Appendix E

Mine Material Geochemistry

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This Environmental Impact Statement, including the Executive Summary, and all chapters of and attachments and appendices to it and all drawings, plans, models, designs, specifications, reports, photographs, surveys, calculations and other data and information in any format contained and/or referenced in it, is together with this disclaimer referred to as the "**EIS**".

Purpose of EIS

The EIS has been prepared by, for and on behalf of Wafi Mining Limited and Newcrest PNG 2 Limited (together the "**WGJV Participants**"), being the participants in the Wafi-Golpu Joint Venture ("**WGJV**") and the registered holders of exploration licences EL 440 and EL1105, for the sole purpose of an application (the "**Permit Application**") by them for environmental approval under the Environment Act 2000 (the "**Act**") for the proposed construction, operation and (ultimately) closure of an underground copper-gold mine and associated ore processing, concentrate transport and handling, power generation, water and tailings management, and related support facilities and services (the "**Project**") in Morobe Province, Independent State of Papua New Guinea. The EIS was prepared with input from consultants engaged by the WGJV Participants and/or their related bodies corporate ("**Consultants**").

The Permit Application is to be lodged with the Conservation and Environment Protection Authority ("**CEPA**"), Independent State of Papua New Guinea.

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Any future development of the Project is subject to further studies, completion of statutory processes, receipt of all necessary or desirable Papua New Guinea Government and WGJV Participant approvals, and market and operating conditions.

Engineering design and other studies are continuing and aspects of the proposed Project design and timetable may change.

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The EIS includes forward looking statements. Forward looking statements can generally be identified by the use of words such as "may", "will", "expect", "intend", "plan", "estimate", "anticipate", "continue", "outlook" and "guidance", or other similar words and may include, without limitation, statements regarding plans, strategies and objectives of management, anticipated production or construction commencement dates and expected costs or production outputs. The Company continues to distinguish between outlook and guidance. Guidance statements relate to the current financial year. Outlook statements relate to years subsequent to the current financial year.

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Forward looking statements are based on the Company's good faith assumptions as to the financial, market, regulatory and other relevant environments that will exist and affect the Company's business and operations in the future.

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Newcrest results are reported under International Financial Reporting Standards (IFRS) including EBIT and EBITDA. The EIS also includes non-IFRS information including Underlying profit (profit after tax before significant items attributable to owners of the parent company), All-In Sustaining Cost (determined in accordance with the World Gold Council Guidance Note on Non-GAAP Metrics released June 2013), AISC Margin (realised gold price less AISC per ounce sold (where expressed as USD), or realised gold price less AISC per ounce sold divided by realised gold price (where expressed as a %), Interest Coverage Ratio (EBITDA/Interest payable for the relevant period), Free cash flow (cash flow from operating activities less cash flow related to investing activities), EBITDA margin (EBITDA expressed as a percentage of revenue) and EBIT margin (EBIT expressed as a percentage of revenue). These measures are used internally by Management to assess the performance of the business and make decisions on the allocation of resources and are included in the EIS to provide greater understanding of the underlying performance of Newcrest's operations. The non-IFRS information has not been subject to audit or review by Newcrest's external auditor and should be used in addition to IFRS information.

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Competent Person's Statement

The information in the EIS that relates to Golpu Ore Reserves is based on information compiled by the Competent Person, Mr Pasqualino Manca, who is a member of The Australasian Institute of Mining and Metallurgy. Mr Pasqualino Manca, is a full-time employee of Newcrest Mining Limited or its relevant subsidiaries, holds options and/or shares in Newcrest Mining Limited and is entitled to participate in Newcrest's executive equity long term incentive plan, details of which are included in Newcrest's 2017 Remuneration Report. Ore Reserve growth is one of the performance measures under recent long term incentive plans. Mr Pasqualino Manca has sufficient experience which is relevant to the styles of mineralisation and type of deposit under consideration and to the activity which he is undertaking to qualify as a Competent Person as defined in the JORC Code 2012. Mr Pasqualino Manca consents to the inclusion of material of the matters based on his information in the form and context in which it appears.

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These materials contain forward-looking statements within the meaning of the safe harbor provided by Section 21E of the Securities Exchange Act of 1934, as amended, and Section 27A of the Securities Act of 1933, as amended, with respect to our financial condition, results of operations, business strategies, operating efficiencies, competitive positions, growth opportunities for existing services, plans and objectives of management, markets for stock and other matters. These include all statements other than statements of historical fact, including, without limitation, any statements preceded by, followed by, or that include the words "targets", "believes", "expects", "aims", "intends", "will", "may", "anticipates", "would", "should", "could", "estimates", "forecast", "predict", "continue" or similar expressions or the negative thereof.

These forward-looking statements, including, among others, those relating to our future business prospects, revenues and income, wherever they may occur in this EIS and the exhibits to this EIS, are essentially estimates reflecting the best judgment of our senior management and involve a number of risks and uncertainties that could cause actual results to differ materially from those suggested by the forward-looking statements. As a consequence, these forward-looking statements should be considered in light of various important factors, including those set forth in these materials. Important factors that could cause actual results to differ materially from estimates or projections contained in the forward-looking statements include, without limitation: overall economic and business conditions in South Africa, Papua New Guinea, Australia and elsewhere, estimates of future earnings, and the sensitivity of earnings to the gold and other metals prices, estimates of future gold and other metals production and sales, estimates of future cash costs, estimates of future cash flows, and the sensitivity of cash flows to the gold and other metals prices, statements regarding future debt repayments, estimates of future capital expenditures, the success of our business strategy, development activities and other initiatives, estimates of reserves statements regarding future exploration results and the replacement of reserves, the ability to achieve anticipated efficiencies and other cost savings in connection with past and future acquisitions, fluctuations in the market price of gold, the occurrence of hazards associated with underground and surface gold mining, the occurrence of labour disruptions, power cost increases as well as power stoppages, fluctuations and usage constraints, supply chain shortages and increases in the prices of production imports, availability, terms and deployment of capital, changes in government regulation, particularly mining rights and environmental regulation, fluctuations in exchange rates, the adequacy of the Group's insurance coverage and socio-economic or political instability in South Africa and Papua New Guinea and other countries in which we operate.

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The information in the EIS that relates to Golpu Ore Reserves is based on information compiled by the Competent Person, Mr Pasqualino Manca, who is a member of The Australasian Institute of Mining and Metallurgy. Mr Pasqualino Manca, is a full-time employee of Newcrest Mining Limited or its relevant subsidiaries, holds options and/ or shares in Newcrest Mining Limited and is entitled to participate in Newcrest's executive equity long term incentive plan, details of which are included in Newcrest's 2017 Remuneration Report. Ore Reserve growth is one of the performance measures under recent long term incentive plans. Mr Pasqualino Manca has sufficient experience which is relevant to the styles of mineralisation and type of deposit under consideration and to the activity which he is undertaking to qualify as a Competent Person as defined in the JORC Code 2012. Mr Pasqualino Manca consents to the inclusion of material of the matters based on his information in the form and context in which it appears.

Wafi-Golpu Project

Mine Material Geochemistry

Report Prepared for

Report Prepared by

SRK Consulting (Australasia) Pty Ltd

COF002_WOR004

June 2018

Wafi-Golpu Project

Mine Material Geochemistry

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Executive Summary

The Wafi-Golpu copper-gold deposit is located in the Morobe Province of Papua New Guinea (PNG) and the proposed Wafi-Golpu Project (the Project) involves the staged development of an underground copper and gold mine, associated processing facilities, and related support services and infrastructure. Mining will be by block caving and will generate a subsidence zone of fractured rock. Access to the mine workings via the declines and ventilation shaft will generate waste rock that will be deposited within managed waste rock dump facilities. Ore would be stockpiled temporarily on surface before being processed with subsequent deep sea placement of the tailings. The declines, ventilation shaft, block caving and rock subsidence would increase the exposure of rock to oxygen, and if acid forming, could lead to acidification of contacting water.

Geochemical characterisation of mine rock has been undertaken in support of previous project optimisation studies and the outcomes from those studies are being used to support the current Project. The geochemical characterisation was conducted on multiple sets of samples obtained between 1990 and early 2015, specifically to identify the potential for mine materials to be sources of acid rock drainage (ARD).

This report provides a summary of the available information and an assessment of its adequacy to assess the ARD potential of mine materials from the declines, ventilation shaft and subsidence zones.

Static testing of rock samples in the deposit area was conducted on samples collected between 1990 and 2011. A consequence of the evolution of the mine plan since 1990 is that most samples originated from locations outside the proposed block cave region and associated subsidence zone, as well as the twin access declines and ventilation shaft of the currently proposed Project.

Approximately 30%, or about 172,000 bank cubic metres (bcm), of the material that would be generated from the currently defined declines would be predominantly non acid forming (NAF), i.e., net acid consuming, and should be suitable for construction, provided the material is competent and its properties are verified. The balance of the material from the declines, and additional tonnages from the ventilation shaft, is expected to be potentially acid forming (PAF) and should be handled accordingly.

The geochemistry of rock within subsidence and decline regions, while spatially variable, indicates the presence of materials which could impact the quality of water entering the mine.

Based on the available results it is expected that as mining progresses and the zone of subsidence increases, the mine water quality could become acidic, with elevated concentrations of metals, particularly zinc, copper, iron and manganese. Therefore, water from the mine workings may be unsuitable for direct discharge and could require treatment to i) comply with PNG water quality guidelines, and, ii) achieve environmental protection objectives articulated in PNG environmental legislation and in relevant international standards.

Testing of additional samples is recommended to characterise the various rock types within the subsidence zone and the declines. The additional testing is required to develop a better understanding of how oxidation and metal leaching could progress within the subsidence zone and in waste rock from the declines and ventilation shaft.

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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 Coffey. The opinions in this Report are provided in response to a specific request from Coffey 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/ Acronym	Description
%	percent
ABA	acid-base account
ABCC	acid buffering characteristic curve
AF	acid forming
AMD	acid mine drainage
ANC	acid neutralising capacity
ARD	acid rock drainage
Bcm	bank cubic metre
BWC	Babwaf Conglomerate
Cu-Au	copper-gold
DTX	Diatreme Unaltered
DTX_A	Diatreme Argillic
DTX_AA	Diatreme Advanced Argillic
EC	electrical conductivity
EGi	Environmental Geochemistry International
EHS	Environmental, Health, and Safety
EIS	environmental impact statement
Fe	iron
GAI	global abundance indicator
GARD Guide	Global Acid Rock Drainage Guide
GDP	Golpu Diorite Porphyry Unaltered
GDP_A	Golpu Diorite Porphyry Argillic
GDP_AA	Golpu Diorite Porphyry Advanced Argillic
GDP_ACT	Golpu Diorite Porphyry Actinolite
IFC	International Finance Corporation
INAP	International Network for Acid Prevention
KCB	Klohn Crippen Berger (consulting company)
kg(H_2SO_4/t)	kilograms sulphuric acid per tonne
LC	Leached Cap
Leapfrog ®	Registered trademark of ARANZ Geo Limited
LGV	Langimar Volcanics
M	metre
m^3	cubic metre
Mbcm	million bank cubic metre
mg/kg	milligram per kilogram
mg/L	milligram per litre
mL	millilitre
mN	metres north
MPA	maximum potential acidity

Abbreviation/ Acronym	Description
mRL	metres reduced level
Mt	million tonnes
Mtpa	million tonnes per annum
NAF	non acid forming
NAG	net acid generation
NAPP	net acid producing potential
NDP	Nambonga Diorite Porphyry
NTU	Nephelometric Turbidity Unit
°C	degrees celsius
OSM	Owen Stanley Metamorphics Unaltered
OSM_A	Owen Stanley Metamorphics Argillic
OSM_AA	Owen Stanley Metamorphics Advanced Argillic
OSM_ACT	Owen Stanley Metamorphics Actinolite
OSM_S	Owen Stanley Metamorphics Shale
PAF	potentially acid forming
PAN	Hekeng Andesite
PDA	Dacite Porphyry Unaltered
PDA_A	Dacite Porphyry Argillic
PDA_AA	Dacite Porphyry Advanced Argillic
PDA_AAROM	Dacite Porphyry Advanced Argillic Run-of-Mine
pH	pH - measure of acidity/ alkalinity
PNG	Papua New Guinea
RL	reduced level
ROM	run of mine
S	sulphur
SRK	SRK Consulting (Australasia) Pty Ltd
t/yr	tonnes per year
UC	Uncertain
WCG	Wafi Conglomerate
WRD	waste rock dump

1 Introduction

1.1 Terms of reference

The Wafi-Golpu copper-gold deposit located in the Morobe Province of Papua New Guinea (PNG), is approximately 300km north-northwest of Port Moresby and some 65km southwest of Lae. The Wafi-Golpu Project (hereafter 'the Project') involves the staged development of an underground copper and gold mine, associated processing facilities, and related infrastructure.

This report provides a summary of the geochemical characterisation completed to date and an assessment of the adequacy of the geochemical characterisation of mine materials from the Project.

The potential regulatory requirements for managing material disturbed by mining are also discussed.

1.2 Objectives

The specific objectives of this assessment were to:

- Summarise available geochemical characteristics of rock materials in the vicinity of the declines, ventilation shaft and block caves to identify the potential risk for adverse environmental impacts associated with material disturbance
- Identify relevant PNG and international policies, legislation, standards and guidelines and assess the potential implications for the Project
- Identify gaps in the geochemical characterisation undertaken and provide recommendations on further work for consideration in the Forward Work Plan of the Project.
- Provide an assessment of the suitability of waste material for use:
  - in construction activities
  - as an acid neutralising resource
  - as a waste rock dump cover
  - as a substrate for vegetation.

2 Background

2.1 Geological setting

2.1.1 Regional geology

Regionally, the Project lies in a block of deformed Upper Mesozoic to Middle Miocene metasedimentary to sedimentary rocks cut by Miocene-Pliocene calc-alkaline dioritic intrusives. Copper and gold mineralisation results from a porphyry system, with the upper portion overprinted by high sulphidation epithermal alteration.

The Golpu Porphyry system consists of multiple, hornblende-bearing diorite porphyries intruded into host sediments of the Owen Stanley Metamorphics. As described by WGJV (2018), the Golpu deposit is approximately 800m by 400m (Figure 2-1), elliptical in plan and extends from 200m below ground surface to a depth of more than 2,000m (Figure 2-2). Hydrothermal alteration (Figure 2-3) related to the porphyry Cu-Au mineralisation forms a predictable zonal arrangement grading from potassic core to propylitic margins.

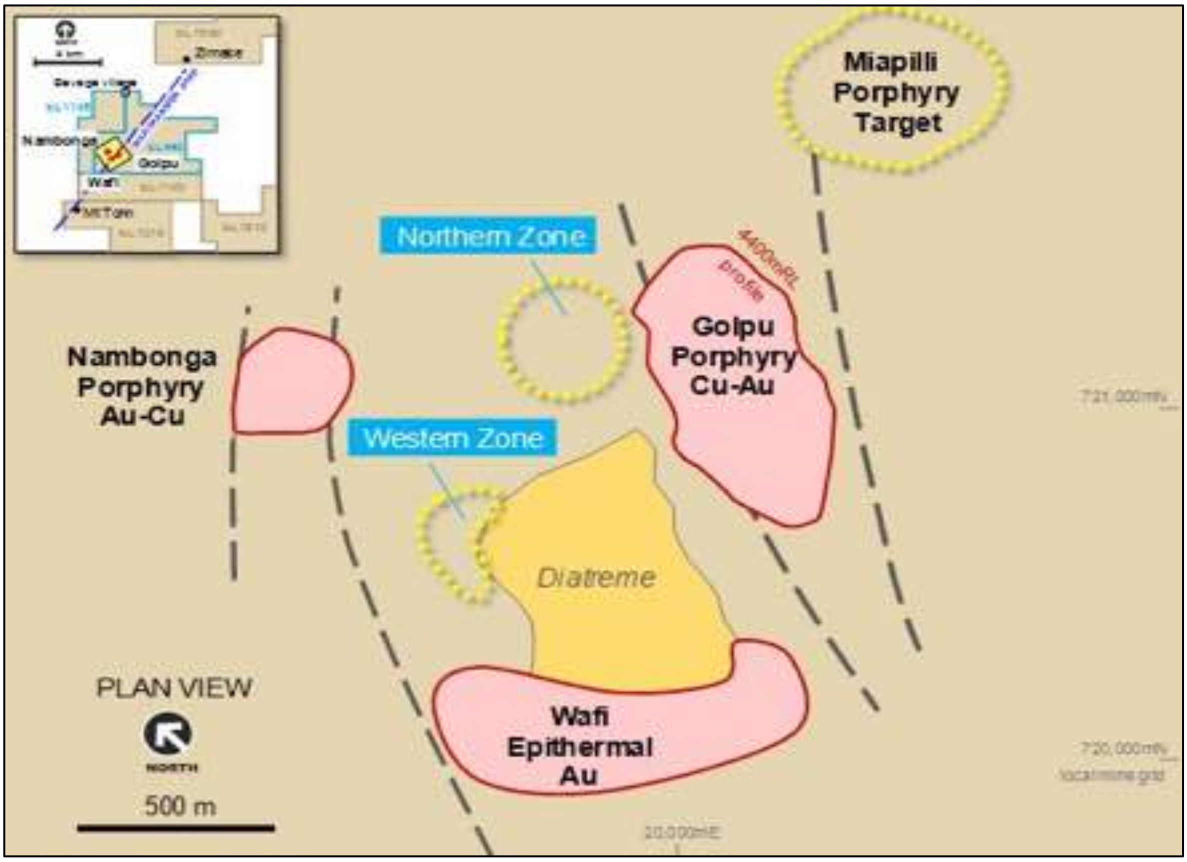


Figure 2-1: Indicative diagram of Wafi, Golpu and Nambonga deposits and the Wafi Diatreme

Source: WGJV, 2014.

A high sulphidation epithermal system is 'telescoped' over the upper portion of the porphyry system forming a central alunite–quartz (advanced argillic) core grading out to dickite–kaolinite (argillic) with an outer margin of sericite alteration. This results in either epithermal dominant, interaction (mixed) or porphyry-only zones within the Golpu deposit.

Mineralisation is derived from either the porphyry or epithermal systems; within the porphyry environment, mineralisation is disseminated, microfracture and stockwork vein controlled.

In the overprinting epithermal system, gold occurs within pyrite or as electrum associated with pyrite-enargite–tetrahedrite. Mineralisation follows the metasedimentary and volcanic host rocks stratigraphy. Arsenic and sulphur are elevated within the high sulphidation epithermal system.

Post-mineralisation thrust faulting has dismembered the original porphyry and epithermal systems, resulting in offsets up to 400m within the mineralised column, and rotated the high grade porphyry core between faults to dip 70° to grid west (Figure 2-2). Owen Stanley Metamorphics Shale and Babwaf Conglomerate lie to the west of the complex hydrogeothermal system.

2.1.2 Deposit geology

The Owen Stanley metasediments comprise interbedded conglomerate, sandstone and siltstone horizons metamorphosed to pelites and psammites. The pelites are usually laminated and foliated and can be carbonaceous.

The Wafi Diatreme complex is a roughly rectangular shaped feature, 800m by 400m at surface with steep inward dipping sides. The diatreme comprises intrusive and sedimentary breccias, volcaniclastics and tuffs and was intruded by several phases of unmineralised dacitic porphyries. Figure 2-1 shows the location of the diatreme with respect to the Nambonga Porphyry, the Golpu porphyries and the Wafi deposit. The diatreme breccia contains clasts of porphyry quartz veins and phyllic altered wallrock, and is interpreted to post-date the porphyry copper-gold mineralisation event.

Three main porphyry phases are identified: Golpu Porphyry, Hornblende (Livana) Porphyry (including the Western Porphyries) and Diorite Porphyry (WGJV, 2014). Intrusives range from small dykes to small stocks/ bosses and apotheoses.

Higher gold and copper grades accompany ‘potassic’ alteration of moderate to strong pervasive biotite + magnetite alteration with K-feldspar. The best developed Kk-feldspar + magnetite alteration is centred in and adjacent to the Hornblende (Livana) and Golpu porphyries. The outermost alteration is chlorite with pyrite, ± albite ± anhydrite. Zonal alteration examples at Golpu are illustrated in Figure 2-3.

The dominant copper-gold containing sulphide species vary laterally and vertically within the deposit from an inner bornite (plus chalcopyrite) core, then to chalcopyrite as the dominant copper sulphide and then grading out to a pyrite-only shell on the mineralisation margin.

The proportion, by volume, of disseminated Cu-Fe sulphides varies between trace up to 10%. Pyrite increases from near absent in the core to 10% on the margin in a reverse relationship to chalcopyrite. Disseminated sulphides are typically located at the site of relict Fe-bearing phases including primary phenocrystic hornblende and hydrothermal alteration derived biotite-magnetite. Figure 2-4 shows the sulphide zonation within the deposit, grading from pyrite on the margin to chalcopyrite/ bornite in the core.

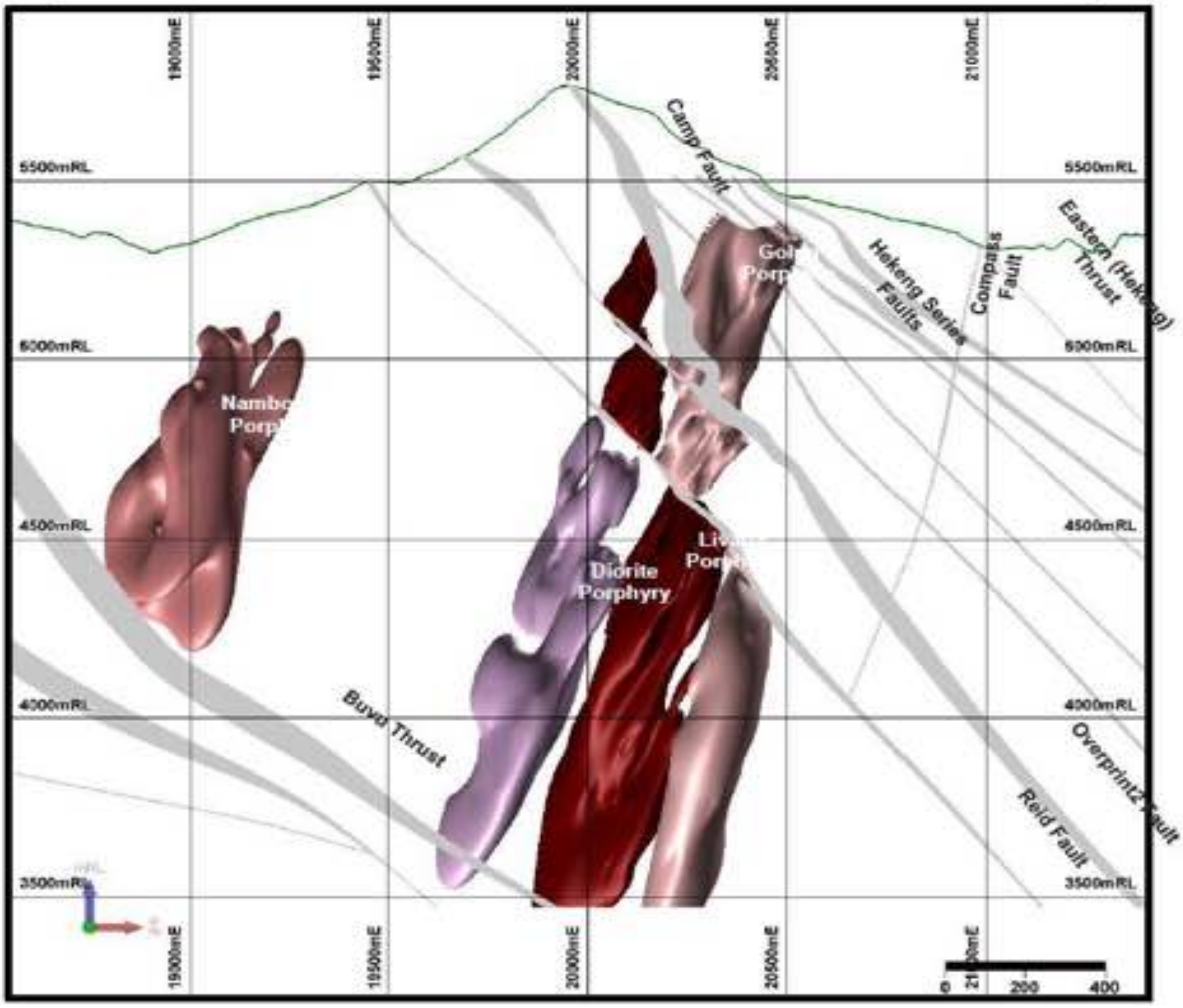


Figure 2-2: Wafi-Golpu structural model in relation to Golpu and Nambonga porphyries

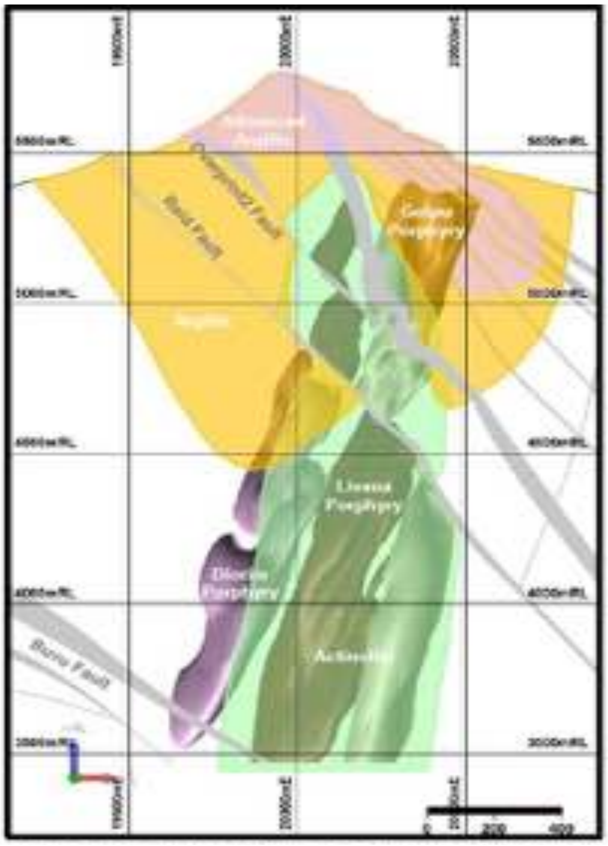


Figure 2-3: Key alteration domains at Golpu

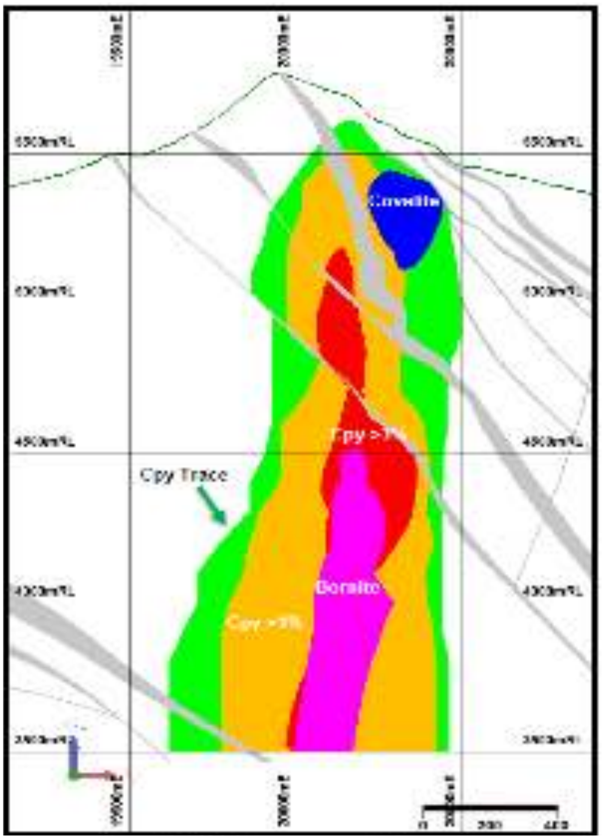


Figure 2-4: Golpu copper sulphide zonation

Note: Cpy – chalcopyrite.

2.2 Project development

Previous studies have considered various approaches to the development of a Wafi-Golpu mine.

Because of changes in the mining approach, supporting infrastructure, such as the Watut Declines for the currently proposed block cave operations, have been relocated. The current Watut Declines alignment is approximately 700m to the north of the initial 2011 alignment (from which samples for geochemical testing were collected). The Nambonga Decline was added to the Project in 2017.

2.3 Block cave mining

Block cave mining is the proposed method for extracting the ore from three levels within the mine.

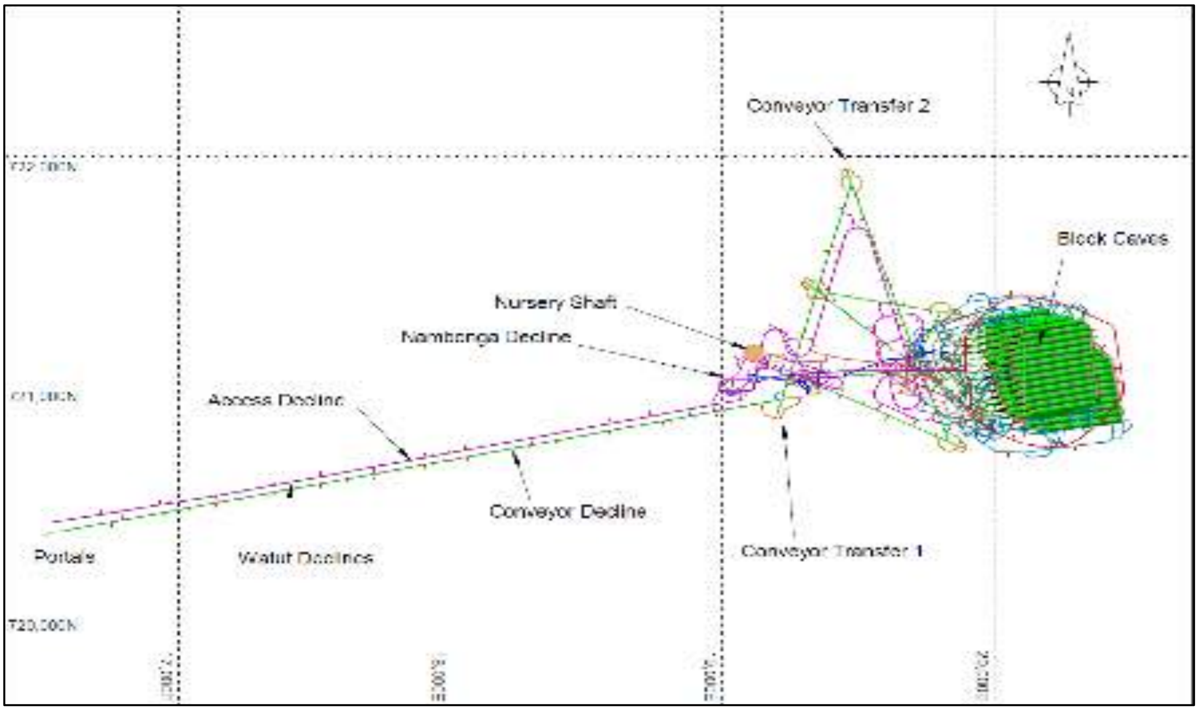
The block caves are designated BC40, BC42 and BC44 and the respective drawpoints are at 4,000, 4,200 and 4,400m reduced level (m RL). Extraction will increase to a design production rate of 16.84 million tonnes per annum (Mtpa) and continue over a 28 year production period, with the three levels operating concurrently in some years.

The volume of broken rock within the subsidence zone above the drawpoints will increase over the mine life. Prior to surface breakthrough of the caving zone, ventilation of the underground workings will introduce air into the fractured rock, and oxidation and solute generation is expected within the underground workings.

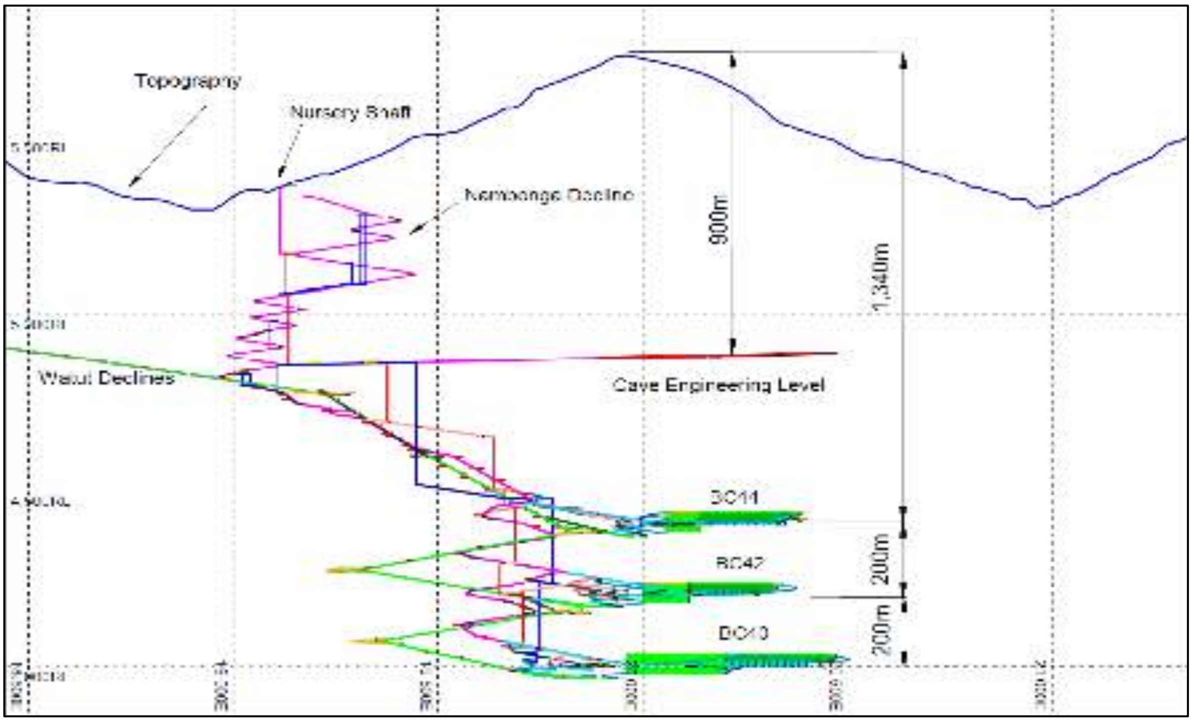
Surface breakthrough of the subsidence zone is expected approximately 30 months after block caving commences. After surface breakthrough has occurred, meteoric water and oxygen ingress would occur readily and the subsidence zone rock will be expected to oxidise and generate solutes. Acidification may also occur depending on the acid base balance of the fractured materials.

The locations of the block cave footprints, access declines and ventilation shaft are shown in Figure 2-5. Terminology to describe features of the block cave subsidence zone is given in Figure 2-6.

At the end of mining, the crater is expected to be approximately 400m deep and 975m across.



(a) Plan view



(b) Vertical projection

Figure 2-5: Proposed Block cave footprints, access declines, ventilation shaft and infrastructure

Source Coffey, 2018.

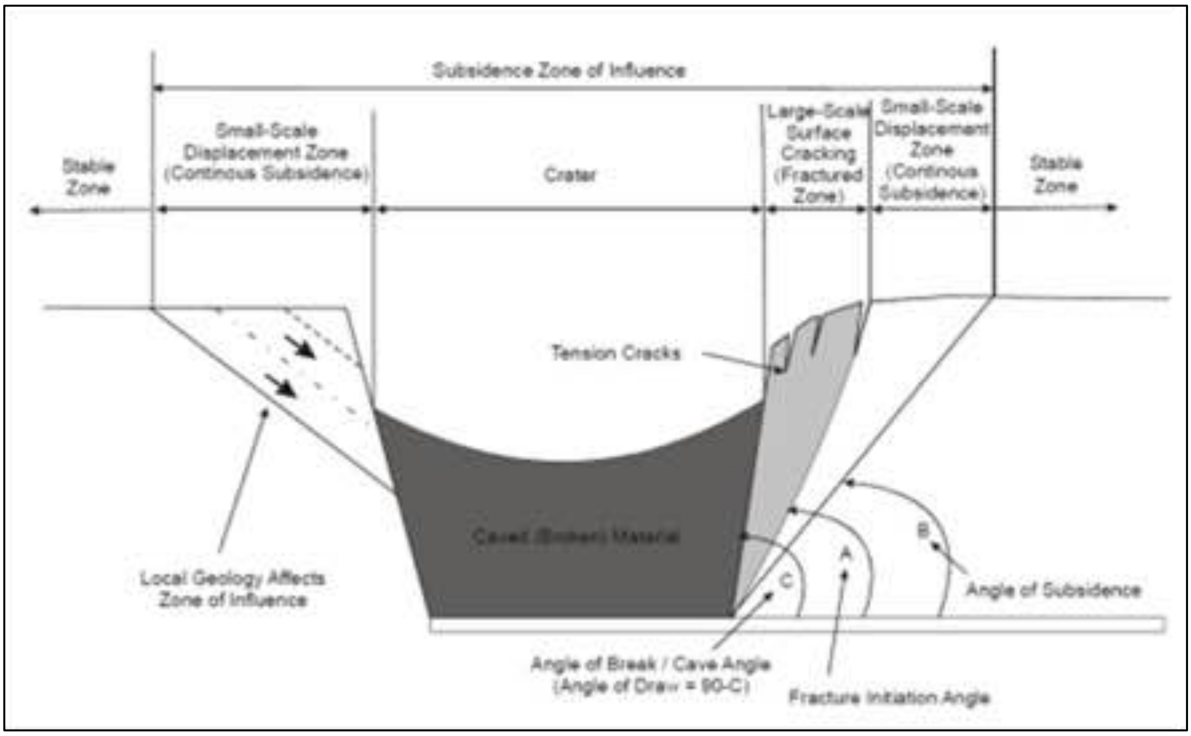


Figure 2-6: Terminology used to describe subsidence features for block and panel cave mines

Source: Sharrock et al., 2015.

2.4 Potential sources of acid rock drainage

The potential sources of ARD at the Project are shown in Figure 2-7 and include:

- Nambonga Decline and Watut Declines – to provide access to the underground exploration drilling platforms for the three stage block cave footprints
- A ventilation shaft
- Watut (Boganchong Creek valley) and Miapilli waste rock dumps (to accommodate waste from the declines, development drives and shafts) with lined cells for storage of PAF waste rock
- A temporary run-of-mine (ROM) stockpile, which will be closed once steady state operation is achieved and a Coarse Ore Stockpile (COS) for plant feed throughout operations
- Rock in the subsidence zone of the staged block cave underground mine
- Disturbed surface soils associated with infrastructure development.

Deep sea placement of the tailings is proposed where it will be inundated in an anoxic environment. Consequently, ARD from tailings would not occur. Geochemical and ecotoxicological characterisation of two tailings samples and an assessment of the long-term effects of metals release from tailings have been reported by CSIRO (2018).

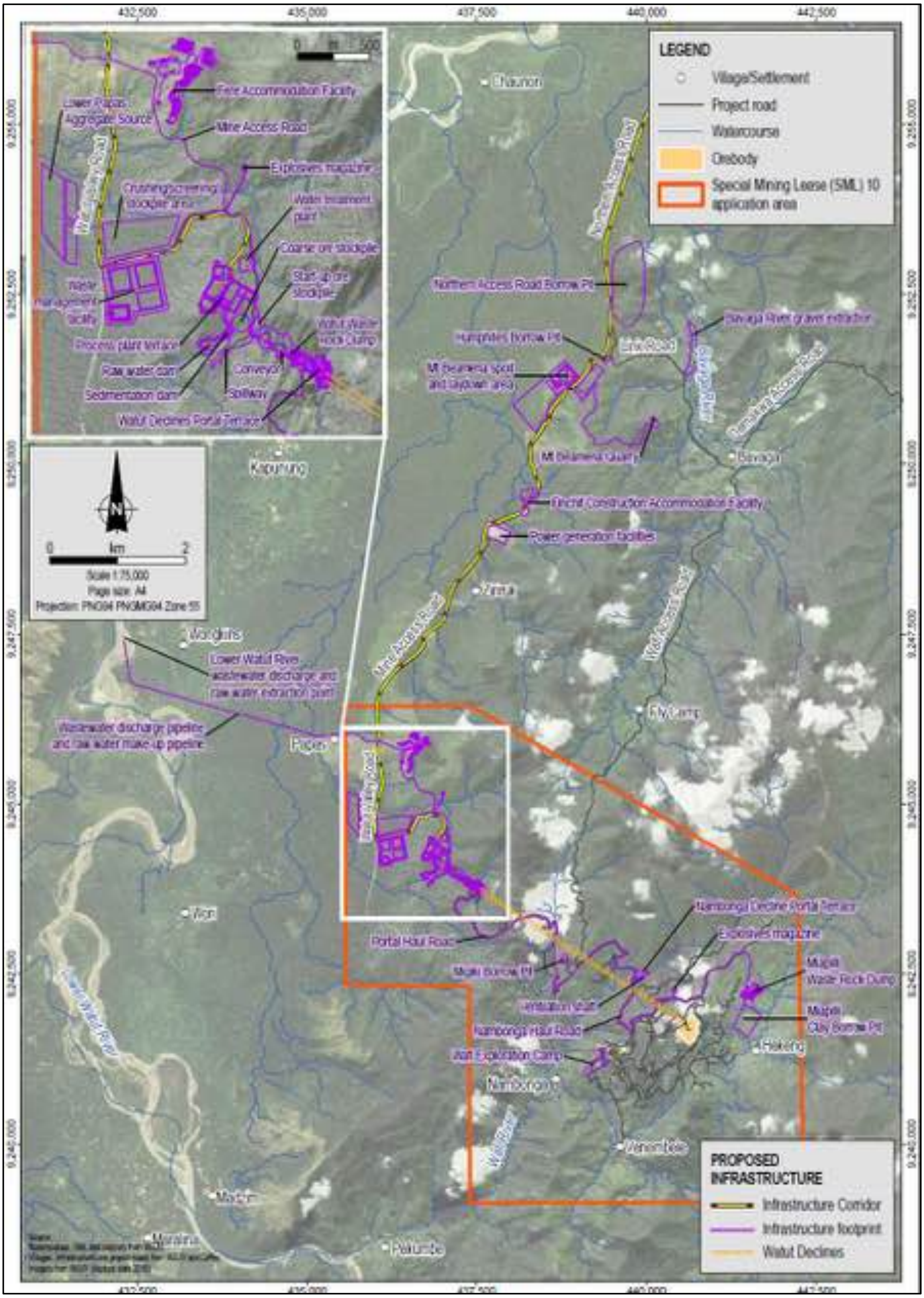


Figure 2-7: Site plan showing major features including potential ARD sources

Source: After Coffey, 2018.

3 Regulatory Context

3.1 PNG Legislation

The following two key pieces of legislation in Papua New Guinea (PNG) are relevant to the management of mineral wastes arising from mining:

- *Mining Act 1992*
- *Environment Act 2000* (and associated sub-ordinate legislation).

Mining Act 1992

The *Mining Act 1992* and associated regulations includes provisions for the grant of mining tenure which may properly be used to authorise storage of tailings, waste rock and other mineral substances (such as topsoil) associated with mining. Section 23(b) of the Act includes provisions for sampling – including for the purpose of geochemical assessment – on exploration licences. Section 162 of the Act describes requirements for preserving drill core and other samples. The mining regulations include provisions for permitting geochemical sampling. Neither the Act nor the associated regulations prescribe geochemical sampling methods.

SRK understands that proposed changes to the Mining Act are to include provisions addressing mine rehabilitation and closure (Gunson, 2017), but has found no evidence to show that these proposed changes have been enacted.

Environment Act 2000

The *Environment Act 2000* and associated regulations, especially the Environment (Water Quality Criteria) Regulation 2002, establish a framework for the regulation of development, including mining, and for the management of water resources so as to:

- Promote the economic, social and physical well-being of people
- Protect air, water, soil and ecosystems from harm and pollution.

The Act articulates key principles to guide the implementation of activities, such as mining, which are likely to result in changes to the environment. In particular, the Act defines a "contaminant" as any substance (including energy, odour and organisms) which, if released into the environment, is likely to cause environmental harm. The term "environmental harm" is defined as "...*any change to the environment, or any part of the environment, which has a detrimental effect on any beneficial value relating to the environment*...". Pollution offences not only include discharging contaminants into the environment (either by act or omission), but also include the placement of a contaminant "... *in any position where it could reasonably be expected to gain access to waters in circumstances where if access was gained the contaminant would result in* ...[the waters being polluted]...".

The Act specifically addresses the issue of disposal of wastes, including "soil, rock or other solid or liquid waste". Waste must not be disposed of in a way that would "*interfere with groundwater...or which does not comply with any standard prescribed for that contaminant*....".

Water quality standards are set out in the *Environment (Water Quality Criteria) Regulation 2002*. To comply with the regulations, a permit holder must not discharge water that does not meet the water quality criteria or cause receiving waters to fall below the relevant water quality criteria, unless authorised by a permit or by other provisions of the regulations.

There are several circumstances under which strict adherence to the water quality criteria may not be required:

1. Where a water quality criterion is exceeded due to natural background variations, then the water quality criterion for that water body or segment of the water body is deemed to be the natural background level of the parameter.
2. If reliable scientific evidence indicates that a prescribed water quality criterion may be exceeded without causing serious environmental harm, then the Director [of the agency administering the legislation] may increase the criterion to the extent it considers appropriate in any particular case.

If an applicant for a permit can demonstrate that it has explored all methods of waste avoidance and minimisation and shown that it is not viable or practicable to further reduce the level of waste constituent prior to its discharge or emission, a permit may provide for a mixing zone within which where the prescribed water quality criteria are not required to be met and the protection of aquatic life may not be guaranteed. Permitting of “prescribed activities” including mining and mineral processing is administered by the Conservation and Environment Protection Authority (CEPA) under the *Environment (Prescribed Activities) Regulation 2002.*

3.2 PNG Environmental Code of Practice – Mining (2000)

Section 38 of the *Environment Act 2000* provides for the promulgation of environmental codes of practice, including guidance on ways to achieve compliance with the objectives of the Act. Codes of practice are voluntary, unless made legally binding through the inclusion of a permit condition requiring adherence to the code.

A Code of Practice for Mining was issued in 2000. The PNG Environmental Code of Practice – Mining provides general comments on management of mineral wastes, but also includes several specific provisions relevant to the management of acid or metalliferous drainage, as follows:

- Where seepage is likely to be contaminated, special design provisions should be made to minimise seepage flows and collect all seepage for treatment.
- Ore concentrate and waste rock stockpiles should be located so as to allow for diversion of water around these piles or to permit the collection of any contaminated drainage.
- ARD has to be collected and treated until metal concentrations and pH-value reach pre-mining levels or levels mutually agreed by all stakeholders.

3.3 PNG Draft Mine Closure Policy and Guidelines (2005)

The draft PNG Mine Closure Policy and Guidelines primarily focus on the administrative and financial requirements to achieve key closure objectives, including:

- Minimisation of negative environmental or social impacts from mining activities during the mine life and elimination, where possible, of negative impacts after mining operation ceases
- Ensuring that as many benefits as possible from mining are sustained beyond the life of a mine.

The closure policy and guidelines do not include specific technical requirements relating to the geochemical characterisation and assessment of mineral wastes, although it is a requirement that mine closure plans should address the “... physical stability, chemical stability [of built landforms and waste impoundments] and should cover mining operations, waste dumps, tailings, plant and infrastructure”. The draft policy has been available for some time but has not yet been approved by the PNG Government.

3.4 APEC Mine Closure Checklist for Governments

The Asia-Pacific Economic Cooperation Secretariat (APEC) has recently released a checklist to guide policy makers in the APEC region in the development of regulatory and governance frameworks for mine closure (APEC, 2018).

3.5 Global Acid Rock Drainage Guide

The Global Acid Rock Drainage (GARD) Guide [http://www.gardguide.com/index], prepared by the International Network for Acid Prevention (INAP), is an online, best practice guide to the assessment and management of acid-generating materials encountered during mining and mineral processing. It addresses the control of acid drainage, neutral drainage and saline drainage from a range of mining sources, including ores, overburden, waste rock, residues/ tailings and mine workings. The GARD Guide is a practical "how to" guide based upon international experience and proven technologies. It is not a regulatory instrument.

The GARD Guide recognises that techniques for managing acid drainage and the endpoints for performance (e.g., water quality standards) may differ depending on the local, regional or country context. Target outcomes may be influenced not only by corporate and regulatory requirements, but also by the social, economic, and environmental context of the mining operation (Figure 3-1).

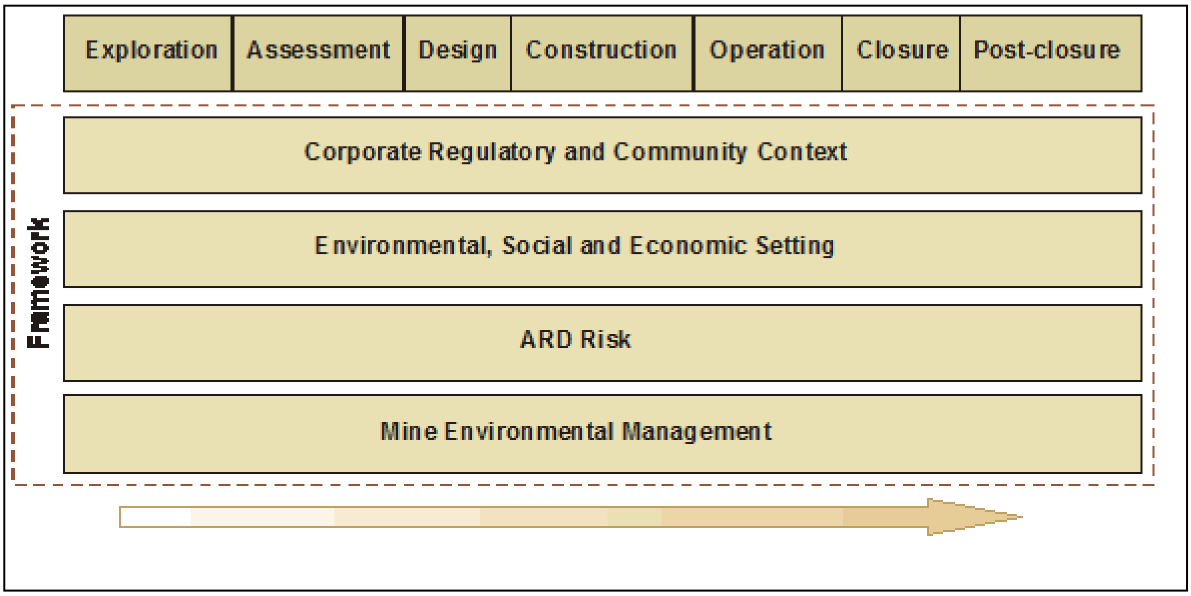


Figure 3-1: Conceptual ARD management framework (GARD)

The geochemical assessments and recommendations presented in this report have been prepared in accordance with the technical approaches recommended in the GARD.

3.6 International Finance Corporation Guidelines and Standards

The International Finance Corporation (IFC) Guidelines and Standards are relevant to the assessment of mineral wastes, but do not prescribe testing approaches. Two key IFC guideline documents relevant to the assessment and management of mineral wastes are:

- Environmental, Health, and Safety Guidelines - Mining (2007)
- Environmental, Health, and Safety (EHS) Guidelines General EHS Guidelines: Environmental Contaminated Land (2007).

The former guidelines include recommended “best practice” water quality criteria relevant to water discharged from a mine site to the environment (including stormwater runoff). The IFC notes that the water quality criteria recommended in the Mining Guidelines *(2007)* (IFC, 2007a) *“are indicative of good international industry practice”* and that the guidelines *“…should be achievable under normal operating conditions in appropriately designed and operated facilities through the application of pollution prevention and control techniques…”.* Nonetheless, the Mining Guidelines (2007) state that in some circumstances it may be appropriate to develop site-specific emission limits. If site-specific approaches are proposed, the guidelines recommend that they should be developed in accordance with the *General EHS Guideline* (2007) (IFC, 2007b).

Under the latter guideline, land is considered to be contaminated when it contains “hazardous materials” at concentrations above background or naturally occurring levels. This potentially has implications for waste characterisation and waste containment design.

The IFC *Performance Standards on Environmental and Social Sustainability* (2012) *and associated Guidance Notes* (IFC, 2012) are also relevant to the assessment and management of mineral wastes, but these also do not prescribe assessment methods. The following elements of the performance standard on pollution prevention (IFC Guidance Notes, 2012) are specifically relevant:

- **GN3** – Environmental aspects of new Projects or major expansions should be assessed. During the design phase, the assessment should consider total use of resources and resource efficiency. Additional matters to be considered as part of the assessment of impacts include background ambient conditions (whether natural and/ or anthropogenic), presence of local communities, impacts on environmentally sensitive receptors, expected Project demand for water, and availability of waste disposal facilities. The assessment should include consideration of the potential for cumulative impacts.
- **GN34** – Where relevant information is available, the assimilative capacity of the receiving environment should be considered when assessing potential impacts on air and water quality.
- **GN35** – The potential impacts of pollutant emissions by Project activities should be assessed in the context of background ambient levels of pollution.
- **GN36** – If background ambient levels exceed the relevant ambient environmental quality guidelines or standards (i.e., ambient conditions are already deteriorated), proponents should demonstrate that they have sought to minimise further deterioration of the environment or preferably to achieve improvement. Projects should generally be designed so as to reduce the potential for significant environmental deterioration.

4 Geochemical Characterisation

4.1 Introduction

Geochemical characterisation is required for materials (rock) that will be exposed to oxygen and water by mining activities since the rock may oxidise and release contaminants (dissolved metals) and acid (sulphuric acid). Waste rock will be produced from the development workings (declines, ventilation shafts) and will be brought to surface. Block cave mining will not result in the production of waste rock per se, but will cause a subsidence zone of fractured rock to develop that will propagate to surface and may cause ready ingress of oxygen and water.

The subsidence zone will consist of i) ore that will be removed in a relatively short timeframe, and ii) surrounding rock that will remain in place at the completion of mining. Since the mine will be actively ventilated, there is potential for the ore to oxidise and potentially generate acid and soluble metals. The degree of oxidation and acid generation from the ore will depend on the duration of exposure after caving, but prior to removal and the lag time to acid generation. If the ore reacts rapidly and has a short lag time to acid generation, the solute release would report to the mine water and would be captured and treated as part of the mining operation. Ore may be stockpiled on surface (e.g., at the coarse ore stockpile); if stored for any length of time the ore would be expected to oxidise and release solutes to surface runoff and toe seepage. As for the mine water, the runoff and seepage would need to be managed, as required, to prevent the receiving environment being affected.

The fractured or broken rock in the subsidence zone will also be expected to oxidise during and after operations. During operations; as noted before, the water would be captured by mine dewatering activities and would be treated as noted for water contacting ore. However, unlike the ore, the fractured non-ore bearing rock will remain in place after operations cease, and in the long term will continue to oxidise until all the sulphide minerals have been depleted. The exposure to oxygen and water during mining operations will depend on the location in the subsidence zone relative to the ground surface and the mine workings. During mining, air will be introduced as part of the mine ventilation, and zones closer to the ore zones would be more oxygenated than others. Since the zones closer to the ore would tend to be more fractured than zones further away from the ore zone, these rocks would tend to oxidise more rapidly during operations. At closure, the declines and ventilation shafts will be sealed and oxygen supply will be cut off from these areas. Furthermore, the water table will recover to a level expected to be close to the pre-mining elevation, so that the primary mechanism for oxygen ingress would be from the ground surface expression of the subsidence zones.

The rate of solute generation and acid generation, and overall potential for solute release, will depend on the reactivity of the sulphide minerals and the interaction with acid neutralising minerals. Therefore, to determine the risk of acid generation and metal leaching, it is necessary to characterise the rock that will be exposed to oxygen and water i) near the drawpoints during active mining, and ii) within the greater subsidence zone after the surface expression occurs.

Since ore will largely be removed for processing (with deep sea disposal of the tailings), the ore is likely to influence the mine water quality during the operations only. Therefore, an understanding of the short-term leaching properties of the ore is required. In the case of the rock within the subsidence zone, an understanding of both the short and longer term geochemical response to oxygenation is required. The following sections summarise the available geochemical test data for the lithological units that are likely to be exposed to oxidation.

4.2 Historical testing

As part of the overall geochemical characterisation program between 1990 and 2011, 340 samples from the mining area were submitted for static testing by Environmental Geochemistry International (EGi). This included testing of samples from the proposed 2011 decline alignment. Tailings and Migiki Borrow Pit samples were also submitted for static testing by Earth Systems (2014). Ten samples from the mining area (EGi, 2009) and one sample of tailings were submitted for kinetic testing (GCA, 2015).

4.2.1 Ore

Static testing

EGi (2009) reported geochemical characterisation results for four ROM ore composite samples. The location of origin of the rock used to form the composites is not stated. The geochemical characteristics of the samples are given in Table 4-1. The samples were all classified as potentially acid forming (PAF), with elevated sulphur and no acid neutralisation capacity (ANC). The pH values are all acidic, which suggests that the samples would oxidise and generate acid rapidly, i.e., no or very short lag time to acidification.

Table 4-1: Geochemical characteristics of ore samples

Parameter	Unit	Phyllic composite	Potassic composite	Metasediment composite
Total Sulphur	%S	13.4	8.1	8.77
ANC	kgH_2SO_4/t	0	0	0
pH	s.u.	3.2	3.1	2.4
NAPP	kgH_2SO_4/t	410	248	268
NAG potential	kgH_2SO_4/t	383	227	226
Minimum NAGpH	s.u	2.4	2.4	2.2
ARD Classification		PAF	PAF	PAF

4.2.2 Development rock and subsidence zone

Most of the samples that have been characterised were part of the 2011 assessment which was based on an early Project development configuration which proposed an open pit arrangement. As a result, none of the samples represent the decline alignments of the currently proposed Project and many of the samples originated from outside the projected subsidence zone. As noted above, the subsidence zone in the shorter term will include ore that will be fractured and oxidise prior to extraction, whereas the remainder of the subsidence zone will expand as mining progresses and will remain after closure.

Static testing

Static testing conducted by EGi comprised standard methods used for geochemical characterisation, as recognised and recommended under Australian and international geochemical characterisation guidelines.

A representative suite of measurements conducted by EGi included:

- Paste pH and paste electrical conductivity
- Total sulphur of solids
- Acid neutralising capacity (ANC) of solids
- Net acid producing potential (NAPP) of solids
- Net acid generation (NAG) of solids.

Selected samples were also subjected to additional tests:

- Multi-element composition of solids
- Water and peroxide extractions
- Multi-element composition of extract liquors
- Kinetic net acid generation (NAG) tests.

Sample locations

Locations of the samples selected for geochemical characterisation are indicated in Figure 4-1. Most of the samples are located outside the subsidence zone. The proposed Watut and Nambonga declines are indicated by grey lines near the collars of recently drilled holes WR505 to WR516. Samples from these holes have not yet been characterised. Samples distributed along a line parallel to the Watut declines indicate the location of the 2011 decline. The Watut declines are approximately 700m to the north of the previously prosed (2011) location (Finn, 2015).

Figure 4-2 shows gradients in sulphur concentration and indicates that the sulphur content tends to be higher towards the subsidence zone.

Figure 4-3 shows a plan view of the current location of the declines, with respect to the Babwaf Conglomerate and the Owen Stanley Metamorphics Shale. It can be seen that shifting the decline to the north by 700m would not alter the major lithological units through which it will pass.

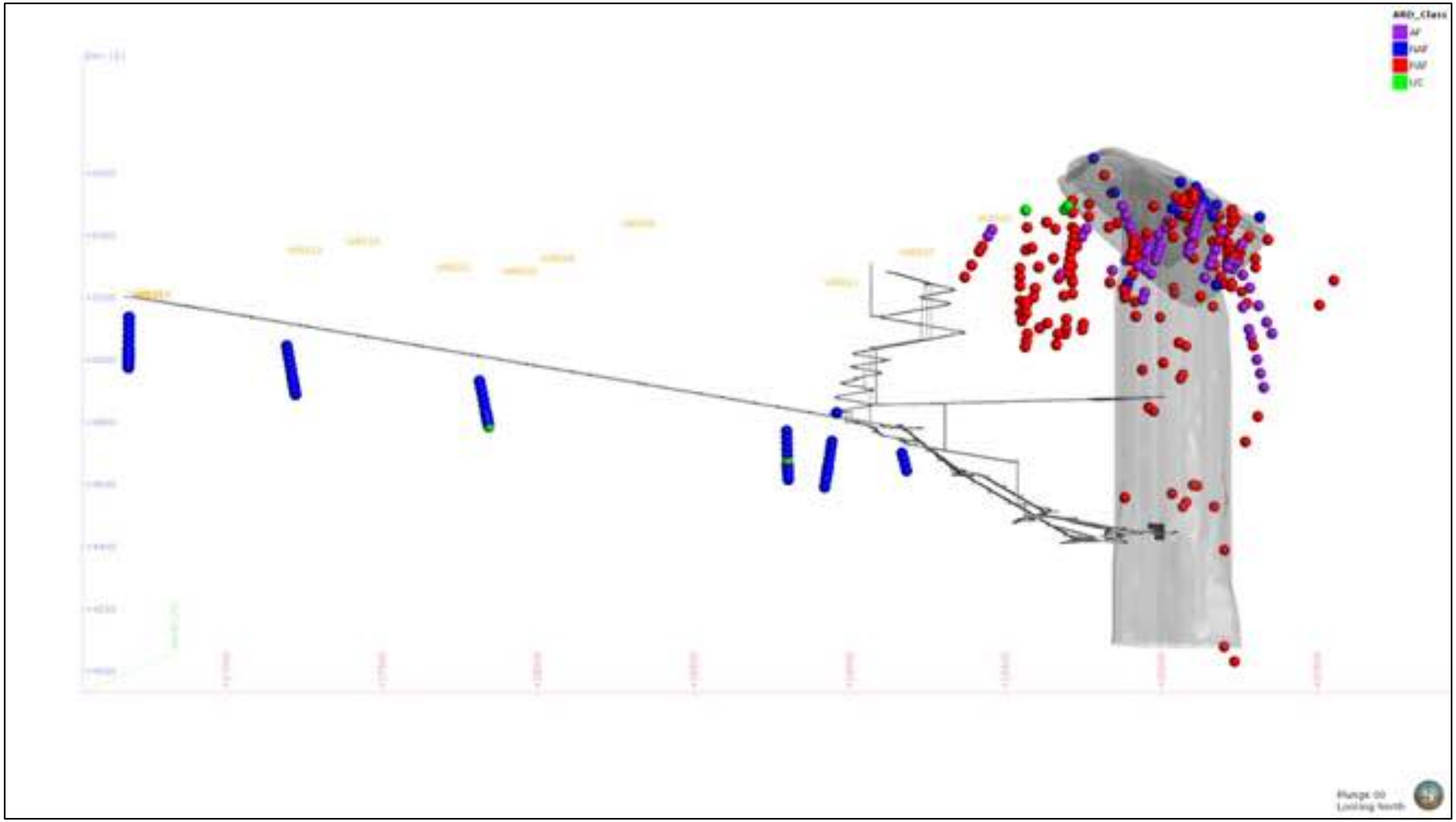


Figure 4-1: Proposed Block cave and decline sample locations – view 1

Source: WOR004_WGGeo_ARDClass_GradeModels_SubsidenceZone_revB.lfview.

Notes:
Large grey volume indicates subsidence zone, grey lines indicate decline, sphere colours:
Blue – NAF
Purple – AF
Green – UC
Red – PAF, classification scheme of EGi.

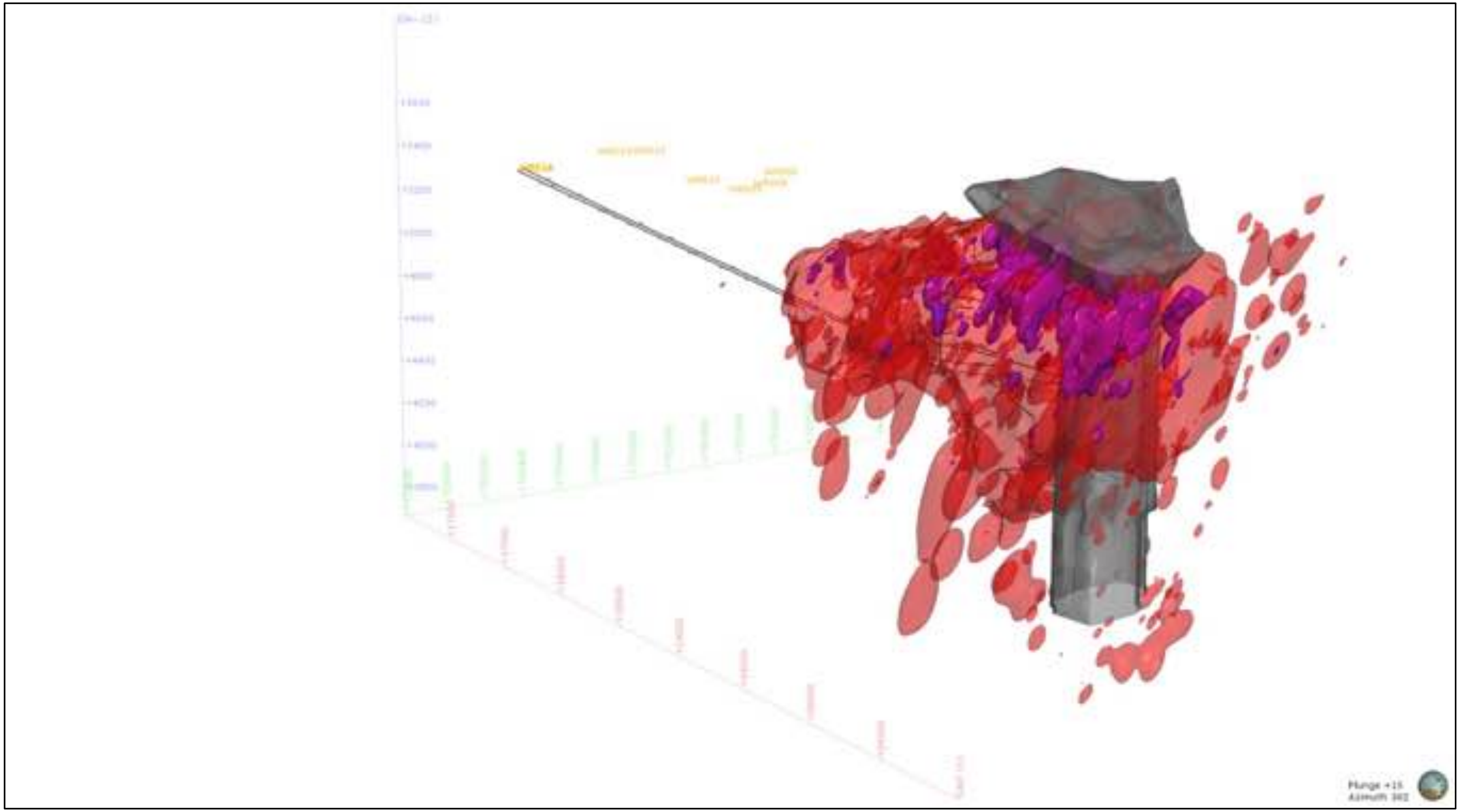


Figure 4-2: Proposed Block cave and decline sample locations – view 2

Source: WOR004_WGGeo_ARDClass_GradeModels_SubsidenceZone_revB.lfview.

Notes:
Volume colours represent sulphur content.
Red – 5%
Purple – 10%.

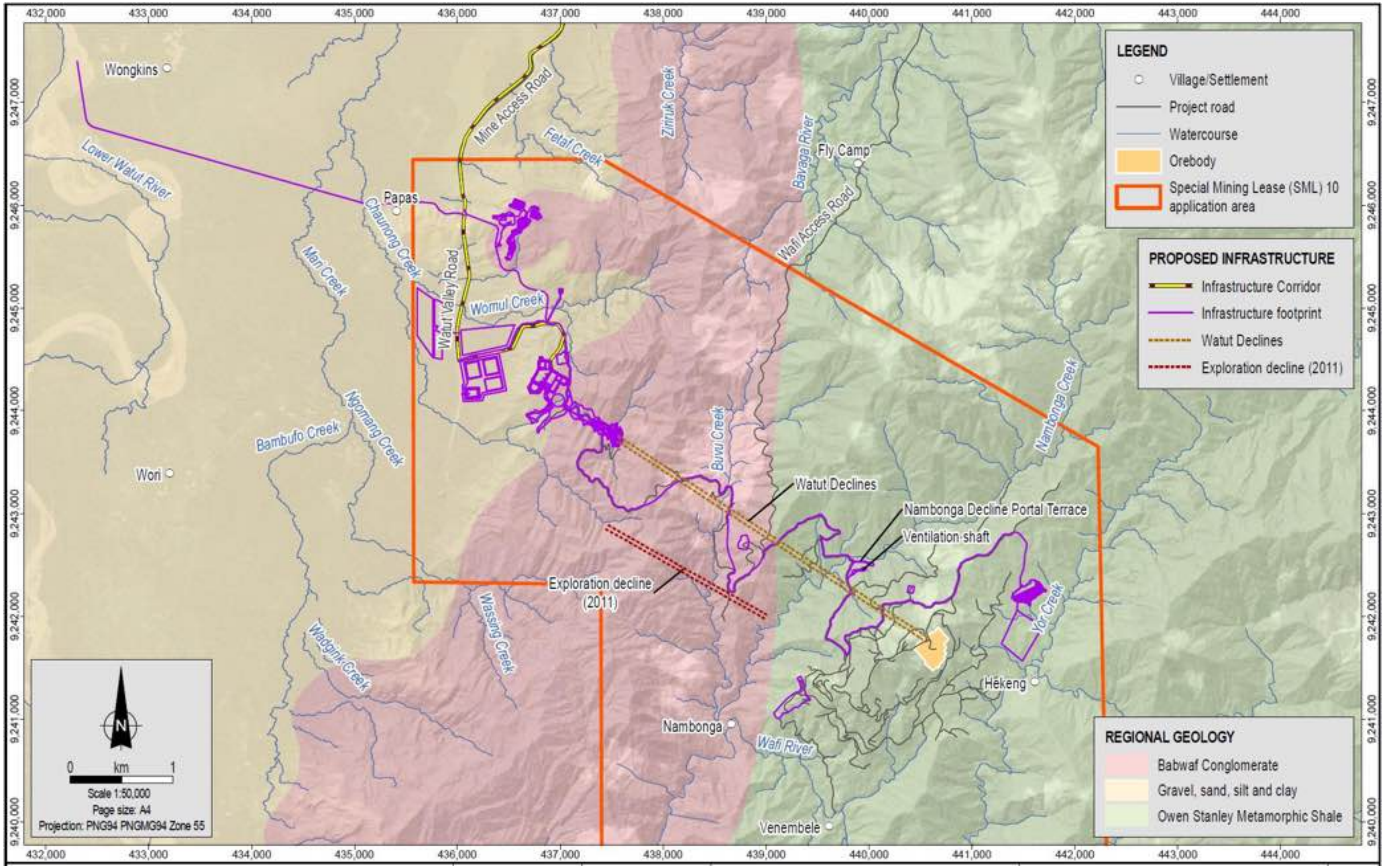


Figure 4-3: Plan view of major geology along the proposed alignment of the exploration declines

Source: Coffey, 2018.

Rock volumes and sample numbers

Table 4-2 provides estimated volumes and rock types that are expected to be produced from the declines for disposal in waste rock dumps. The table also shows the estimated volumes that would be fractured within the subsidence zone (Finn, 2018). Waste rock produced from the declines will comprise Babwaf Conglomerate and Volcanics, Owen Stanley Metamorphic Shale, Oxide and Owen Stanley Metamorphic Unaltered rock types. The volume of rock expected to be mined from the three declines (Nambonga and twin Watut Declines) is approximately 895,000bcm.

Eleven rock types occur within the subsidence zone, where most of the volume would be Oxide, and Argillic, Advanced Argillic or Actinolite Owen Stanley Metamorphics. The expected volume of rock remaining in the subsidence zone is approximately 180Mbcm.

Seventy-three samples (about 21% of all samples tested) originated from inside the subsidence zone.

Four rock types are represented by fewer than five samples; this number of samples is inadequate to provide a reliable measure of average values of geochemical characteristics and to indicate the variation about the average. The rock types are GDP_A, LC, PDA_A and PDA_AA (Table 4-2 provides rock type descriptions). However, these four rock types are each less than 1% of the volume in the subsidence zone. Due the small volumes, these rock types are not expected to significantly influence the overall potential for AMD; therefore, characterisation of additional samples of this rock type is not required.

Table 4-2: Decline and subsidence zone rock types, volume and sample numbers

Rock type	Description	Total volume in declines (bcm)	Tonnage inside declines (t)	Volume inside subsidence zone (bcm)	Tonnage inside subsidence zone (t)	Percentage of rock type inside decline (%)	Percentage of rock type inside subsidence zone (%)	No. of AMD samples	Percentage of all samples	No. samples inside subsidence zone	No. samples outside subsidence zone
BWC	Babwaf Conglomerate	59,843	155,592	0	0	6.5	0.0	43	13	0	43
DTX	Diatreme Unaltered	0	0	0	0	0.0	0.0	0	0	0	0
DTX_A	Diatreme Argillic	2,852	7,415	0	0	0.3	0.0	6	2	0	6
DTX_AA	Diatreme Advanced Argillic	0	0	712,000	1,851,200	0.0	0.4	8	2	1	7
GDP	Golpu Diorite Porphyry Unaltered	0	0	0	0	0.0	0.0	0	0	0	0
GDP_A	Golpu Diorite Porphyry Argillic	0	0	1,160,000	3,016,000	0.0	0.6	1	0	1	0
GDP_AA	Golpu Diorite Porphyry Advanced Argillic	0	0	96,000	249,600	0.0	0.1	11	3	11	0
GDP_ACT	Golpu Diorite Porphyry Actinolite	19,482	53,575	7,256,000	19,954,000	2.2	4.0	14	4	13	1
LC	Leached Cap	0	0	1,592,000	4,139,200	0.0	0.9	3	1	3	0
LGV	Langimar Volcanics	57,079	154,113	0	0	6.4	0.0	17	5	0	17
OSM	Owen Stanley Metamorphics Unaltered	504,621	1,362,476	64,000	172,800	56.6	0.0	59	17	0	59
OSM_A	Owen Stanley Metamorphics Argillic	49,603	128,969	34,024,000	88,462,400	5.4	18.9	59	17	9	50
OSM_AA	Owen Stanley Metamorphics Advanced Argillic	0	0	24,384,000	63,398,400	0.0	13.6	29	9	7	22
OSM_ACT	Owen Stanley Metamorphics Actinolite	54,132	146,155	56,856,000	153,511,200	6.1	31.7	7	2	7	0
OSM_S	Owen Stanley Metamorphics Shale	54,952	148,372	0	0	6.2	0.0	44	13	0	44
Oxide	Oxide	1,304	3,130	52,920,000	127,008,000	0.1	29.5	33	10	17	16
PAN	Hekeng Andesite	0	0	0	0	0.0	0.0	2	1	0	2
PDA	Dacite Porphyry Unaltered	21,246	57,363	0	0	2.4	0.0	0	0	0	0
PDA_A	Dacite Porphyry Argillic	0	0	496,000	1,289,600	0.0	0.3	3	1	3	0
PDA_AA	Dacite Porphyry Advanced Argillic	31	80	0	0	0.0	0.0	1	0	1	0
	Total	**895,083**	**2,406,074**	**179,560,000**	**463,052,400**	**100**	**100**	**340**	**100**	**73**	**267**

Notes: Source of original data D. Finn (2018) file ARD_Geochemistry_Raw_Data_Combined_flagged RevP.xlxs/Vol Dstrbn.

Paste pH and paste Electrical Conductivity

EGi reported paste pH and paste electrical conductivity (EC) for all samples. Figure 4-4 presents results for the three rock types with predominantly NAF sample characteristics – BWC, LGV and OSM_S.

As indicated above, these waste types would be produced from the declines. There is a general trend for electrical conductivity to increase as the pH decreases. This is consistent with the sulphide minerals having (partially) oxidised and produced acid, lowering the pH and increasing metal solubility.

Figure 4-5 to Figure 4-7 present paste pH and paste EC results for rock types present in the subsidence zone. For rock types DTX_A, GDP_AA, OSM_AA and Oxide, there is no clear relationship between the paste pH and paste EC. The paste EC increases with pH for rock type DTX_AA, whilst for rock types OSM_S, OSM, OSM_A, the paste EC increases with decreasing pH. The former indicates a potential for neutral mine drainage, and the latter for acid mine drainage.

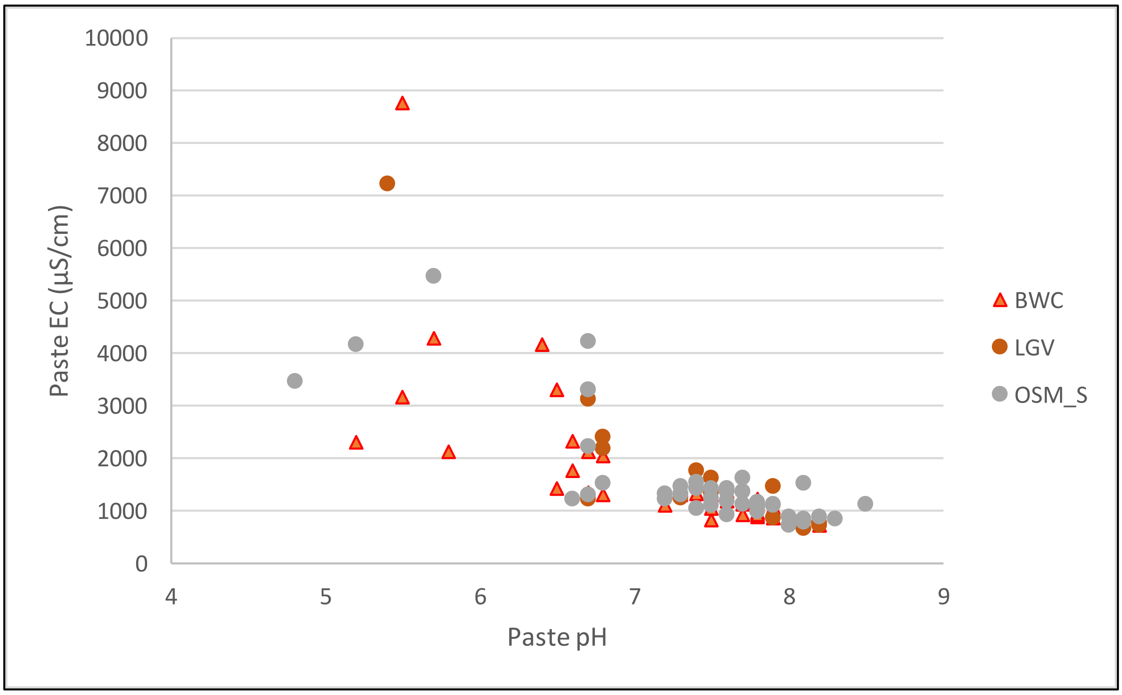


Figure 4-4: Paste pH vs paste EC for BWC, LGV and OSM_S rock types

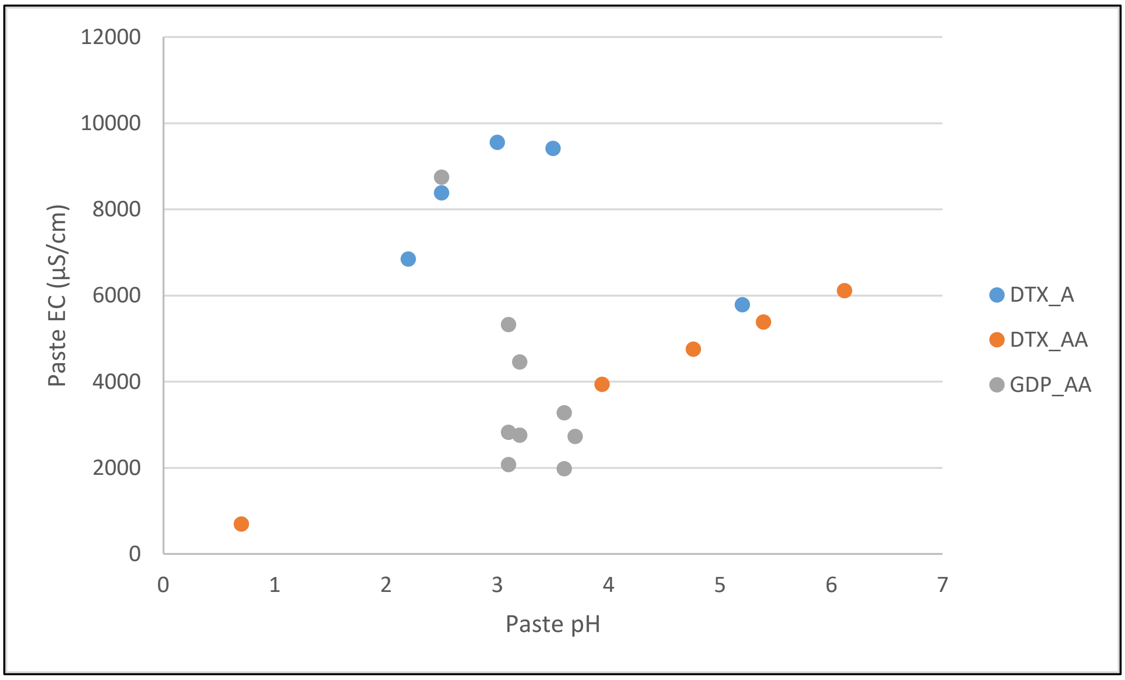


Figure 4-5: Paste pH vs paste EC for DTX_A, DTX_AA and GDP_AA rock types

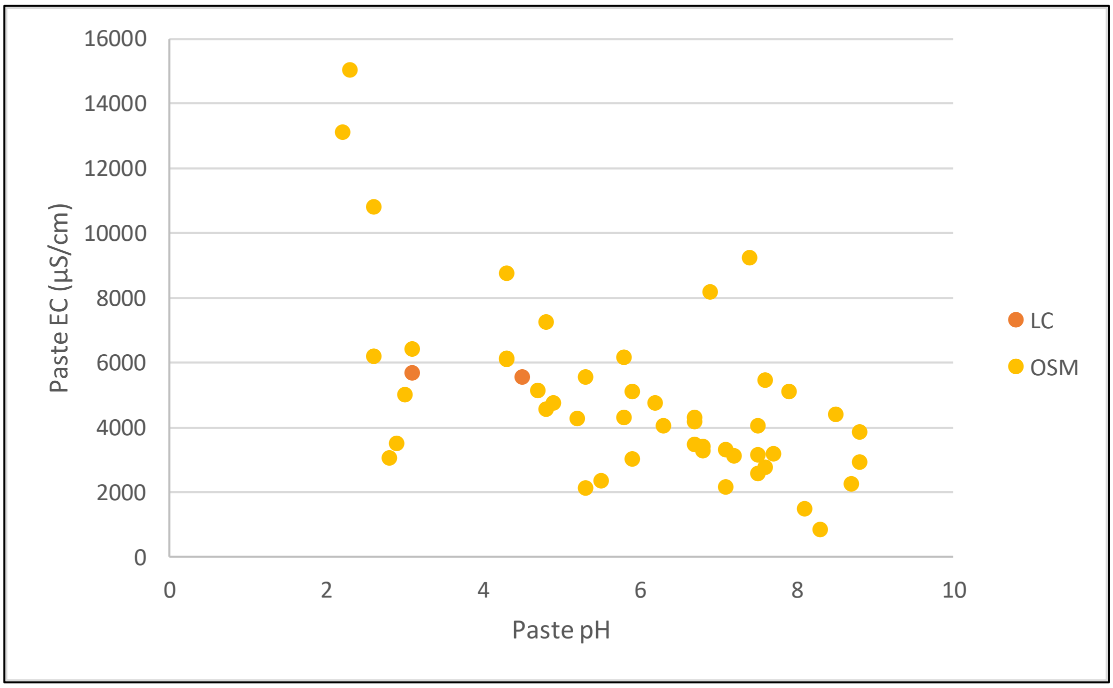


Figure 4-6: Paste pH vs paste EC for LC, OSM_S and OSM rock types

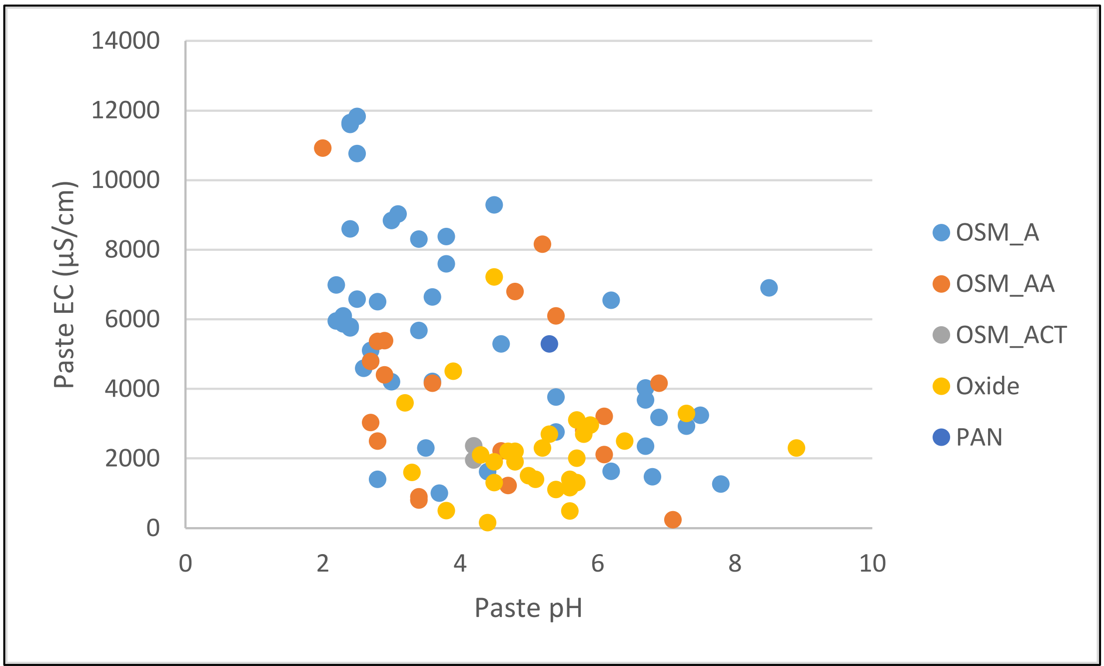


Figure 4-7: Paste pH vs paste EC for OSM_A, OSM_AA, OSM_ACT, Oxide and PAN rock types

Maximum potential acidity

Table 4-2 present summary statistics for the maximum potential acidity (MPA) for rock types geochemically characterised.

The MPA values of BWC, LGV and OSM_S are relatively low and indicate that these rock types have limited capacity to produce acid and salinity (sulphate). For example, approximately 95% of BWC samples had an MPA less than 8kgH_2SO_4/t. The MPA of BWC and LGV samples was lower than that of OSM_S samples. Thus, from a geochemical perspective, rock from these units may be more suitable for use as construction materials (Section 4.4).

Assuming the median values presented in Table 4-3 are representative of the median MPA for the rock types in the subsidence zone, 11 rock types have a median MPA of more than 100kgH_2SO_4/t and four rock types have an MPA greater than 300kgH_2SO_4/t.

Table 4-3: Summary statistics for MPA

Rock type	Count	Minimum	Average	Median	Maximum
BWC	43	1.8	4.7	4.3	11.3
DTX_A	6	136	326	312	505
DTX_AA	8	8.0	224	256	435
GDP_A	1	416	416	416	416
GDP_AA	11	45	352	370	514
GDP_ACT	14	97	267	228	600
LC	3	142	331	337	514
LGV	17	2.1	6.4	4.9	23.6
OSM	59	55	190	197	349
OSM_A	59	43	202	197	401
OSM_AA	29	1.5	171	155	392
OSM_ACT	7	18.7	140	141	330

Rock type	Count	Minimum	Average	Median	Maximum
OSM_S	44	4.0	10.8	10.7	22.3
Oxide	33	0.6	52	17.7	286
PAN	2	4.3	4.4	4.4	4.6
PDA_A	3	152	214	164	324
PDA_AA	1	99	99	99	99

Note: Units are kgH_2SO_4/t.

NAPP vs NAGpH

In general, rock type characteristics vary with distance from the midline of the Golpu deposit (Figure 4-2), and it is therefore possible that the geochemical characteristics within the subsidence zone differ from those outside. Acid base accounting (ABA) by EGi evaluated the net acid producing potential for all 340 samples and measured the NAGpH for 327 samples. The compiled results (Finn, 2015) are presented in Figure 4-8 to Figure 4-17. Samples from within and outside the subsidence zone are presented separately.

The figures illustrate the relatively small number of samples of each rock type that have been geochemically characterised. Where samples from inside and outside the subsidence zone have been characterised, the figures illustrate that the average and range of values of NAPP and NAGpH for samples from outside the subsidence zone would not reliably represent the average and range for materials inside the subsidence zone.

BWC and LGV samples from the 2011 decline alignment were NAF. A sufficient number of samples of the rock types from the new alignment of the decline should be characterised to provide confidence that the waste rock from the decline will be NAF and will have similar leaching characteristics to the rock along the 2011 decline alignment. The majority of OSM_S rock samples were classed as NAF; however, one sample was UC and another PAF and had a low NAPP.

Of the samples representing OSM_A, 50 samples (19% of the subsidence zone) from outside the subsidence zone, and 9 samples from inside, have been characterised and were classed as PAF. Additional OSM_A samples from within the subsidence zone should be characterised for comparison with those from outside the subsidence zone to verify the material properties.

The OSM_ACT rock type represents the largest volume (32%) of material in the subsidence zone; however, only seven samples have been characterised. All samples were classified PAF. Characterisation of additional samples is required.

Oxide material makes up 30% of the volume of the materials within the subsidence zone. Samples from inside and outside the subsidence zone have similar characteristics and commonly have low NAPP values. Inside the subsidence zone, the number of Oxide samples classified as NAF, UC and PAF was 0, 7 and 10, respectively. Outside the subsidence zone, the distribution of samples in the NAF, UC and PAF classes was 0, 3 and 13, respectively. The Oxide rock type (which is PAF) represents 30% of the material inside the subsidence zone. Thirty-three samples have been tested and additional Oxide samples should be characterised to improve the confidence in the material classification.

Twenty one OSM_AA samples from outside and seven from inside the subsidence zone were characterised. All samples from outside were PAF. OSM_AA occupies 14% of the subsidence zone volume. Additional samples of OSM_AA from inside the subsidence zone should be characterised.

Four percent of the rock in the subsidence zone is GDP_ACT. Thirteen samples from inside, and one from outside the subsidence zone, have been characterised. All samples were PAF and the NAPP values range between 100 and 500kg(H_2SO_4/t), a fivefold variation in acid potential. Additional samples should be characterised to improve the estimate of the overall acid potential.

DTX_A, DTX_AA, GDP_A and GDP_AA each make up less than 2% of the subsidence zone volume. Six samples of DTX_A were samples from outside the subsidence zone and none from within. All samples were classified as PAF. Additional samples from within the subsidence zone should be characterised to improve the representation of the 712,000bcm of DTX_AA material within the subsidence zone.

Seven samples of DTX_AA were PAF with NAPP values ranging from 50 to 450kg(H_2SO_4/t), the eighth sample was classified UC. No DTX_AA material will be mined. No additional samples of DTX_AA should be characterised.

One sample of GPA_A has been characterised and was PAF. As stated earlier, more samples should be characterised and they should be taken from within the subsidence zone.

OSM samples fall into the NAF, uncertain (UC) and PAF classes. This might be a result of OSM characteristics varying with distance from the orebody. It is therefore recommended that additional OSM samples are characterised, with emphasis on selection of samples near the proposed (2014) decline and towards the orebody.

All GDP_AA samples are PAF and the NAPP values range from about 20 to 510kg(H_2SO_4/t). All samples were from inside the subsidence zone. Only a limited number of additional samples may be required. A small number of LC, PAN and PDA_A samples were classified as PAF. However, as these lithological units individually make up less than 1% of the total mass, characterisation of additional samples is not recommended.

Recommendations for supplemental testing to ensure samples are statistically representative for each lithological unit within the subsidence zone, and to generate the kinetic data to support future water quality predictions, are provided in Section 4.3.

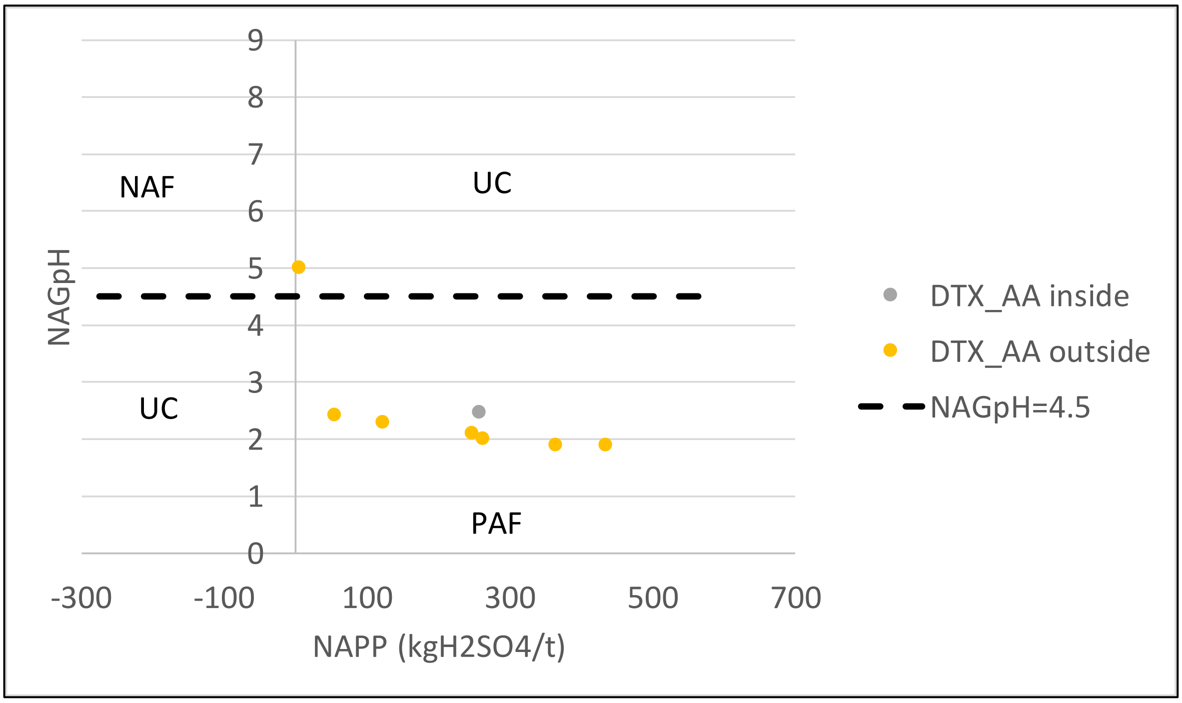


Figure 4-8: NAPP vs NAG for DTX_AA rock type inside and outside subsidence zone

Source: ARD_Geochemistry_Raw_Data_Combined_flagged>RevP.xlsx>ARD_Geochemistry_Raw_lock.

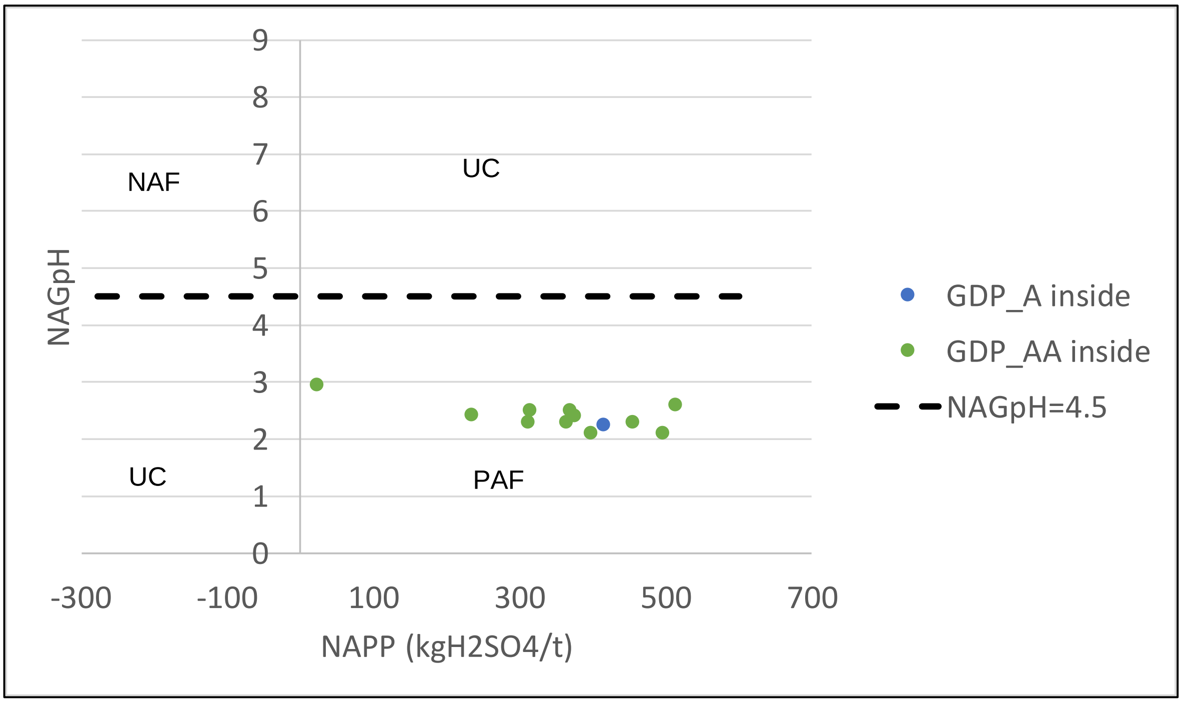


Figure 4-9: NAPP vs NAG for GDP_A and GDP_AA inside subsidence zone

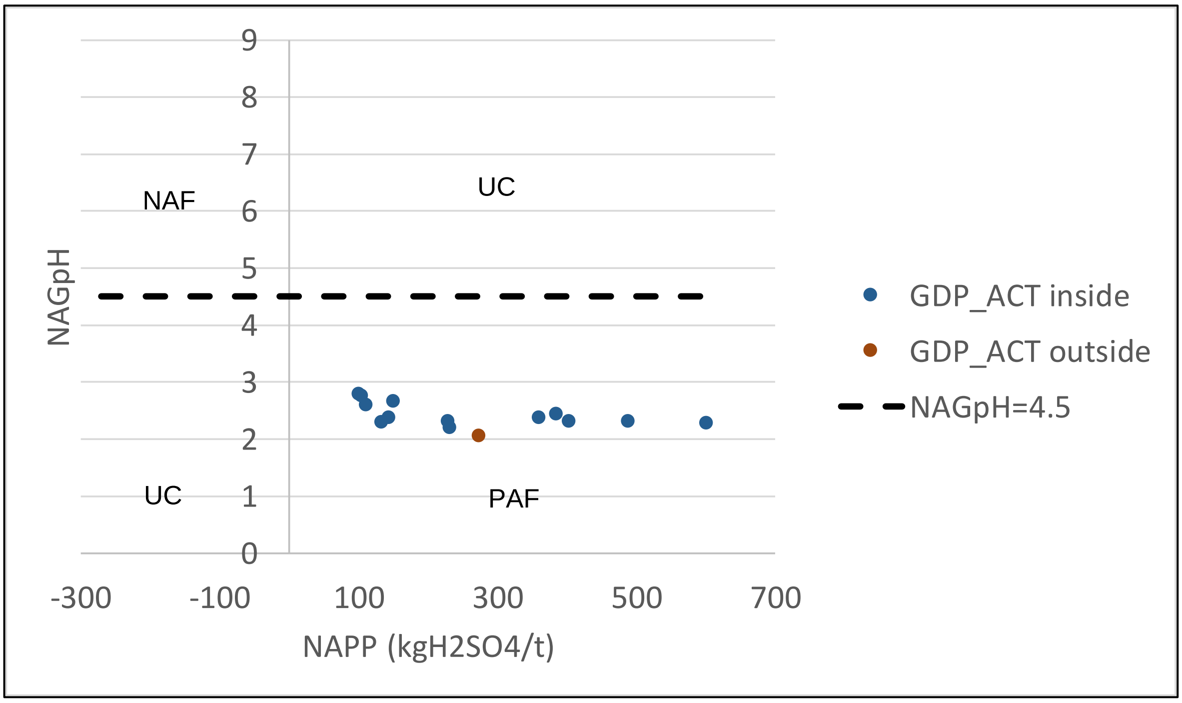


Figure 4-10: NAPP vs NAG for GDP_ACT rock type inside and outside subsidence zone

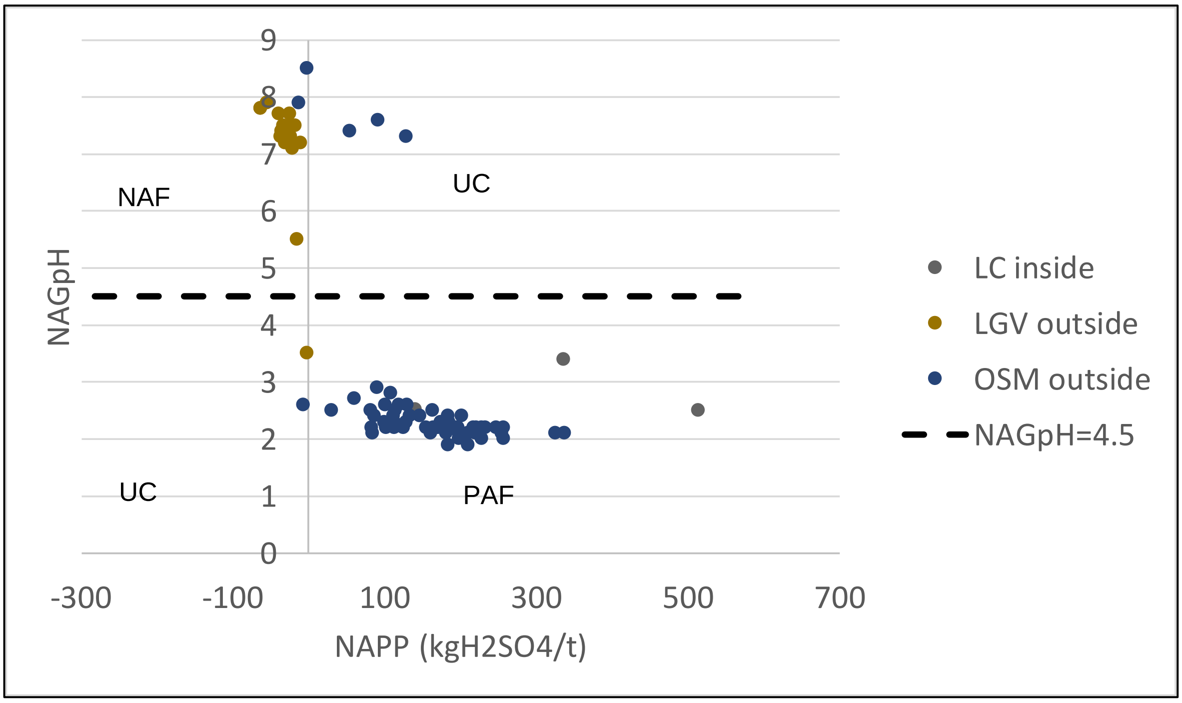


Figure 4-11: NAPP vs NAG for LC inside and LGV and OSM rock type outside subsidence zone

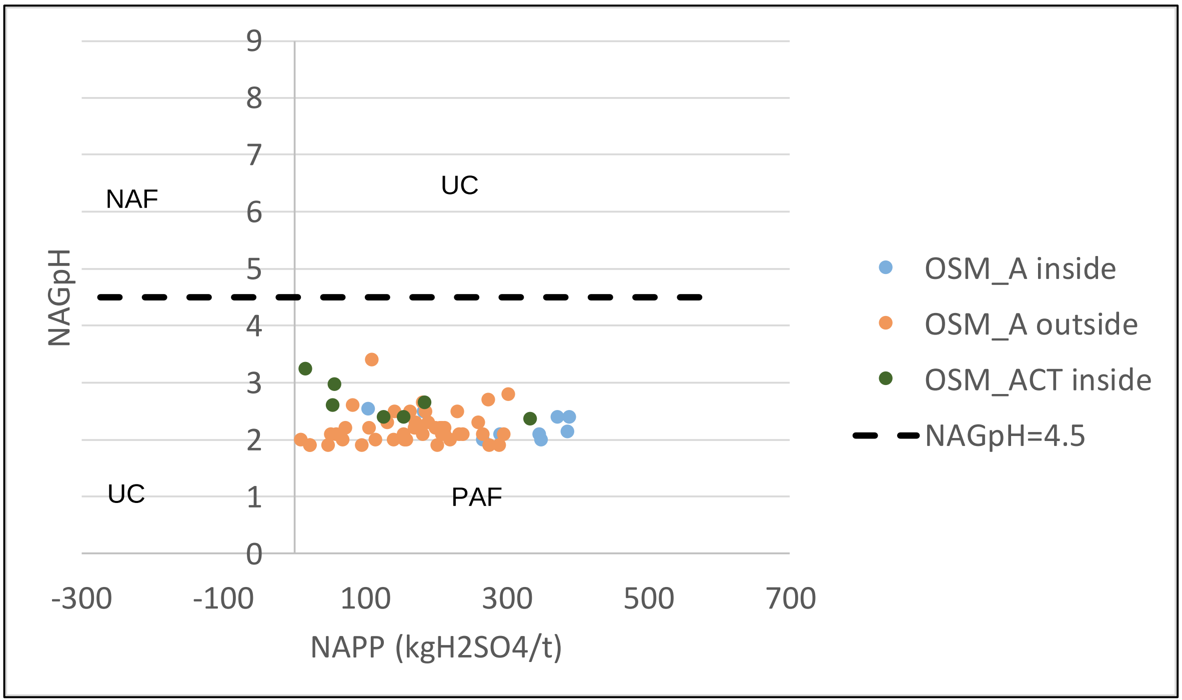


Figure 4-12: NAPP vs NAG for OSM_A and OSM_ACT rock type inside and outside subsidence zone

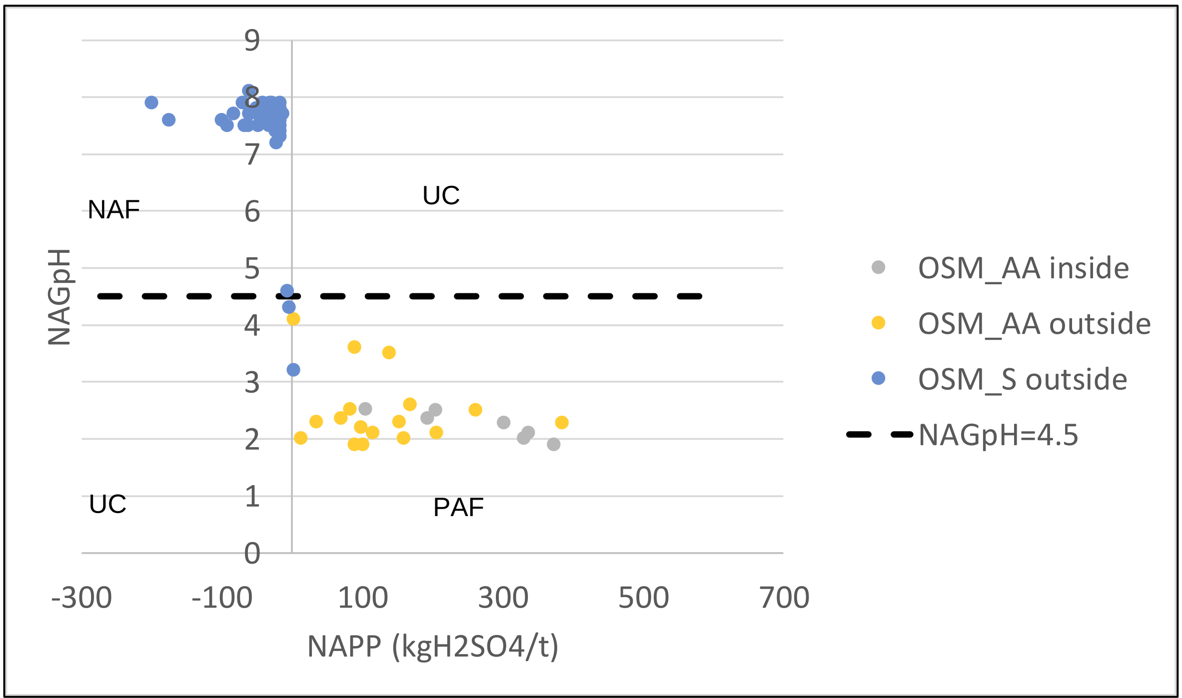


Figure 4-13: NAPP vs NAG for OSM_AA and OSM_S rock types inside and outside subsidence zone

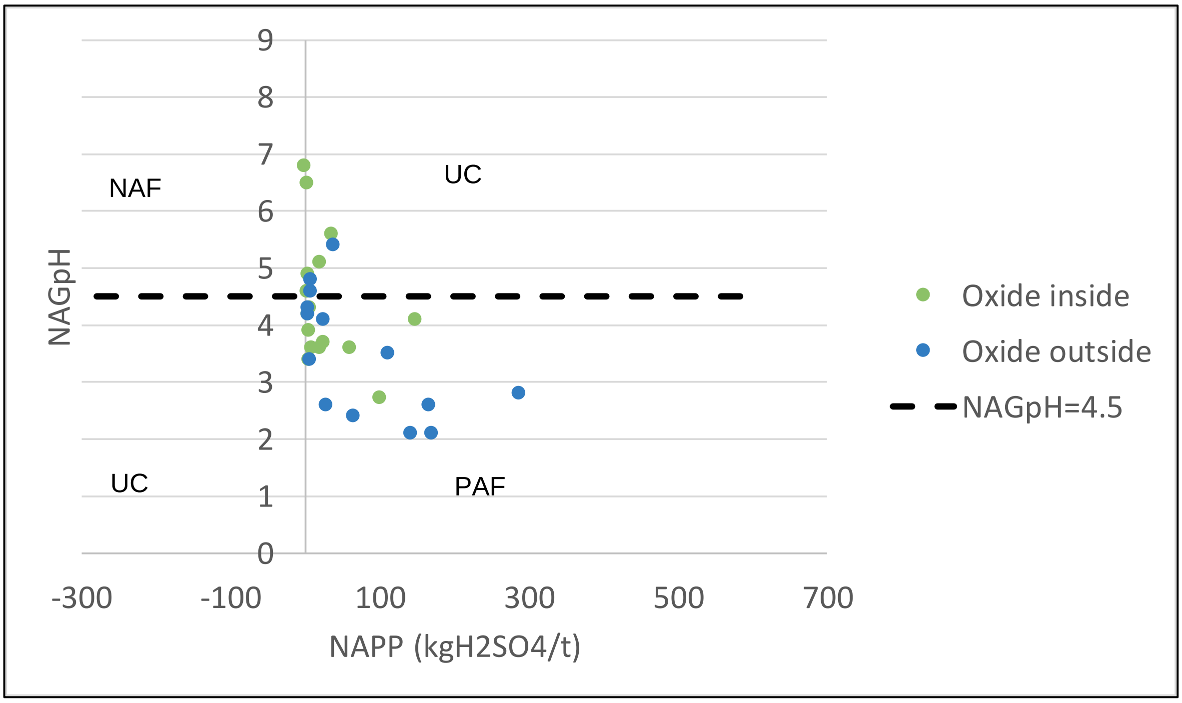


Figure 4-14: NAPP vs NAG for Oxide rock type inside and outside subsidence zone

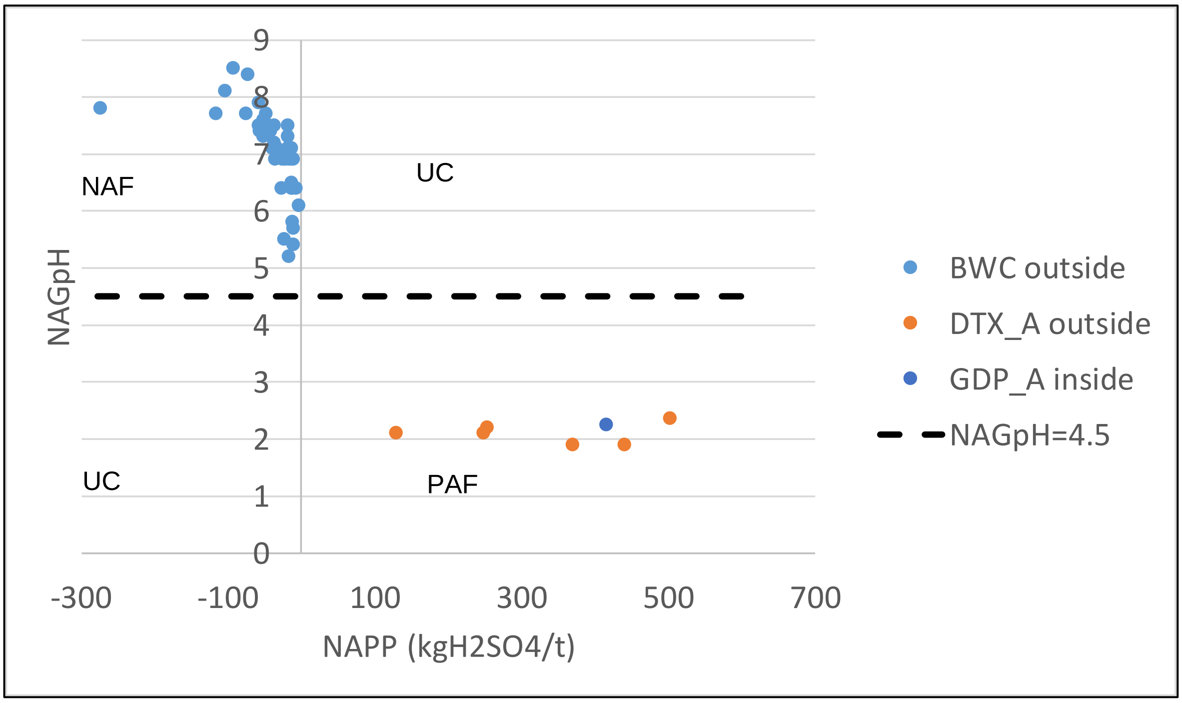


Figure 4-15: NAPP vs NAG for BWC, DTX_A and GDP_A rock type

Notes:
BWC, LGV samples originated outside the current decline region;
DTX_A samples are from outside the subsidence zone; and
GDP_A samples are from inside the subsidence zone.

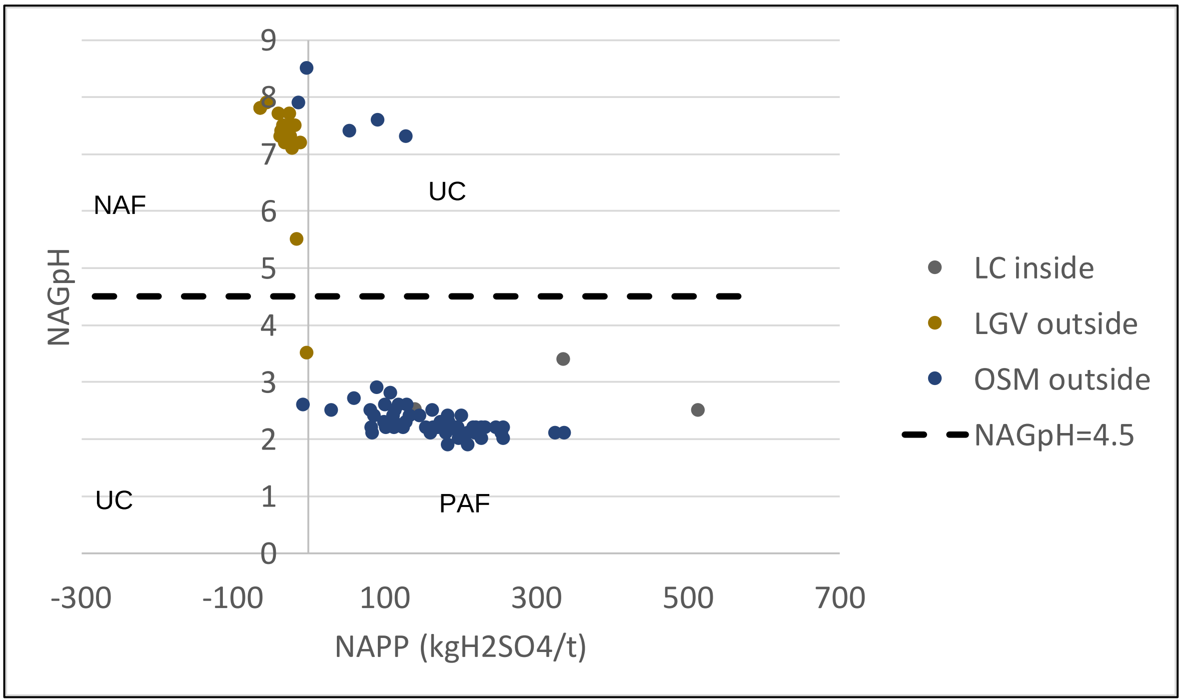


Figure 4-16: NAPP vs NAG for LC from inside and OSM_S and OSM rock type from outside the subsidence zone

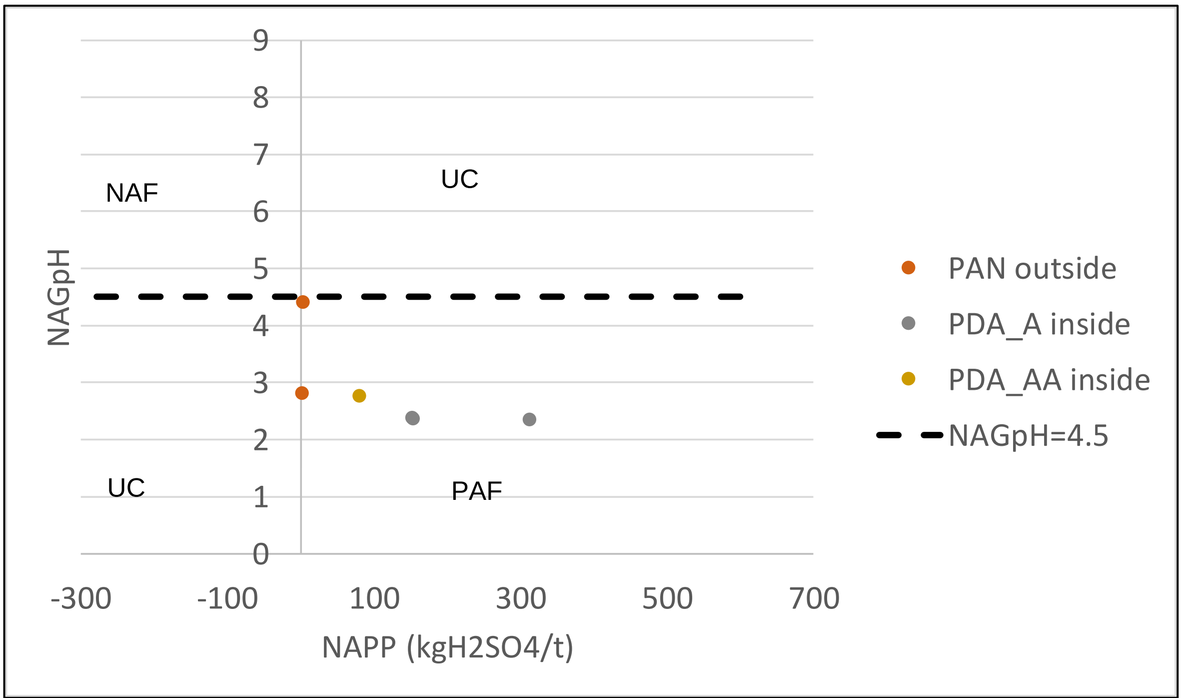


Figure 4-17: NAPP vs NAG for PAN, PDA_A and PDA_AA samples relative to the subsidence zone

Elemental enrichment

EGi (2011) analysed samples from drill core holes along the alignment of the proposed 2011 declines. A total of 105 samples were collected from the Babwaf Conglomerate and Owen Stanley Metamorphics Shale. (Note that at the time, Langimar Volcanics were not specifically identified and were considered as part of the Babwaf Conglomerate.)

Of the 105 samples, 12 BWC and eight OSM_S samples were assayed. As reported by EGi (2013), except for sulphur there were no significant enrichments in the samples representing BWC and OSM_S. However, the results indicate minor enrichment (global abundance indicator (GAI) = 1 or 2) of several elements, including cobalt (12 samples), chromium (1 sample), copper (2 samples), mercury (1 sample), and selenium (8 samples).

EGi also assayed samples intended to be representative of the mining area, although most were from outside the subsidence zone. Review of the assay data compiled by Finn (2015) indicated that some rock types have significant enrichment of some metals. The number of samples with GAI values of 3 or more are presented in Table 4-4.

Although the elemental assay results provide an indication of enrichment in solid samples, the results do not necessarily indicate that the element will be a concern with respect to water quality.

Table 4-4: Number of samples with significant enriched elemental abundance

Rock type	As	Cd	Mo	Pb	S	Sb	Se	Tl	Zn
BWC									
LGV									
DTX_A		2	1	1	2		1		
DTX_AA		1	1		3		3		1
GDP_A			1		1		1		
GDP_AA			2		1		2		
GDP_ACT	7	2	7	5	14	1	13	1	
LC					1		1		
OSM_S							8		
OSM	4	1		1	6	2	1		
OSM_A	4	5	4	5	9	1	9	1	1
OSM_AA	4		2	3	7	1	6		
OSM_ACT			1	1	2	1	5		
Oxide	1				2		3		
PAN									
PDA_A	1	2		2	3		1	1	
PDA_AA		1	1		1		1		

Note: Approximately 80 samples were assayed.

Kinetic testing

EGi (2014) subjected samples referred to as waste rock and ore to column testing for a period of 104 weeks. Table 4-5 lists the samples tested and provides an indication of sulphur content and lag time.

Figure 4-18 shows the locations of the samples. All samples came from the subsidence zone surrounds; none originated from the block cave ore zones and therefore are not samples of ore within the current Project description.

Typically, the leachate characteristics had stabilised at the end of the test period, and therefore may be used for scaling calculations to infer water quality from the subsidence zone and any waste rock dumps.

Table 4-5: Waste rock samples subjected to kinetic testing

Column ID	Geology	Material type	Drill core (interval)	EGi ID No.	S content (wt%)	Lag
WGJV-01	Golpu (above argillic)	Cu Ore	WR362 (323-333m)	#3566	17.40	Fast reacting
WGJV-02	Metasediment (below argillic)	Waste	WR390 (650-660m)	#3567	6.25	Fast reacting
WGJV-03	Wafi Conglomerate	Waste	WR390 (100-110m)	#3568	0.26	Short
WGJV-04	Gold cap & Supergene	Au Ore	WR362 (73-83m)	#3569	0.03	NAF
WGJV-05	Diatreme (argillic)	Waste	WR367 (212-222m)	#3570	13.70	Fast reacting
WGJV-06	Golpu (below argillic)	Waste	WR389 (713-723m)	#3571	6.97	Fast reacting
WGJV-07	Hornblende Porphyry	Cu Ore	WR377 (1,500-1,510m)	#3572	6.46	Extended
WGJV-08	Golpu West	Cu Ore	WR377 (1,096-1,106m)	#3573	5.53	Extended
WGJV-09	Golpu (below argillic)	Cu Ore	WR337 (974-984m)	#3574	5.76	Extended
WGJV-10	Golpu (above argillic)	Waste	WR398 (291-301m)	#3575	13.60	Fast reacting

Notes: Lag times for leachates to become acidic under laboratory conditions were fast reacting – immediate, short ≤3 months, extended >2 years.

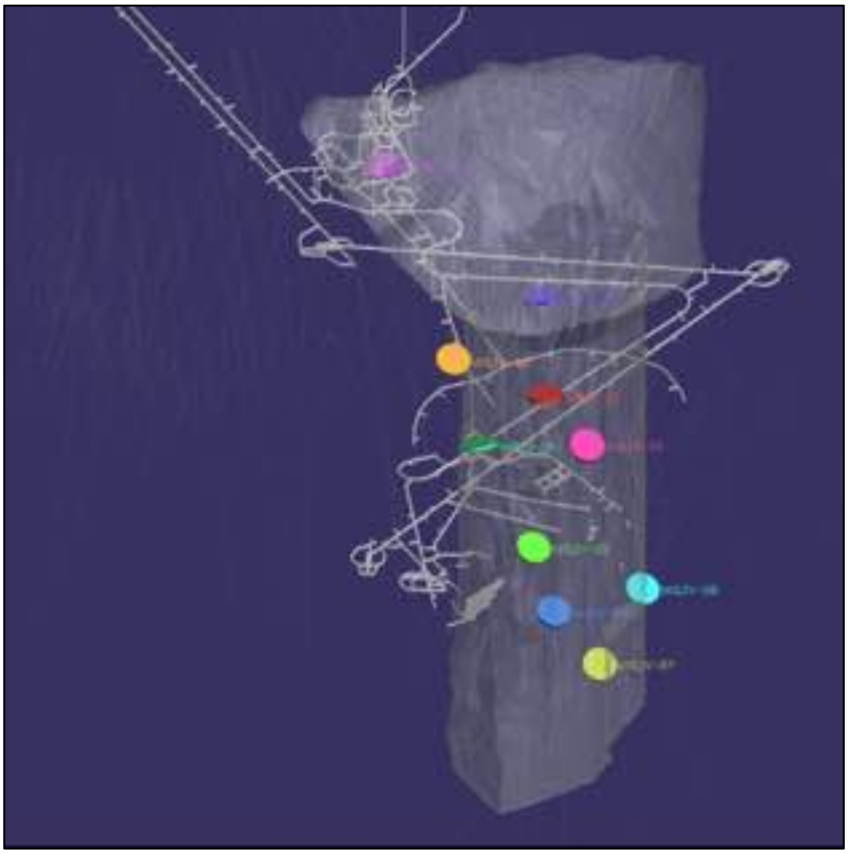


Figure 4-18: Locations of EGi 'waste rock' and 'ore' samples kinetically tested

Note: Subsidence zone is shaded light grey and the block cave zones are shaded darker grey.

4.3 Summary and recommended further work

Table 4-6 summarises available geochemical information and includes:

- Tonnages of rock types within the declines and subsidence zone
- Numbers of samples sourced from inside and outside the zone that would be mine affected (i.e., declines or subsidence zone)
- Average values of geochemical parameters for each of the lithological units (MPA, ANC, NAPP)
- Net potential ratio (NPR), the ratio of ANC to MPA, for each lithological unit
- Geochemical classification attributed to the overall rock type
- Status of sampling to date
- Risks associated with relying on available test results.

Most of the disturbed rock is predicted to be PAF. All 11 rock types present in the subsidence zone, making up more than 460Mt of rock, were classified as PAF. A further mass of more than 1,700,000t PAF rock would be removed from the declines with additional Oxide and OSM PAF rock coming from the ventilation shaft. The remainder of the rock from the declines (approximately 706,000t) would be NAF and of rock types BWC, LGV and OSM_S.

Seven rock types were sampled inside and outside the subsidence zone. For three of these rock types, the MPA and the NAPP were larger inside the zone of subsidence than outside, indicating that there is spatial variability in the geochemical characteristics within a given rock type and that material from within the subsidence zone has a greater potential for producing ARD.

Some rock types that make up 1% or more of the rock volume in the subsidence zone have poor statistical representation within the subsidence zone. For example, characterisation of 153Mt of OSM_ACT is based on testing of seven samples, and three other lithological units are represented by fewer than five samples.

As a result of the spatial variability of geochemical characteristics and the small numbers of samples from within the subsidence zone currently representing some lithologies, static and kinetic testing of additional samples is recommended for the majority of rock types. The kinetic testing in particular would help refine future predictions of water quality from the subsidence zone. SRK therefore recommend that further work be undertaken on appropriately sampled materials (location of origin of the samples representative of mining impacted materials) to generate supplemental static and kinetic data.

Once the additional geochemical data become available, the properties can be compared to the samples that have previously been subjected to kinetic testing and the adequacy of the available kinetic data for predicting likely future water quality in the subsidence zone and the waste rock dump can be assessed.

Table 4-6: Summary of geochemical information

Code and location	Rock Code	Lithological Description	Mass inside decline (t)	Mass in subsidence zone (t)	Number of samples	Number Samples within applicable zone (decline/ subsidence)	ANC	MPA	NPR	Average NAPP (kgH_2SO_4/t)	ARD Class	Status
BWC Outside	BWC	Babwaf Conglomerate	155,592	-	43	Outside	45	5	9.52	-40	NAF	Samples from a previous decline alignment
DTX_A Outside	DTX_A	Diatreme Argillic	7,415	-	6	Outside	1	325	0	324	PAF	All samples from outside zone
DTX_AA Inside	DTX_AA	Diatreme Advanced Argillic	-	1,851,200	1	Inside	1	258	0	258	PAF	Large mass/only one sample
DTX_AA Outside					7	Outside	3	215	0.01	213	PAF	
GDP -	GDP	Golpu Diorite Porphyry Unaltered	-	-	-	-	-	-	-	-	-	
GDP_A Inside	GDP_A	Golpu Diorite Porphyry Argillic	-	3,016,000	1	Inside	0	416	0	416	PAF	Large mass/only one sample
GDP_AA Inside	GDP_AA	Golpu Diorite Porphyry Advanced Argillic	-	249,600	11	Inside	6	297	0.02	293	PAF	No rock in subsidence zone or declines
GDP_AA Outside					0	Outside	0	384	0	384	PAF	
GDP_ACT Inside	GDP_ACT	Golpu Diorite Porphyry Actinolite	53,575	19,954,000	13	Inside	8	277	0.03	275	PAF	13 samples from zone/ large mass/ sample ratio small
GDP_ACT Outside				-	1	Outside	9	214	0.04	209	PAF	
LC Inside	LC	Leached Cap	-	4,139,200	3	Inside	1	332	0	331	PAF	Small mass of total
LGV Outside	LGV	Langimar Volcanics	154,113	-	17	Outside	37	6	5.81	-31	NAF	Samples from a previous decline alignment
OSM Outside	OSM	Owen Stanley Metamorphics Unaltered	1,362,476	172,800	59	Outside	33	188	0.17	155	PAF	All samples from outside current decline alignment and outside SZ
OSM_A Inside	OSM_A	Owen Stanley Metamorphics Argillic	128,969	88,462,400	9	Inside	19	294	0.06	288	PAF	No samples from current decline alignment; large mass within subsidence zone (SZ)
OSM_A Outside					50	Outside	12	198	0.06	186	PAF	
OSM_AA Inside	OSM_AA	Owen Stanley Metamorphics Advanced Argillic	-	63,398,400	7	Inside	7	232	0.03	228	PAF	Only seven samples inside, PAF inside > PAF outside
OSM_AA Outside					22	Outside	1	150	0	149	PAF	
OSM_ACT Inside	OSM_ACT	Owen Stanley Metamorphics Actinolite	146,155	153,511,200	7	Inside	12	181	0.06	171	PAF	Large mass, only seven samples; higher PAF capacity inside SZ
OSM_ACT Outside				-	0	Outside	2	38	0.05	37	PAF	
OSM_S Outside	OSM_S	Owen Stanley Metamorphics Shale	148,372	-	44	Outside	55	11	5.12	-44	NAF	Samples from a previous decline alignment
Oxide Inside	Oxide	Oxide	3,130	127,008,000	17	Inside	1	28	0.02	27	PAF	17 samples inside, variable PAF
Oxide Outside				-	16	Outside	0	71	0	70	PAF	
PAN Outside	PAN	Hekeng Andesite	-	-	2	Outside	0	4	0	4	PAF-LC	N/A
PDA_A Inside	PDA_A	Dacite Porphyry Argillic		1,289,600	3	Inside					PAF	Only three samples, relatively high PAF
PDA_A Outside	PDA_A		-		0	Outside	0	207	0	207	PAF	Samples outside SZ
PDA_AA Inside	PDA_AA	Dacite Porphyry Advanced Argillic	80	-	1	Inside	9	90	0.1	81	PAF	One sample inside SZ
		Total	**2,217,242**	**463,052,400**								

Source: ARD_Geochemistry_Raw_Data_Combined_flagged RevP.xlsx > Report T4-7.

Note: SZ = Subsidence Zone.

4.4 Suitability as construction materials

Rock types that are NAF with a low sulphur content would have a low potential to produce neutral mine drainage and release metals, and would be considered suitable for construction materials from a geochemical perspective. Their geochemical characteristics would also make them suitable for use as a waste rock dump cover. However, waste rock dump covers are typically designed to reduce water and oxygen ingress to PAF wastes and generally need to be resistant to erosion. Testing of additional parameters would need to be undertaken to confirm the suitability of the NAF materials as a waste rock dump cover and for construction use (i.e. to establish whether the rock is competent and durable). The lithologies that will be produced as waste from the decline, and from the borrow pits, will need to be assessed against these criteria to determine whether they are suitable for construction use. NAF lithologies present in the decline include BWC, LGV and OSM_S. Based on their geochemical characteristics, these materials would be suitable as construction materials – subject to verification of geochemical properties as per testing proposed in Section 4.3.

4.5 Neutralising resource and vegetation establishment

Lithological units that contain excess neutralising capacity are BWC, LGV and OSM_S. The samples characterised were collected from the 2011 alignment and the characteristics of rock from the current decline alignment are yet to be confirmed. Table 4-7 provides summary statistics. All BWC and LGV samples were net acid consumers. Some OSM_S samples had a low capacity to produce acid, but on average could be expected to consume acid. Not all ANC may be readily available to neutralise acid, and additional static testing should be undertaken to improve the estimate of the neutralising capacity.

Table 4-7: NAPP values for potentially neutralising lithological units

Lithological unit	No. of samples	NAPP (kgH_2SO_4/t)		
		Minimum	Average	Maximum
BWC	43	-274	-39.9	-2.7
LGV	17	-63	-30.5	-2.4
OSM_S	44	-200	-44	2.2

As discussed in the section above on ‘Elemental Enrichment and Extractable Elements’, metal concentrations in long-term seepage from the BWC and OSM_S are expected to be low. (Note that at the time of the metal leaching assessment, BWC and LGV lithologies were both designated as BWC).

Whilst NAF waste rock types have not been characterised for soil nutrient content, they are expected to be low in organic matter and likely have limited nutrient content. The particle size will determine the capacity to retain moisture and may further limit establishment of vegetation. The capacity to support vegetation will furthermore depend on the metal leaching (some metals may be toxic even under neutral pH conditions) properties of the waste rock, which has not been determined as yet. Nevertheless, considering the tropical high rainfall environment, it is expected that vegetation would establish naturally on these materials.

4.6 Ventilation shaft

A single ventilation shaft will be installed near to the Nambonga Decline Portal (Figure 4-3). No geochemical characterisation of samples has been conducted on samples taken specifically from the shaft location. The shaft is located in an area of low density drilling; it passes north of the decline approximately 2,600m from, and to the east of, the portal. The rock types in the shaft are OSM, oxide and Nambonga Porphyry, with only OSM and oxide reporting to waste rock dump (Mancha, 2015).

5 Conclusions

Static testing of rock samples from the region in and around the deposit was conducted on samples collected between 1990 and 2011. However, most of the samples were sourced from outside the subsidence zone that will result from the current mine plan, and outside the current alignment of the declines.

Materials that will be mined during the development of the Watut and Nambonga declines include BWC, LGV, OSM_S, and OSM. While the OSM_S, the BWC and the LGV materials are shown to be predominantly NAF (i.e., net acid consuming), most of the samples were sourced well away from the current decline locations and the material properties should be verified for the current alignments. The current Watut declines are aligned within the same rock types on a similar plane and it is not expected that a change from NAF/ PAF classification would arise following further sampling. These materials, BWC, LGV and OSM_S, constitute approximately 30% (172,000bcm) of the materials that will be generated from the declines and should be suitable for construction – provided they are competent and durable, and their low sulphur content is verified. The balance of the materials is expected to be PAF and should be handled accordingly.

Rock types mined during the development of the Nambonga Decline will include DTX_A, OSM, OSM_A and NDP. The first three lithological units have been classed as PAF, whilst the NDP has not been characterised. The first three rock types should not be used for construction. This recommendation also applies to the NDP, which is a porphyry, and is therefore reasonable to assume it is PAF.

In areas affected by block caving, sulphur grades tend to increase towards the subsidence zone. Samples collected in the past outside of the zone may therefore not necessarily be representative of the rock types that will be affected by subsidence. Nevertheless, the results show that most of the material types that will be present within the subsidence zone are likely to be acid forming. It is recommended that this be verified through supplemental sampling and testing. In general, acidification of the PAF rock in the subsidence zone is expected to lead to acidic drainage with elevated metal concentrations.

As the subsidence zone develops, it is expected to be aerated (through ventilation activities) and consequently the subsidence zone material will contribute to acid generation and metal loadings in the mine water. Overall, water that is proposed to be extracted from the mine workings is therefore predicted (on the basis of currently available data) to be unsuitable for direct discharge and may require water treatment.

Project Code: COF002 (Formerly: WOR004)

Report Title: Wafi-Golpu Project - Mine Material Geochemistry

Compiled by

Andrew Garvie

Principal Consultant

Peer Reviewed by

John Chapman

Principal Consultant

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Date Issued: 18 June 2018

Name/Title	Company
Lana Griffin	Coffey

Rev No.	Date	Revised By	Revision Details
0	15 September 2015	Andrew Garvie	Draft Report to client
1	16 September 2015	Andrew Garvie	Second Draft Report to client
2	18 November 2015	Andrew Garvie	Final Report
3	24 November 2015	Andrew Garvie	Final Report
4	10 April 2018	Andrew Garvie	Updated Report – Draft
5	11 April 2018	Andrew Garvie	Updated Report – Draft
6	24 April 2018	Andrew Garvie	Final Report
7	14 June 2018	Andrew Garvie	Update to Final Report
8	18 June 2018	Andrew Garvie	Updated Final Report