from the CaO and MgO similarly may result in an overestimation. Furthermore, based on experience elsewhere, the actual availability of the ANC may be substantially less than that inferred by this method. Therefore it would be prudent to undertake some degree of verification of the approach adopted herein.

The potential for AMD in pit wall runoff is considered to be low. The overall proportion of high sulfur material exposed on the pit walls is low (less than 5% exposure using the 0.1% sulfur threshold, and less than 2% exposure using the 0.2% sulfur threshold). It is however noted that the sulfur-bearing material forms isolated ‘hot-spots’, generally located near the crest of the pit walls. As these locations lie above the expected level of the final pit lake surface, it is possible they could represent a small source of solute load in pit wall runoff.

In the absence of leach data, it has not been possible to assess the potential for saline drainage from the materials. It is possible that soluble salts are present, particularly in materials mined from near-surface locations. Such salts could leach readily resulting in short-term pulses of salinity in contact waters.

Potential pathways and receptors for AMD from OB29/30/35 have been identified. However, impacts on receptors are difficult to quantify based on current information. Should pits remain as open voids post closure, they should act as indefinite sinks for groundwater and capture some seepage and runoff from OSAs. Under this scenario, although the pit lakes would be anticipated to salinise over time due to evapo-concentration, impacts on the key environmental receptors would be unlikely.

If the pits were backfilled partially to above the regional groundwater table, or completely, regional groundwater flow would be re-established and flow pass through the backfill. Solutes contained in the backfill below the water table would be released to the groundwater and ongoing solute loading may occur from the waste above the water table and the wall rocks. Selective placement of PAF materials below the water table would mitigate future oxidation and therefore would reduce the overall risk of acid generation and impacts on the environmental receptors. At the current time, BHPBIO do not plan to place PAF material in the pit voids – although they may consider back-filling using NAF material. Partial backfilling to below the predicted long term steady state water elevation would result in an indefinite groundwater sink as described for the pit lake scenario.

No data were available to assess the potential for spontaneous combustion. None of the mined materials were from the Mount McRae Shale, a unit known for the combined presence of sulfidic and carbonaceous materials (i.e. high risk for spontaneous combustion). However, a significant proportion of waste rock volume is from the Detritals (particularly at OB29); elsewhere in the Pilbara, lignite within the Detritals has been recognised as a potential source of spontaneous combustion. The Detritals at OB29 appear to contain significant sulfur; should any of this material be lignite, then there may be a spontaneous combustion risk.

Project Code: BHP107

Report Title: Orebodies 29, 30 and 35: Preliminary Acid and Metalliferous Drainage Risk Assessment

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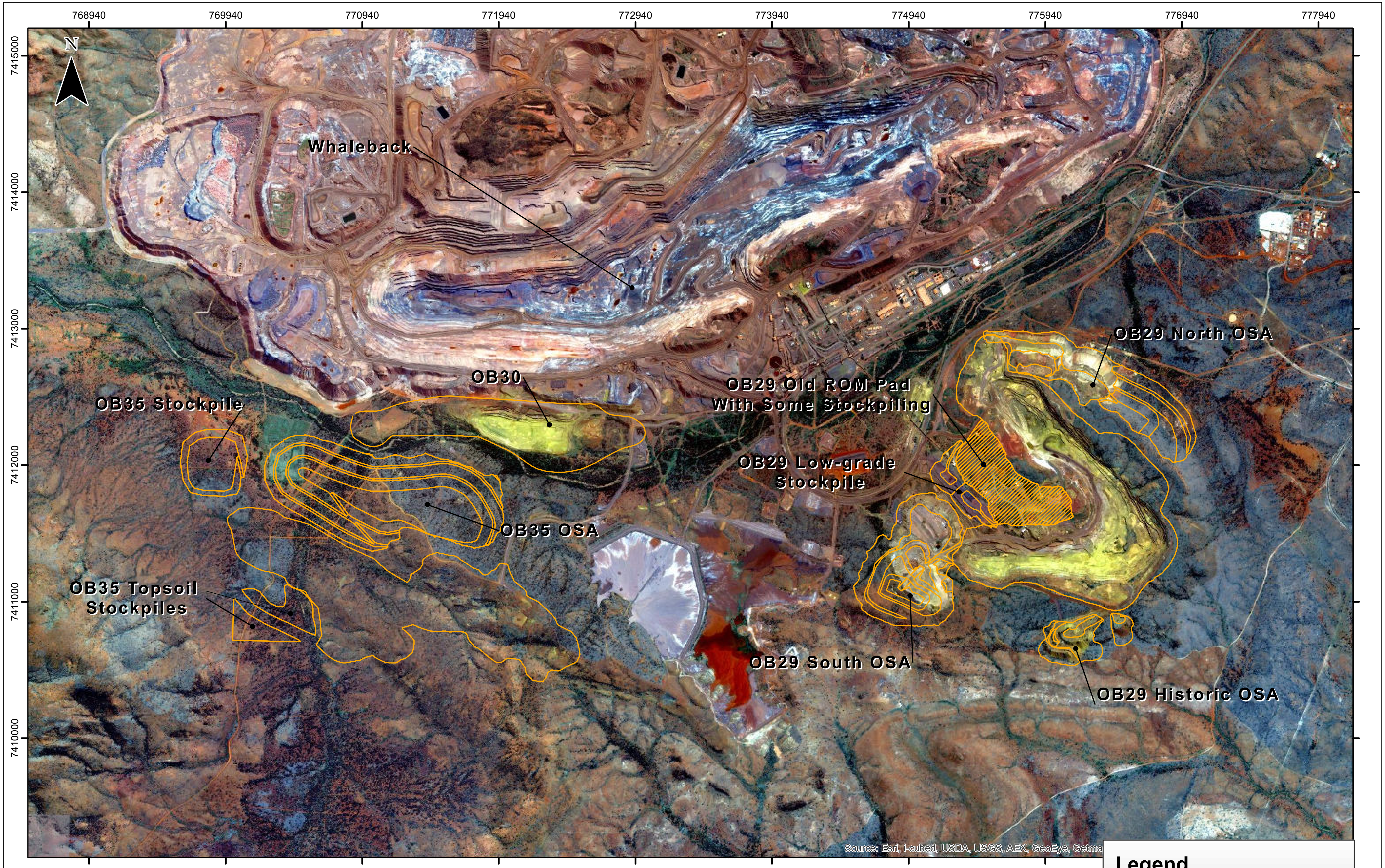
Figures



Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getma

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Orebody 29, 30 and 35 Layout Plan

Figure 1

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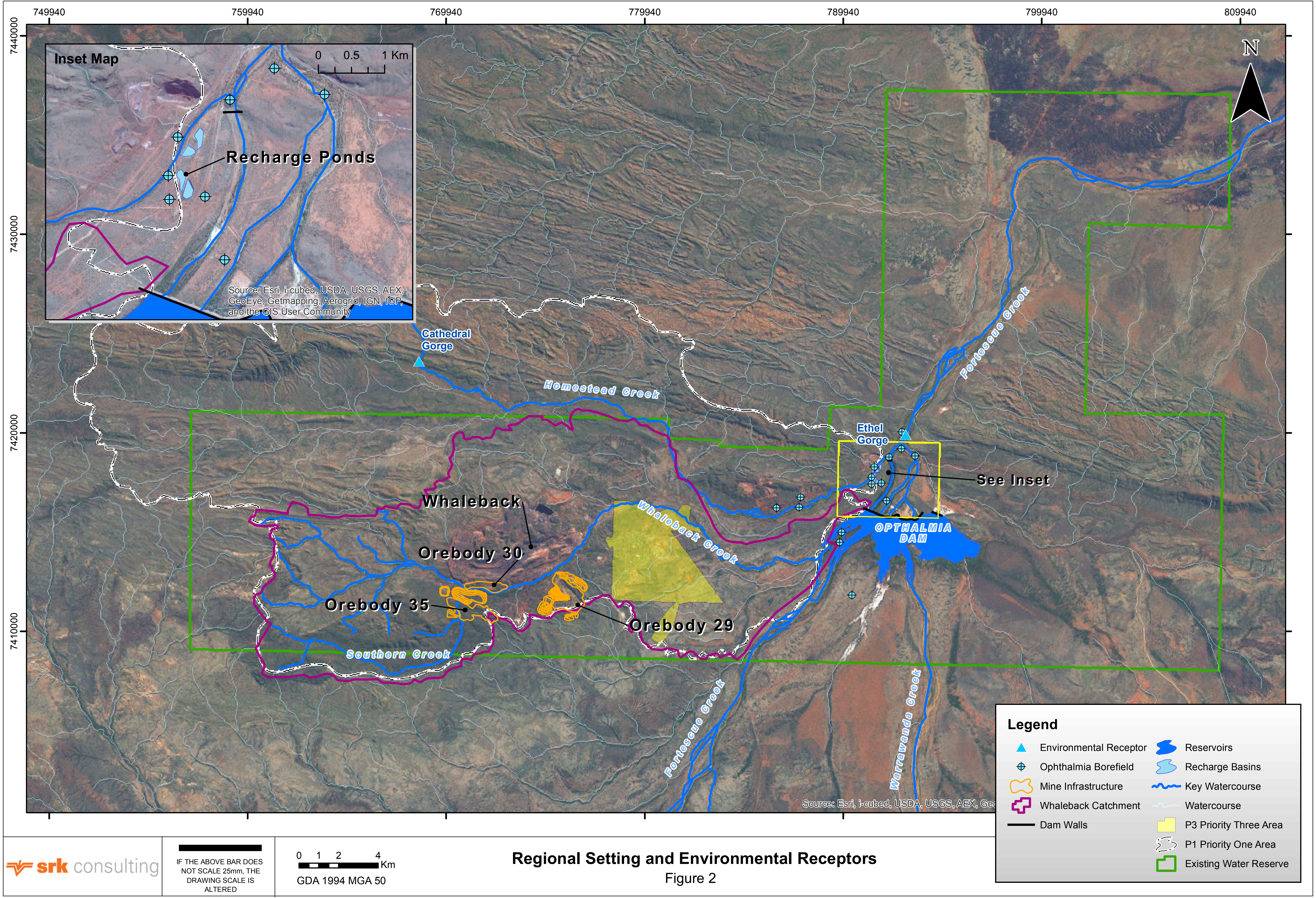
Revision: C Date: 18/06/2013



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Regional Setting and Environmental Receptors

Figure 2

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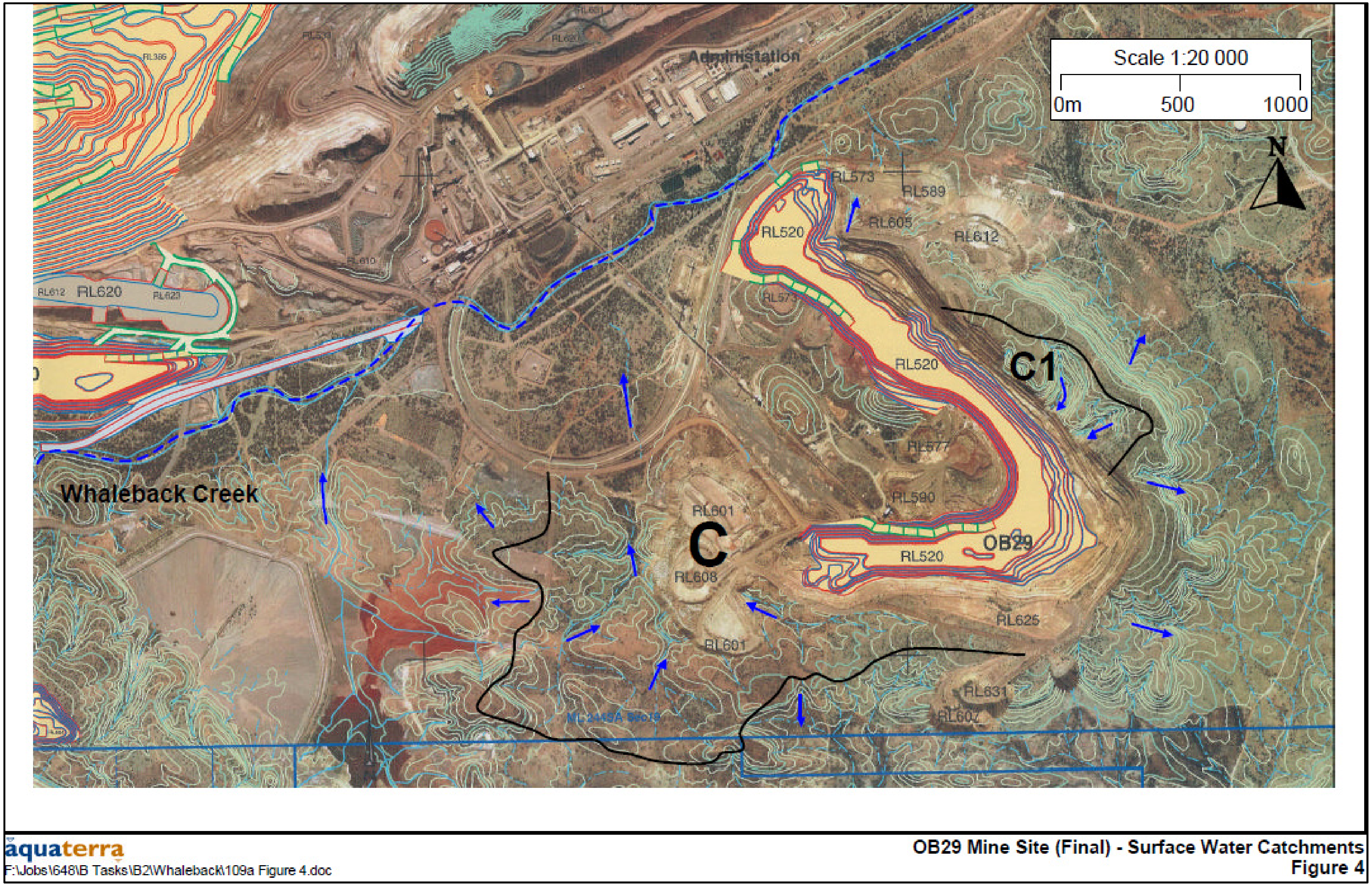


Figure 3: **OB29 surface water catchment**

Source: Aquaterra, 2006

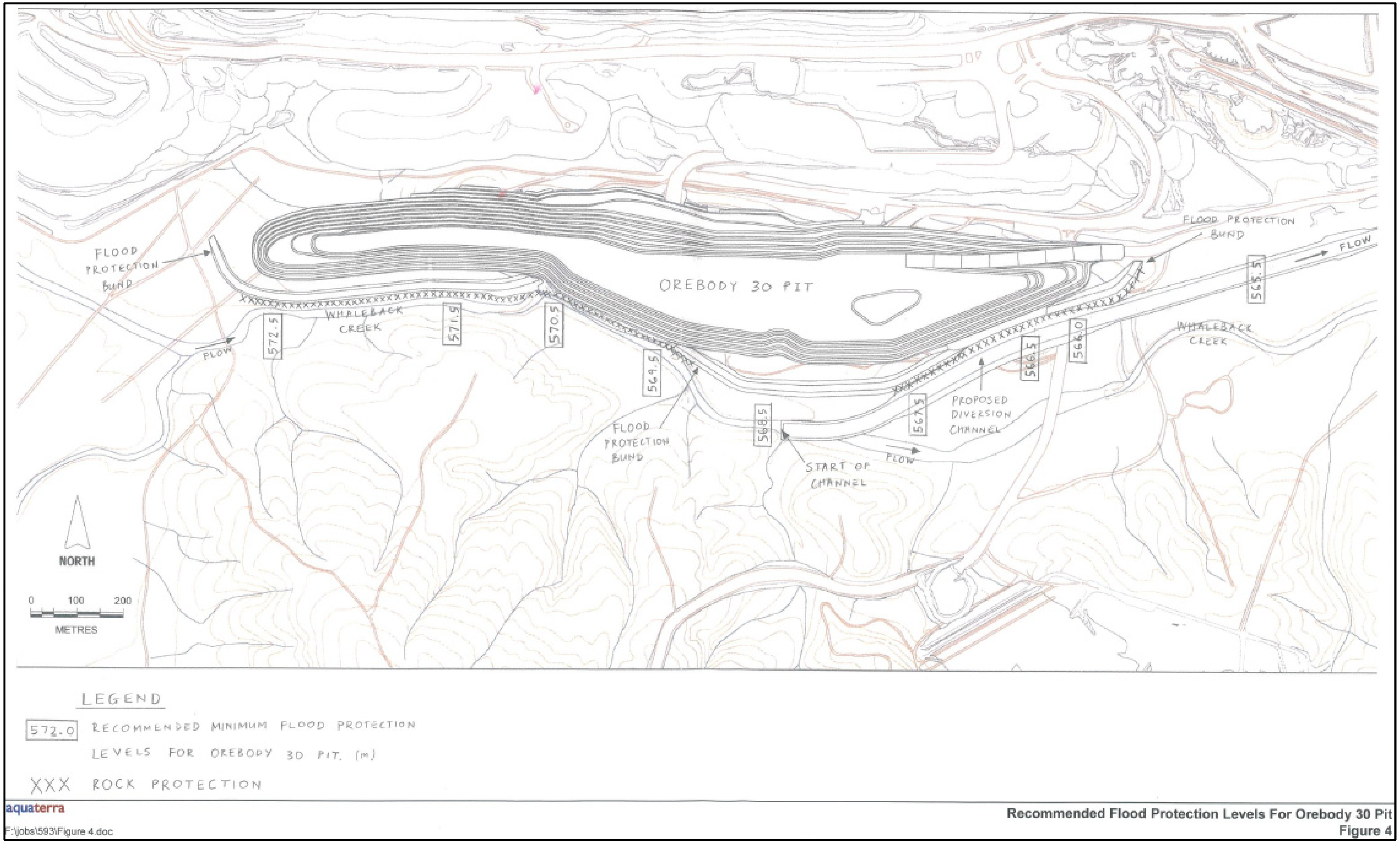


Figure 4: OB30 surface water catchment

Source: Aquaterra, 2005

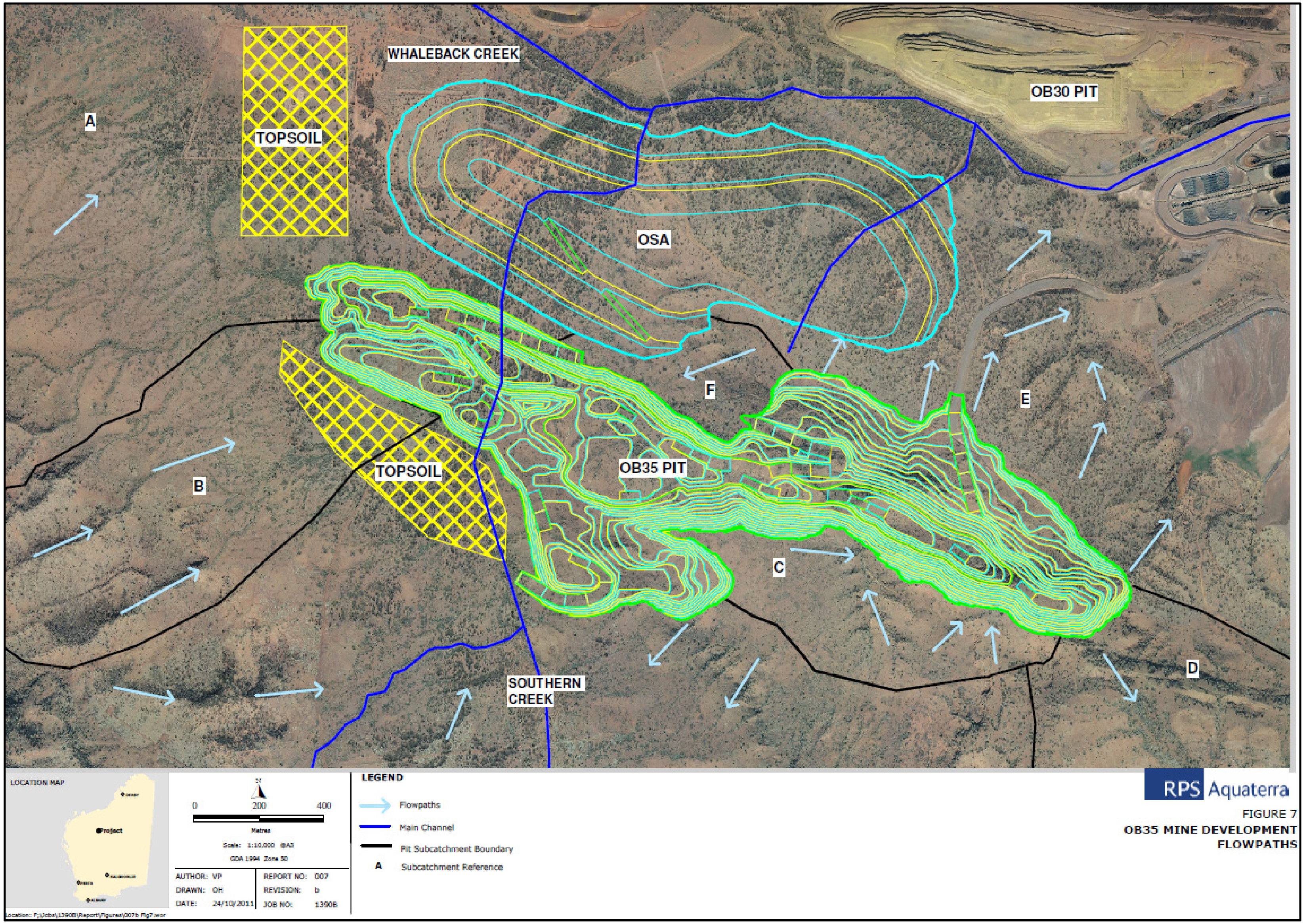


Figure 5: OB35 mine development flow paths

Source: RPS Aquaterra, 2011

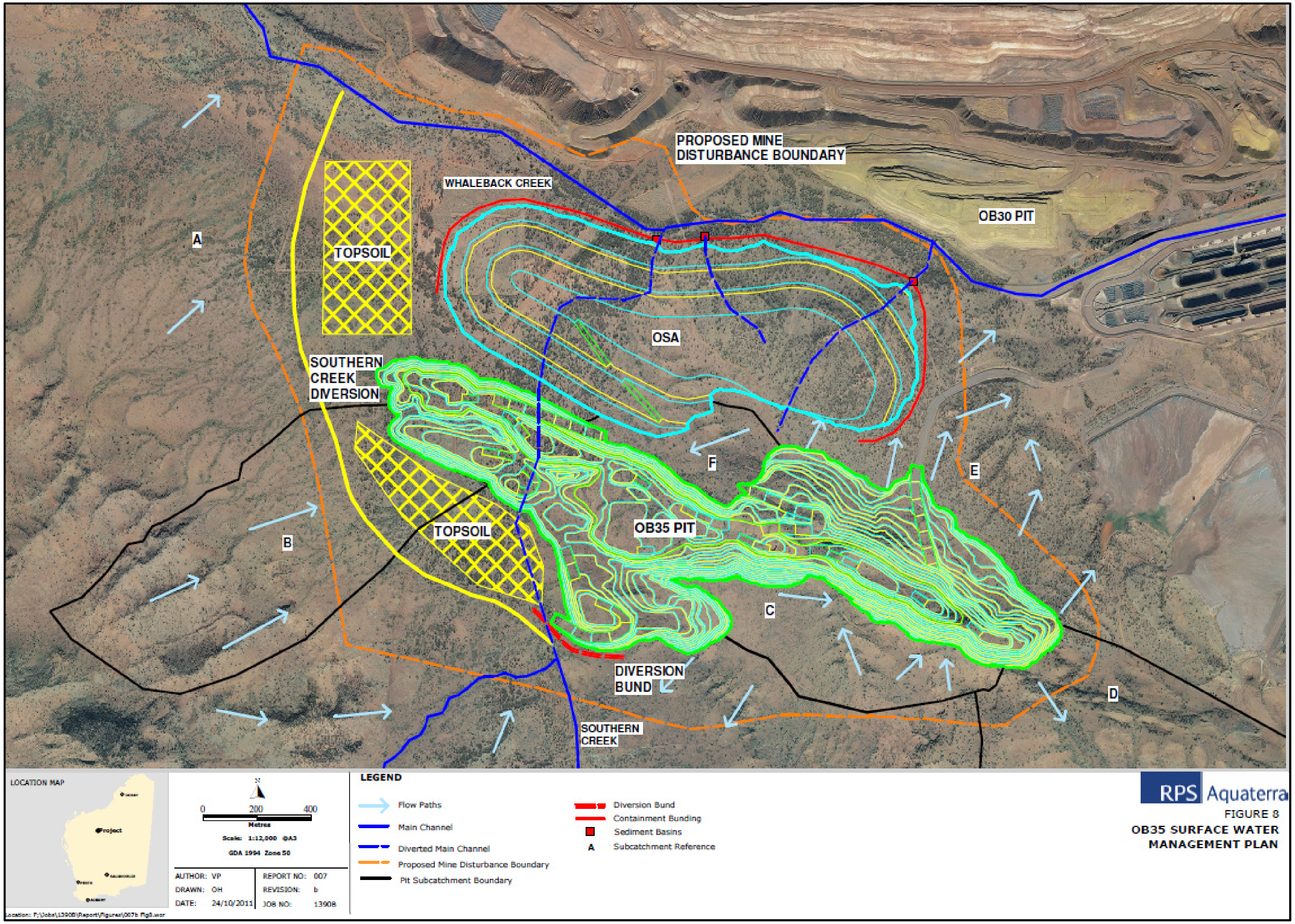
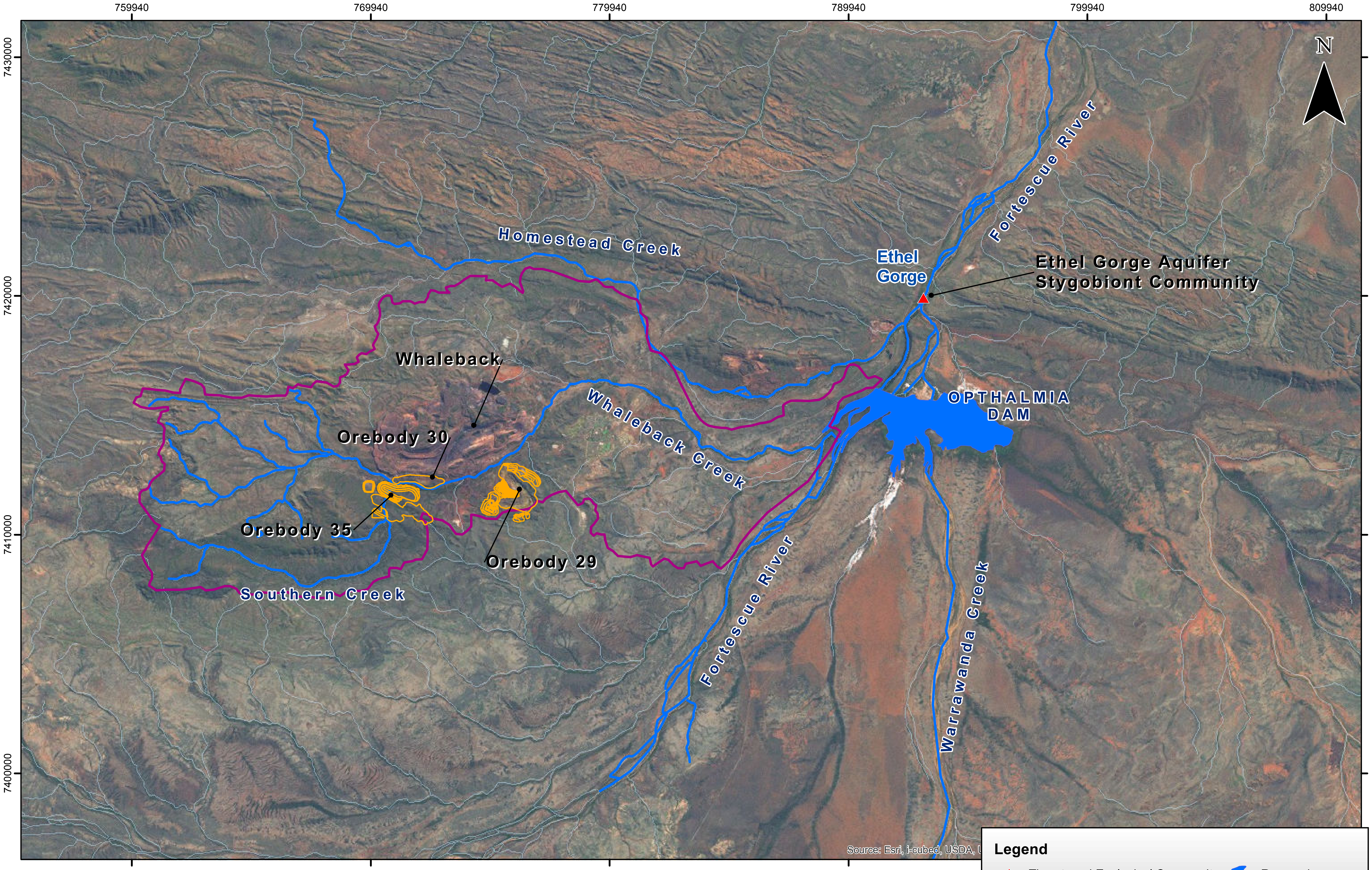


Figure 6: OB35 Surface Water Management Plan

Source: RPS Aquaterra, 2011



Source: Esri, i-cubed, USDA, U

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Identified Threatened Ecological Communities

Figure 7

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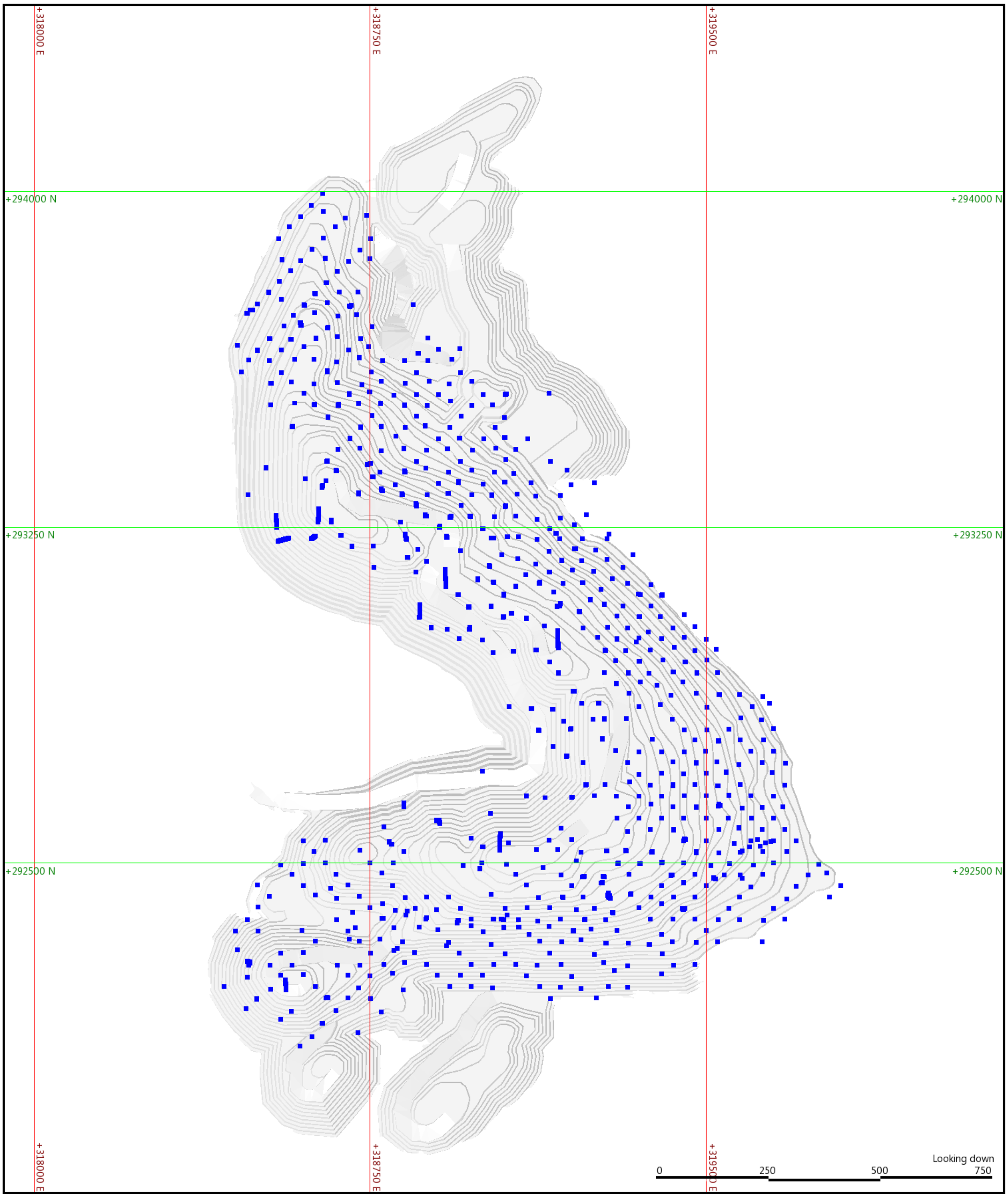


Figure 8: Image of OB29 pit shell showing spatial distribution of drill holes with sulfur data

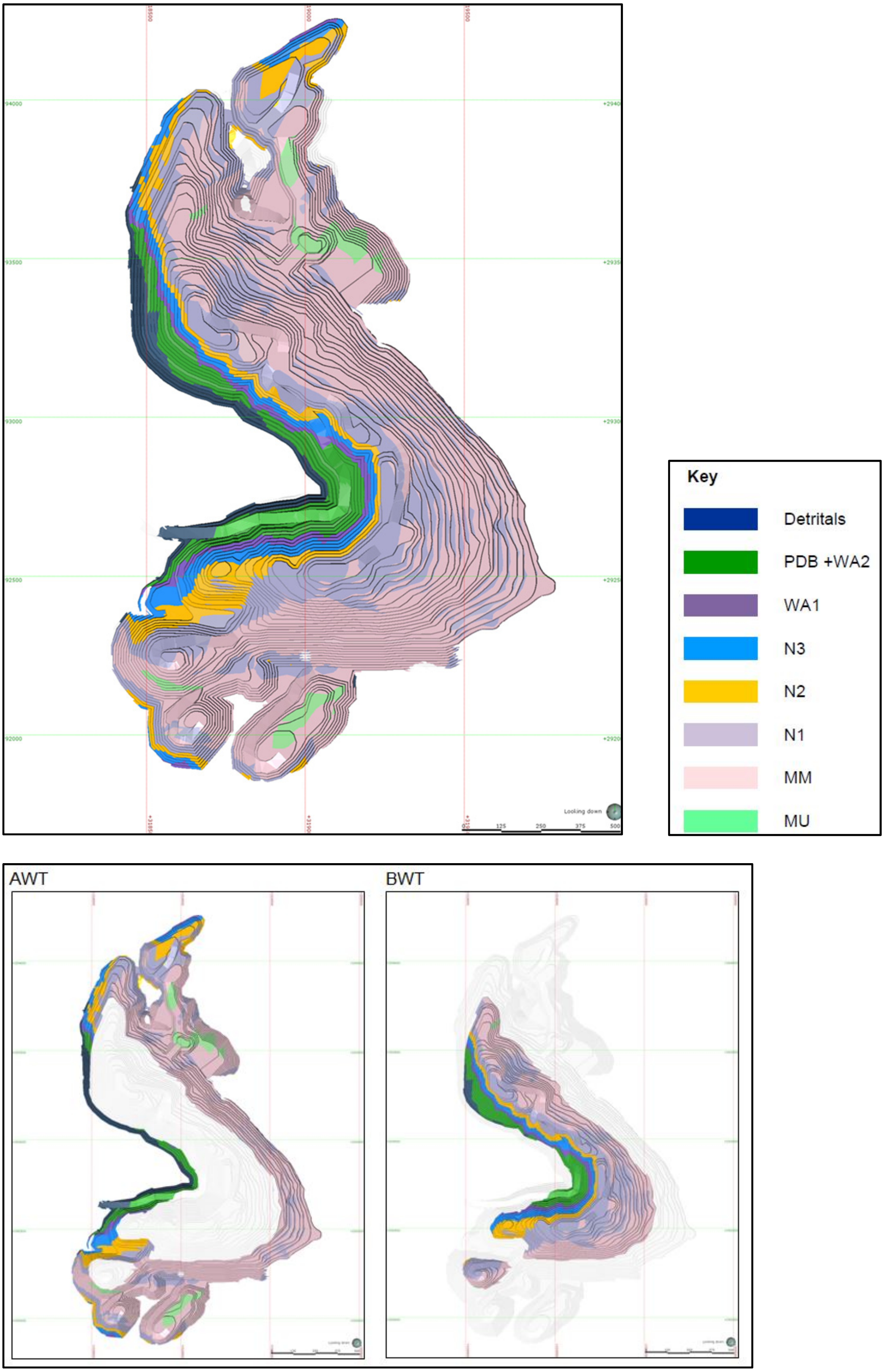


Figure 9: **Image of OB29 final pit shell showing exposed lithologies**

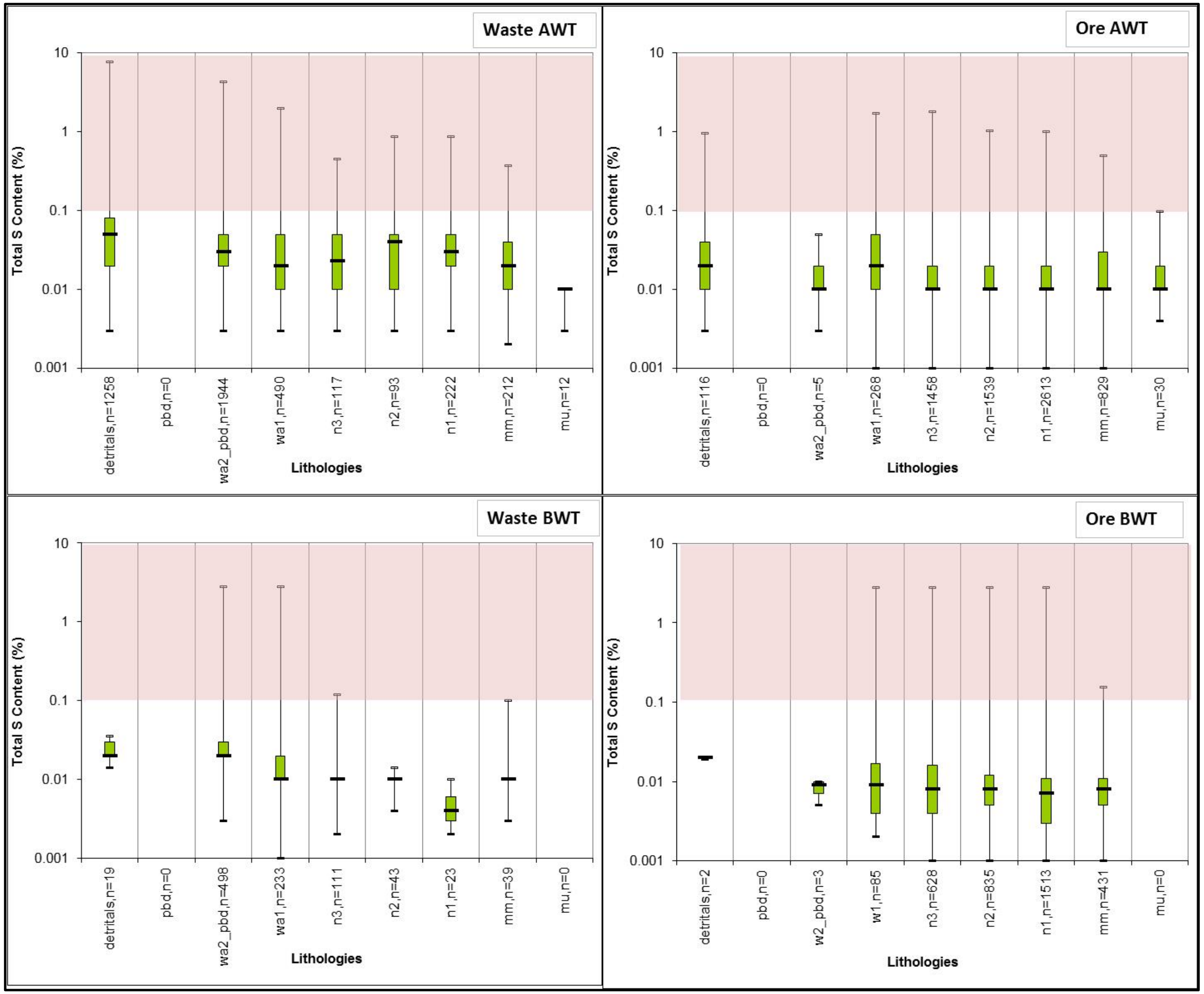


Figure 10: **Box and whisker plots showing sulfur statistics, by lithology (OB29)**

Note: The box and whisker plots show the minimum and maximum sulfur values (short horizontal dashes), median sulfur values (bold black dashes), and data falling within the 25th and 75th percentiles (green boxes). The number of samples, n, from each lithological unit is shown along the x-axis.

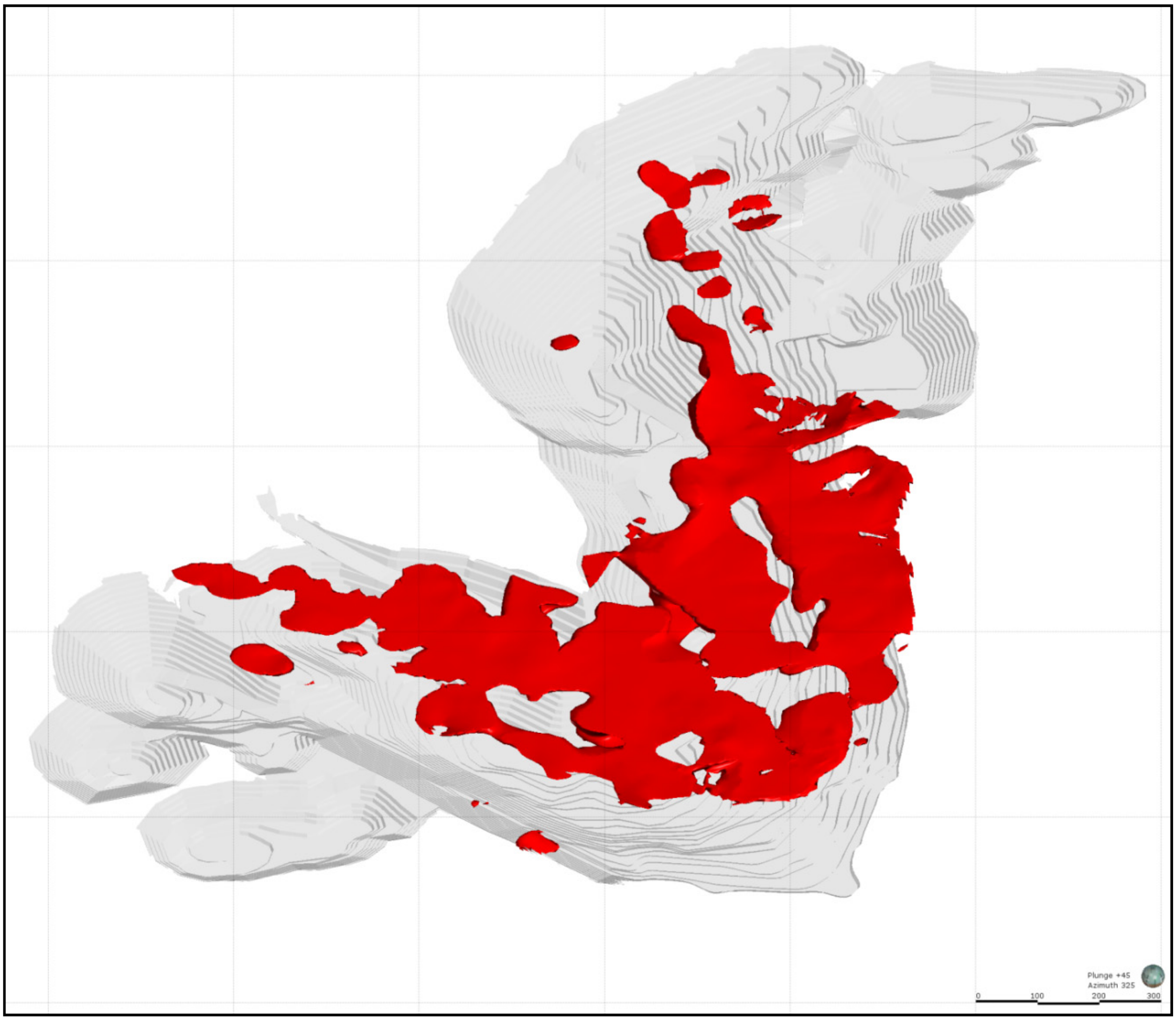


Figure 11: Image of OB29 pit showing the distribution of waste rock containing more than 0.1% sulfur

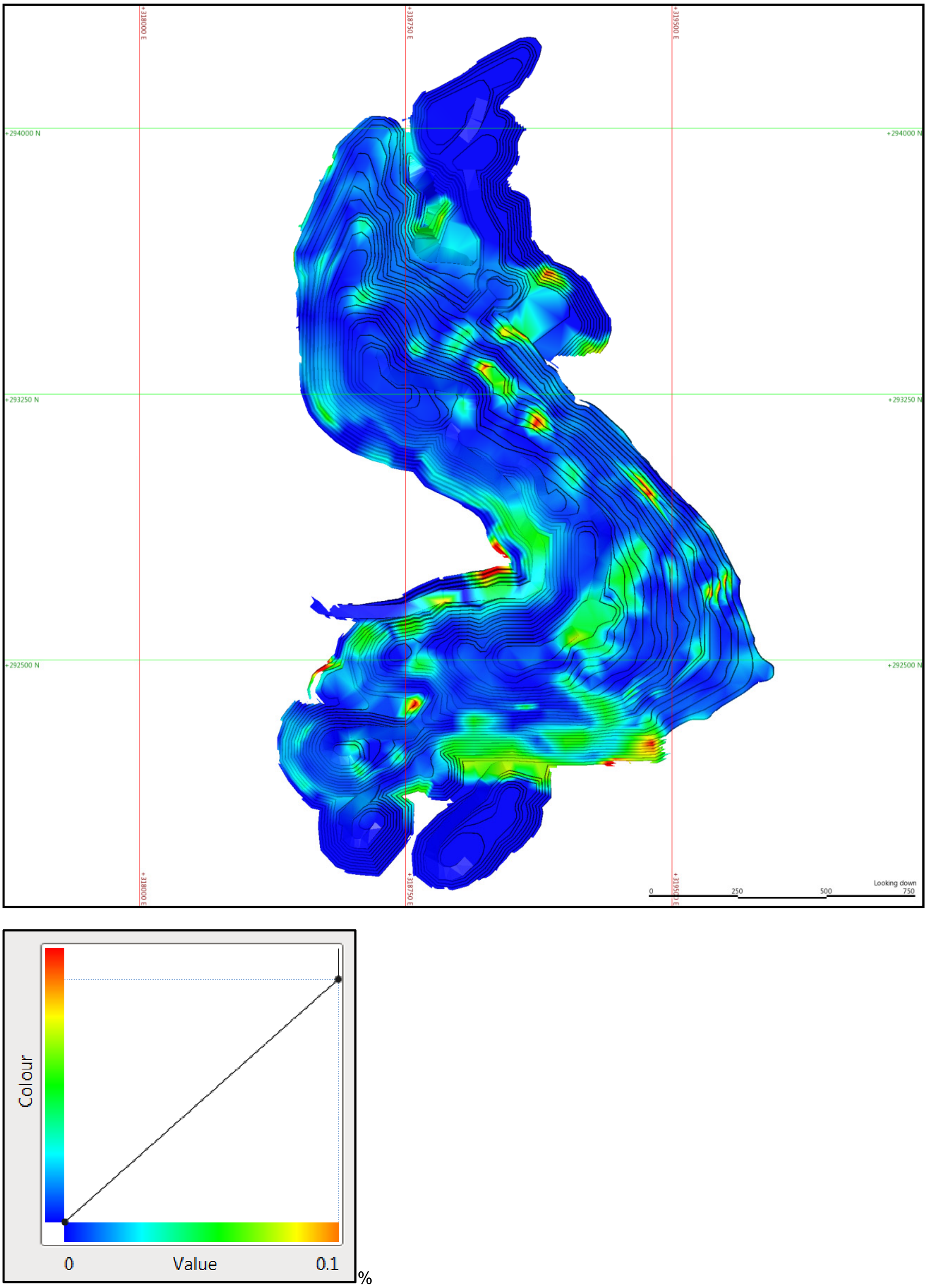


Figure 12: **Image of OB29 pit shell showing the distribution of sulfur**

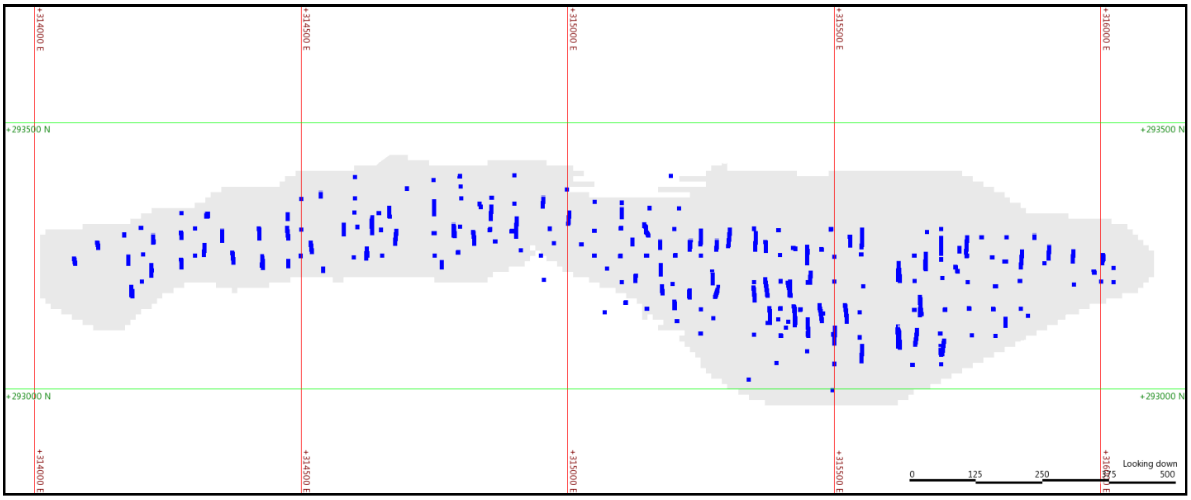


Figure 13: Image of OB30 pit shell showing spatial distribution of sulfur

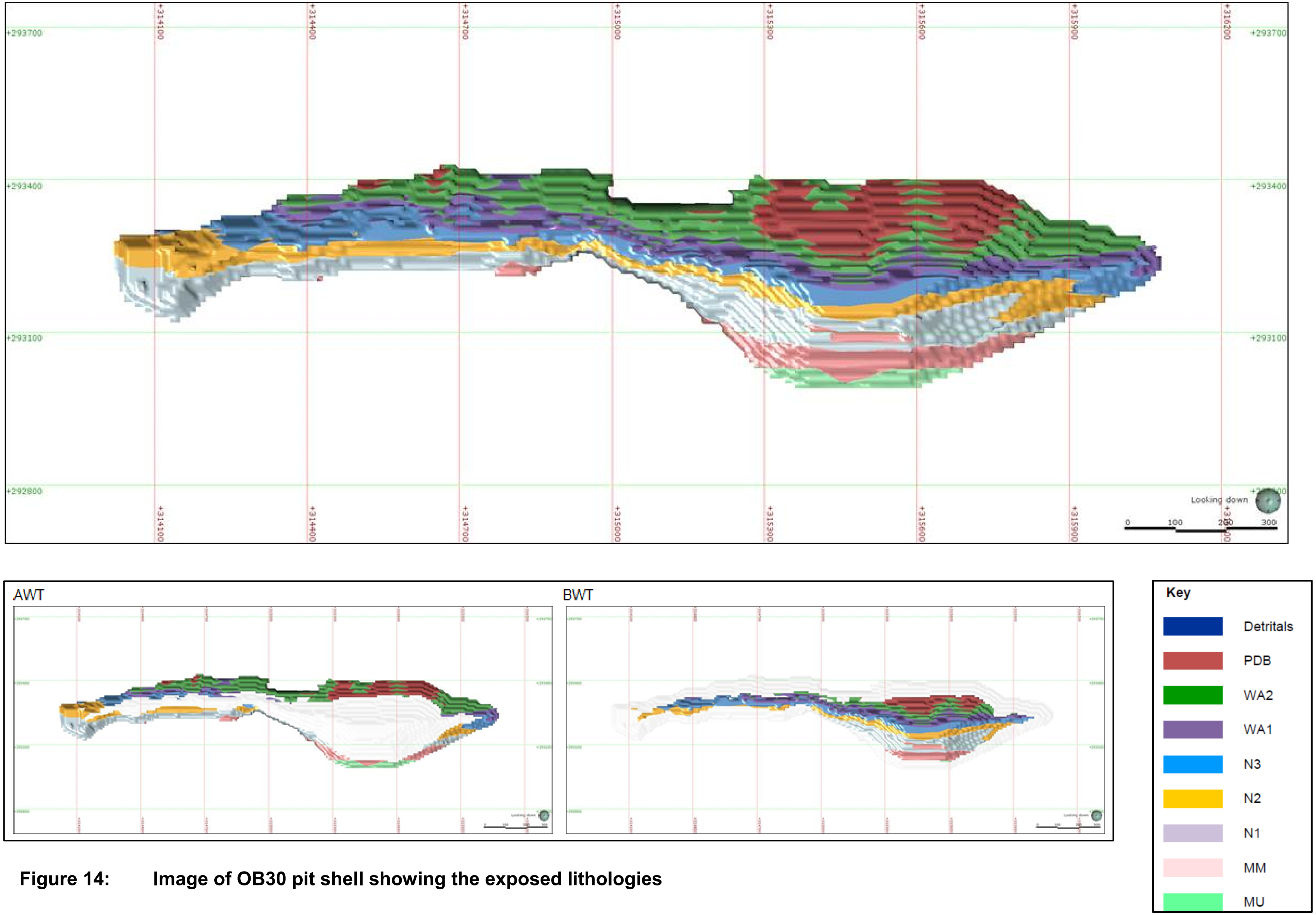


Figure 14: Image of OB30 pit shell showing the exposed lithologies

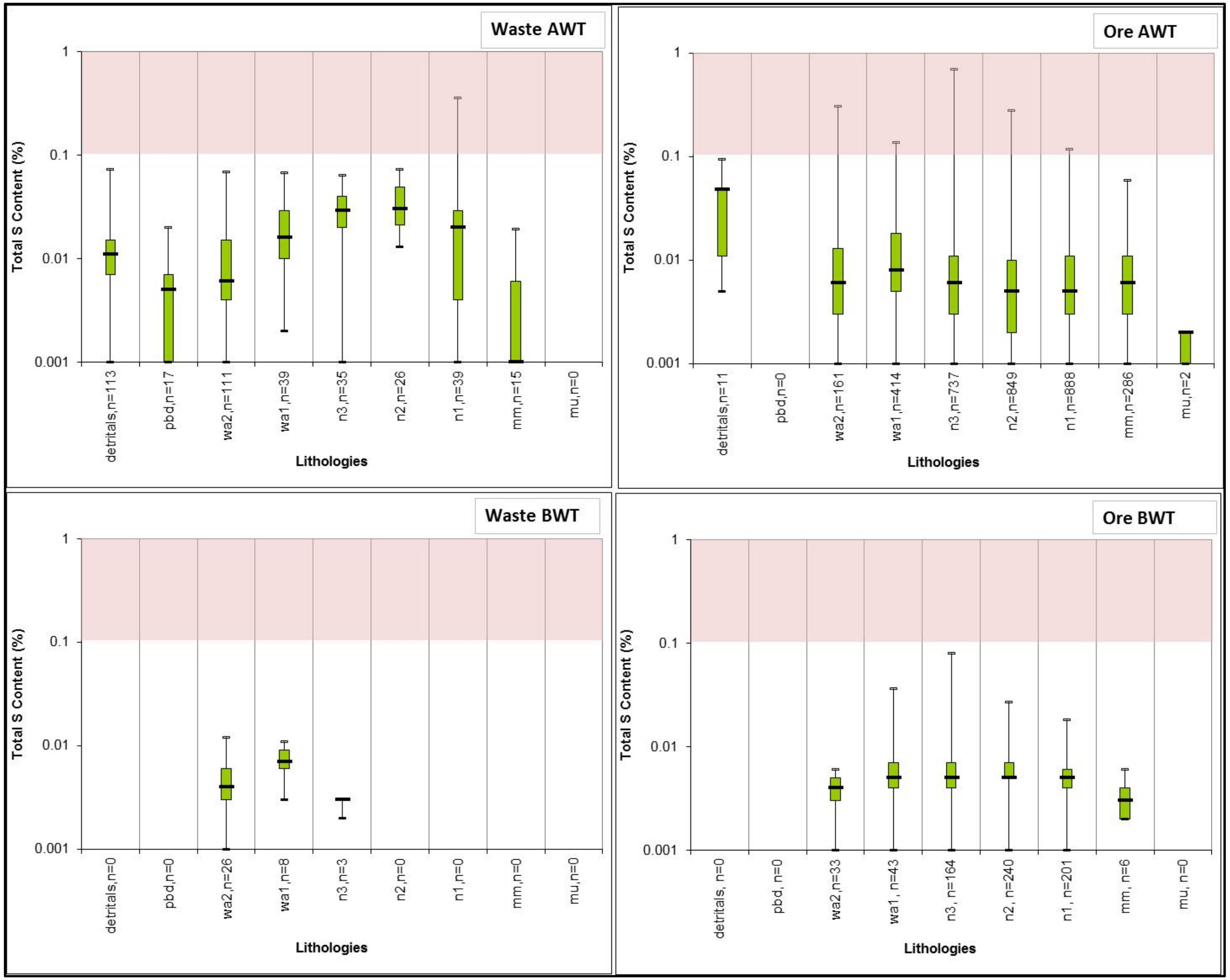


Figure 15: Box and whisker plots showing sulfur statistics, by lithology (OB30)

Note: The box and whisker plots show the minimum and maximum sulfur values (short horizontal dashes), median sulfur values (bold black dashes), and data falling within the 25th and 75th percentiles (green boxes). The number of samples, n, from each lithological unit is shown along the x-axis.

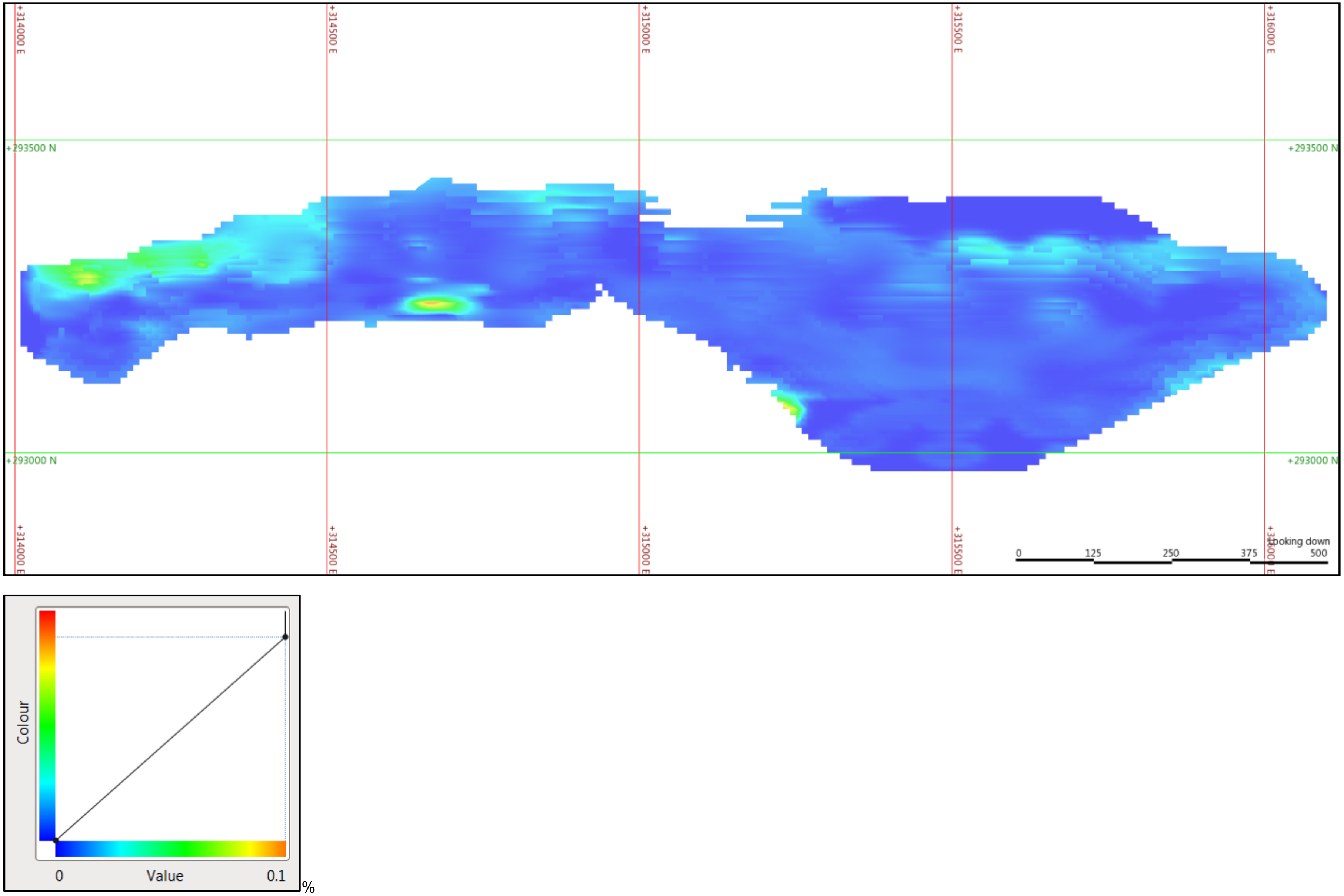


Figure 16: **Image of OB30 pit shell showing the distribution of sulfur**

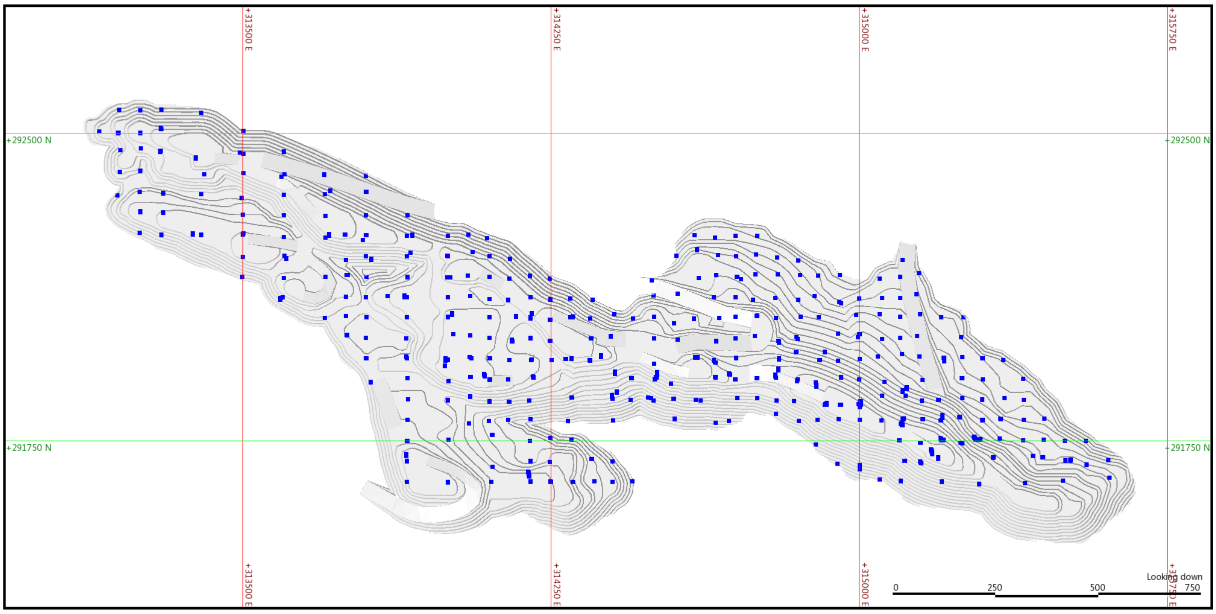


Figure 17: Image of OB35 pit shell showing spatial distribution of sulfur

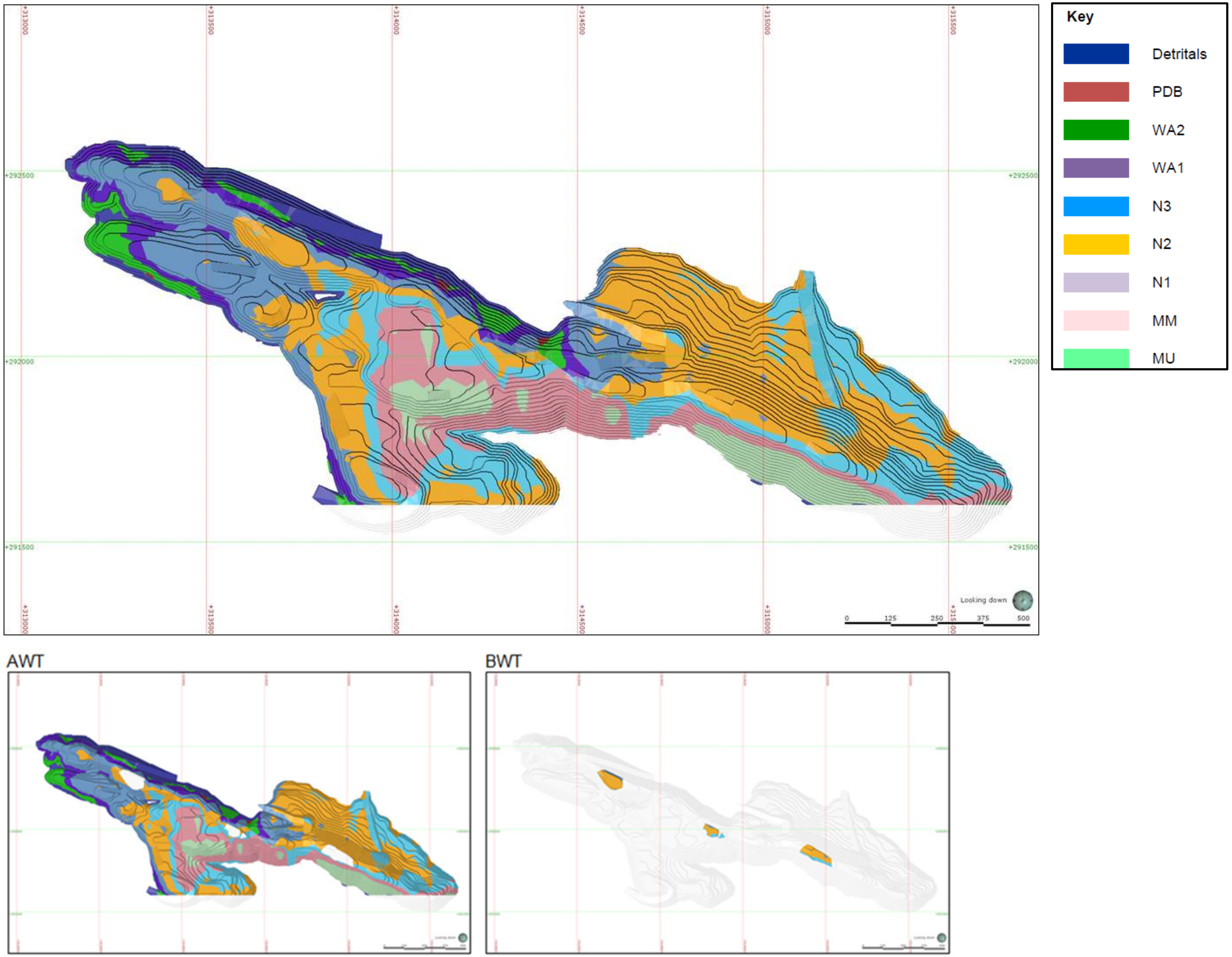


Figure 18: Image of OB35 pit shell showing the exposed lithologies

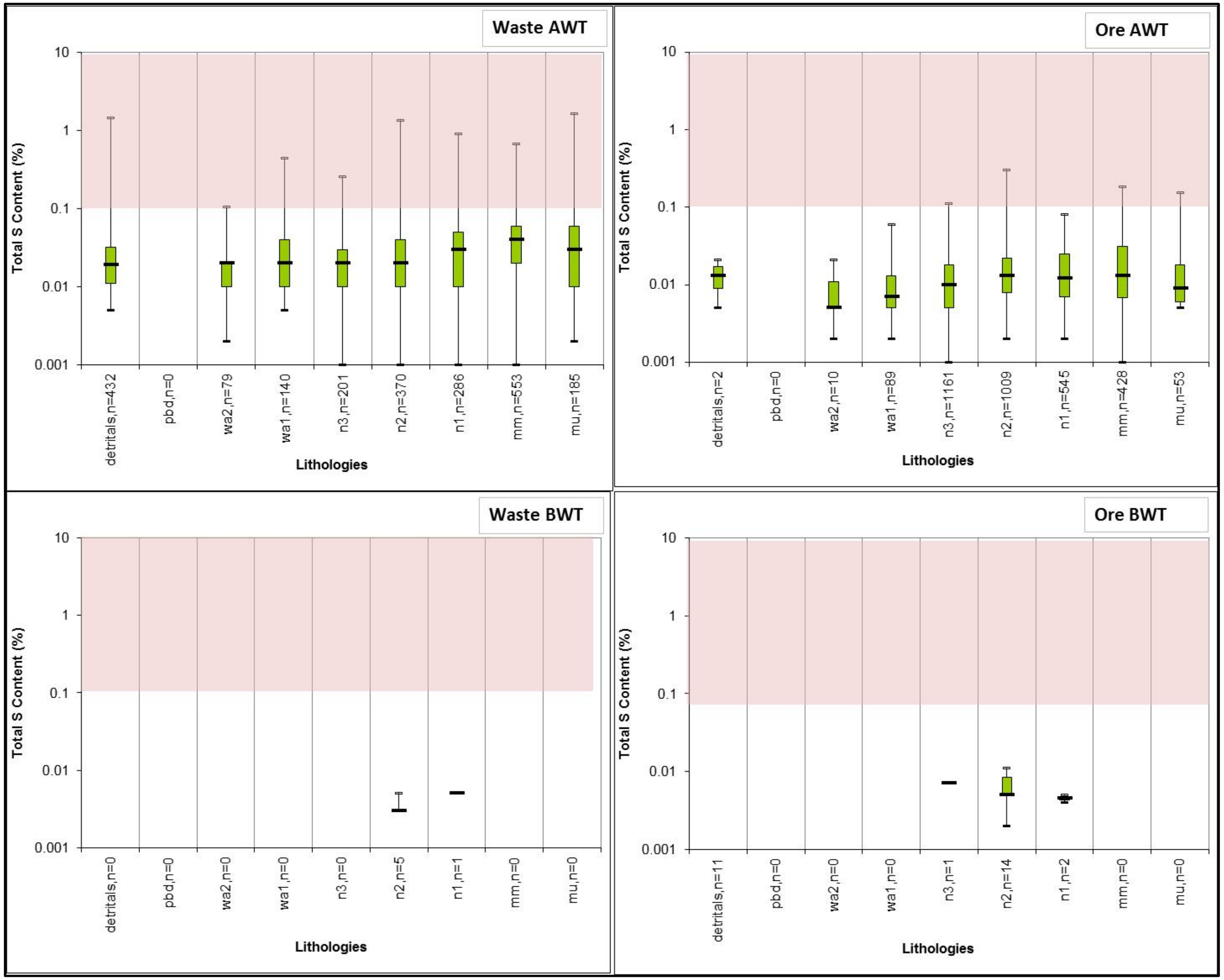


Figure 19: Box and whisker plots showing sulfur statistics, by lithology (OB30)

Note: The box and whisker plots show the minimum and maximum sulfur values (short horizontal dashes), median sulfur values (bold black dashes), and data falling within the 25th and 75th percentiles (green boxes). The number of samples, n, from each lithological unit is shown along the x-axis.

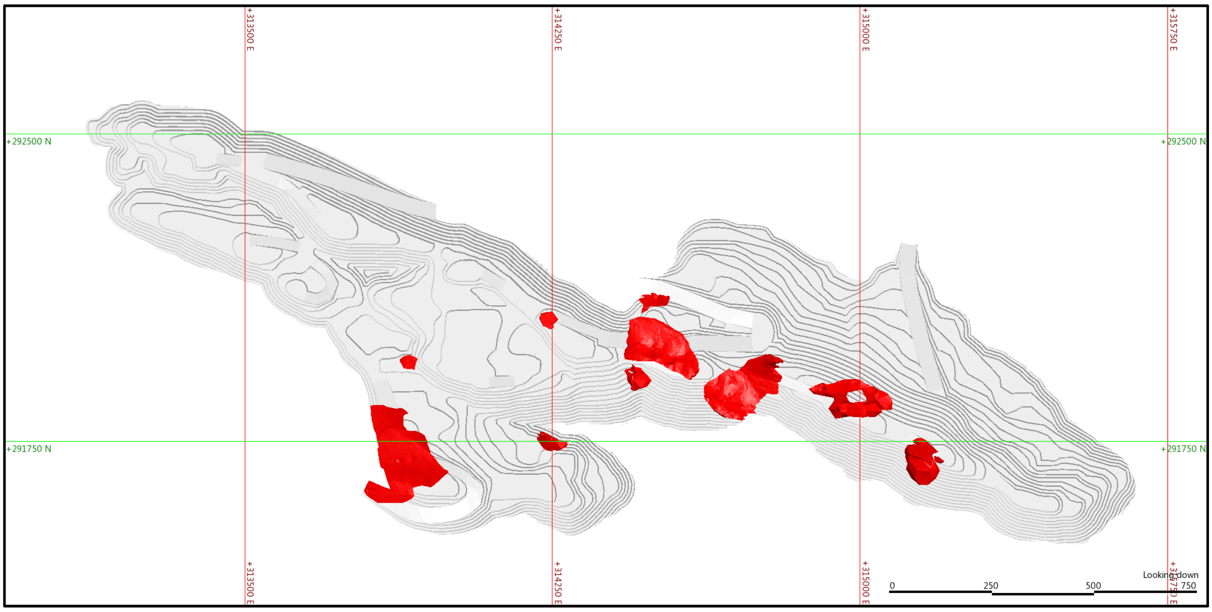


Figure 20: Image of OB35 pit volume showing the distribution of waste rock containing more than 0.1% sulfur

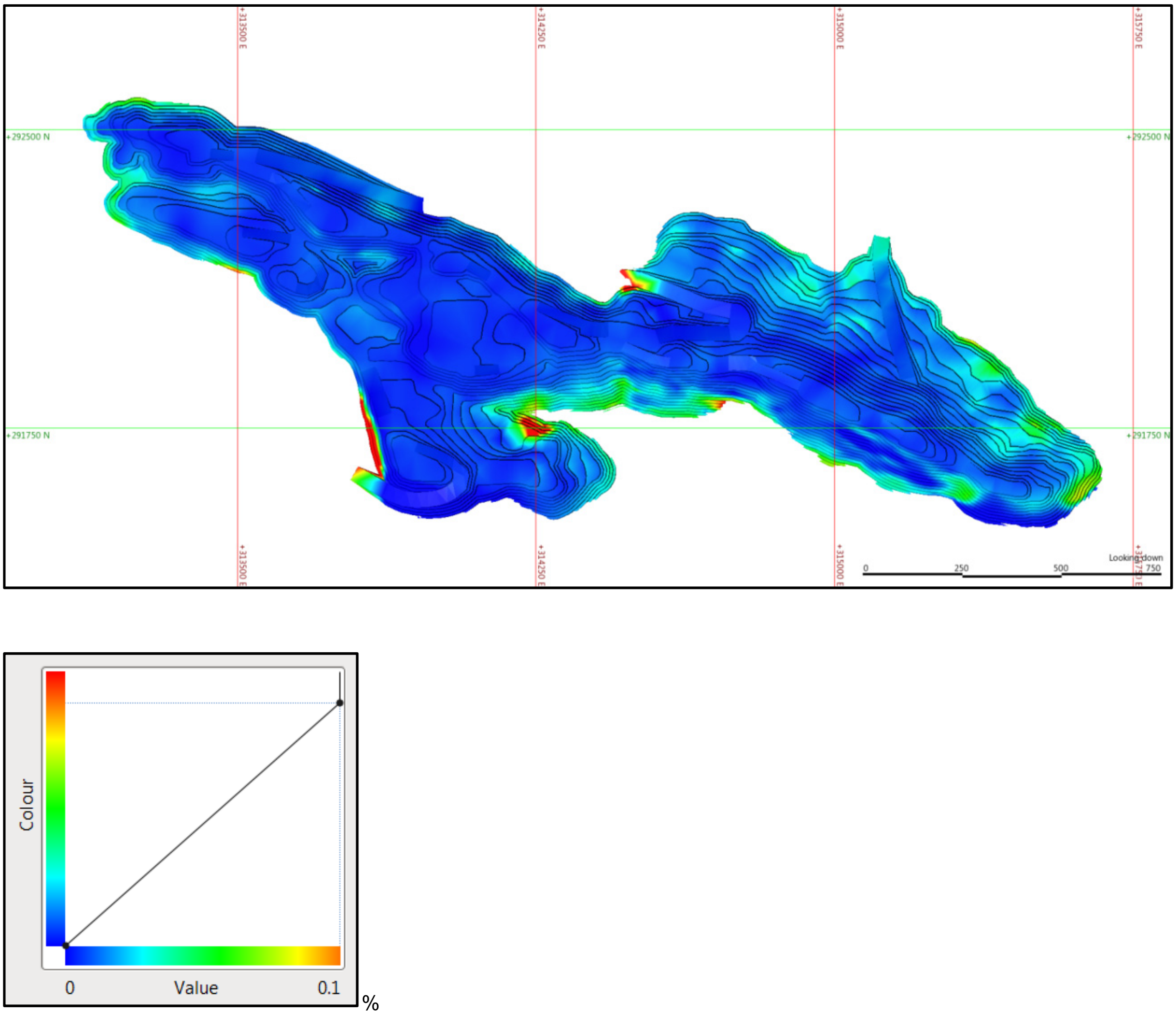


Figure 21: Image of OB35 pit shell showing the distribution of sulfur

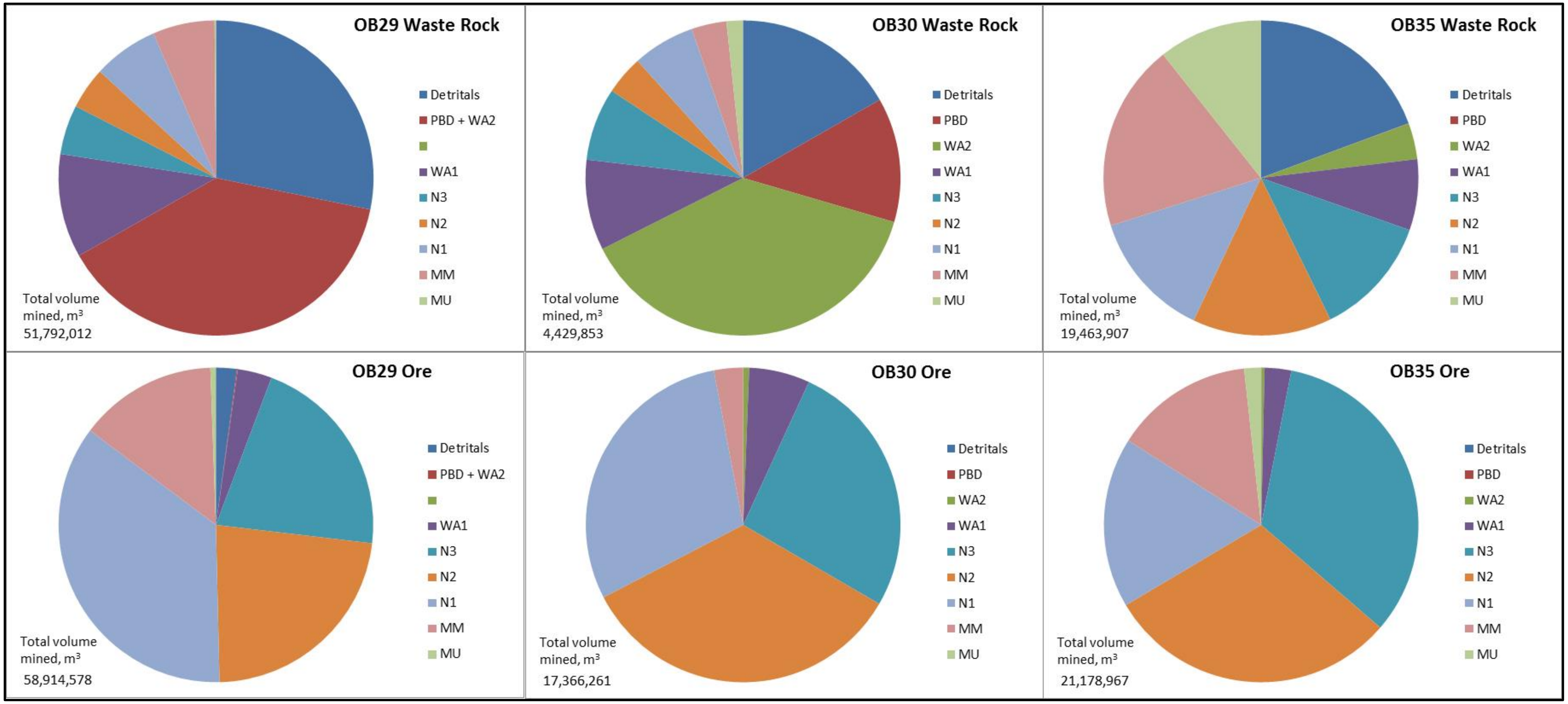
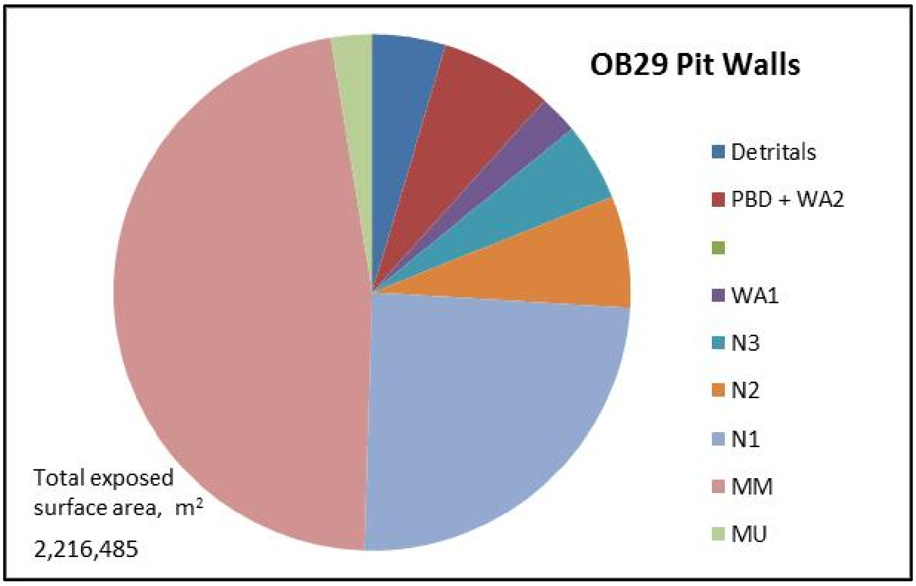
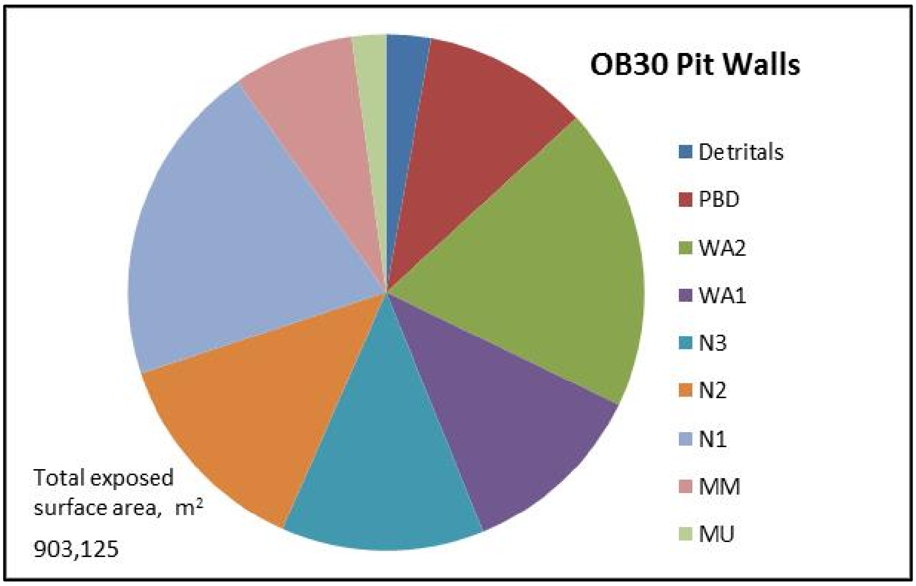


Figure 22: Pie-charts comparing the lithological composition of mined waste rock and ore (OB 29, 30 and 35)





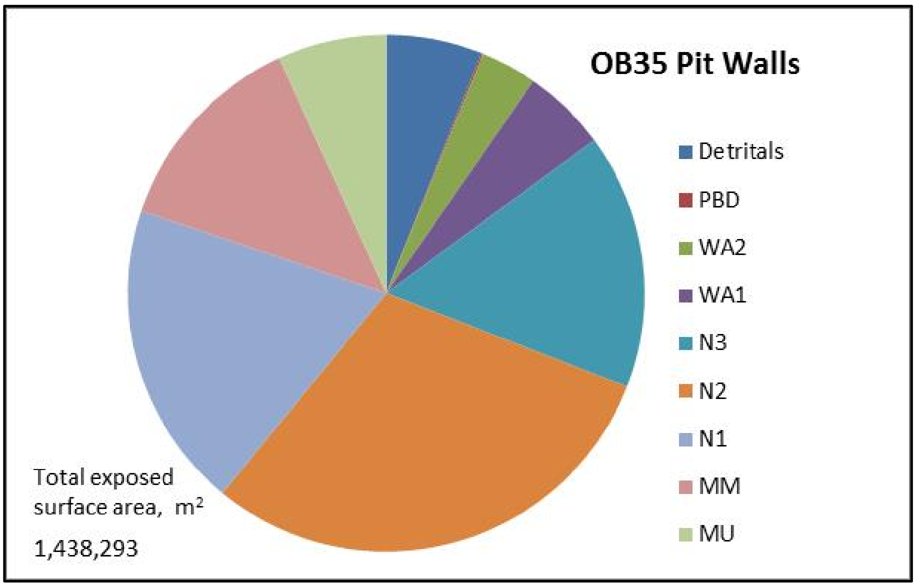


Figure 23: **Pie-charts comparing the lithological composition of exposed pit walls (OB 29, 30 and 35)**

Appendices

Appendix A: Surface Water Monitoring Data (Whaleback Creek)

Appendix A - Surface Water Monitoring Data (Whaleback Creek)

License ID	Units	Whaleback Creek U/S		Whaleback Creek D/S of Power Station								ANZECC Freshewater Triggers (95%)
Site No.		**WBSW042**		**WBSW043**								
Date		**1-Mar-09**	**16-Apr-10**	**1-Mar-09**	**30-Apr-10**	**7-Jan-11**	**16-Feb-11**	**2-Mar-11**	**9-Jan-11**	**28-Feb-12**	**18-Mar-12**	
pH		7.74	7.22	7.53	7.43	7.23	7.35	7.83	7.7	No flow	7.3	-
EC	uS/cm	234	104	231	407	30	59	259	100		150	-
TDS	mg/L	192	95	172	245	56	34	151	115		92	-
TSS	mg/L	1320	29	102	4	110	620	9	34		120	-
SO4	mg/L	2	4	39	70	-	6	-	11		15	-
Na	mg/L	5	6	13	24	2	-	12	5		10	-
K	mg/L	4	4	4	7	4	2	5	4		2	-
Ca	mg/L	33	8	22	25	3	3	21	6		6	-
Mg	mg/L	9	4	8	12	2	2	10	3		4	-
Fe	mg/L	1.23	0.06	<0.05	<0.05	0.37	0.22	0.18	0.16		0.2	-
Mn	mg/L	1.28	0.001	<0.001	0.003	0.001	0.002	0.008	0.001		0.001	1.9
Zn	mg/L	0.005	<0.005	<0.005	<0.005	0.34	<0.005	<0.005	<0.005		<0.005	0.008
Cu	mg/L	<0.001	0.002	0.001	0.001	0.003	<0.001	0.004	0.003		0.002	0.0014
Al	mg/L	0.02	0.04	0.02	<0.01	0.34	0.21	0.12	0.12		0.08	0.055[a]
Cd	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	0.0002
Pb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	0.0034
As	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	0.024[b] 0.013[c]
Hg	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	0.0006[d]
Cr	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	0.001[e]
Mo	mg/L	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001		0.002	-

Notes:

U/S - upstream; D/S - downstream. Concentrations above ANZECC Freshwater trigger (95%) guideline values are shaded blue.

Surface water analyses results from the BHP Billiton Annual Environmental Report Mt Whaleback, OB29, 30 and 35 (July 2011-June 2012).

[a] Aluminium trigger if pH > 6.5; [b] Arsenic trigger for As (III); [c] Arsenic trigger for As (V); [d] Mercury trigger for inorganic Hg; and [e] Chromium trigger for Cr (VI).

SRK Report Client Distribution Record

Project Number: BHP107

Report Title: Orebodies 29, 30 and 35: Preliminary Acid and Metalliferous Drainage Risk Assessment

Date Issued: 20/08/2013

Name/Title	Company
Richard Marton	BHPBIO

Rev No.	Date	Revised By	Revision Details
0	24/06/2013	Russell Staines	Draft Report
1	18/07/2013	Alison Hendry	Final Report
2	20/8/2013	Alison Hendry	Final Report