TECHNICAL REPORT

Soil capping, mine waste and final void assessment

Vecco Critical Minerals Project

Prepared for: **Vecco Group**

RGS

MINE WASTE AND
WATER MANAGEMENT

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Glossary of terms and acronyms

Acid consuming	A sample that contains excess acid neutralising capacity (e.g., > 700 kg H_2SO_4/t).
Acid forming	A sample that produces a soluble acidity of < $pH_{1:5}$ 4.5.
Acidity	A measure of hydrogen ion (H+) concentration; generally expressed as pH.
ABA	Acid Base Account. Evaluation of the balance between acid generation and acid neutralisation processes. Determines the maximum potential acidity (MPA) and the inherent acid neutralising capacity (ANC), as defined below.
ALS	Australian Laboratory Services.
AMD	Acid and metalliferous drainage from mine waste materials characterised by low pH, elevated metal concentrations, high sulfate concentrations and high salinity.
ANC	Acid Neutralising Capacity expressed as kg H_2SO_4 per tonne of sample. A measure of a sample's maximum potential ability to neutralise acid.
ANC:MPA	The ratio of the acid neutralising capacity to the maximum potential acidity of a sample. Used to assess the risk of a sample generating acid conditions.
AS	Australian Standards
Dispersive	Dispersive soil and rock materials are structurally unstable and disperse into basic particles such as sand, silt and clay in water. When a dispersive soil is wet, the basic structure has a tendency to collapse, whereas when it is dry it is prone to surface sealing and crusting.
EC	Electrical Conductivity, expressed as µS/cm.
eCEC	Effective cation exchange capacity provides a measure of the mass of exchangeable cations (Ca, Mg, Na and K) in a sample.
Eh	Redox potential. A measure of the tendency of a chemical species to acquire or lose electrons to an electrode. Used to measure oxidising (+ve) or reducing (-ve) conditions in a saturated column.
EIS	Environmental Impact Statement.
ESP	Exchangeable sodium percentage provides a measure of the sodicity of a material and propensity to erode.
EA	Emmerson Aggregate
FIMS	Flow Injection Mercury System.
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectrometry.
INAP	International Network on Acid Prevention
KLC	Kinetic Leach Column. Leaching setup that generates time-dependent data on the kinetics and rate of acid generation and acid neutralising reactions under laboratory controlled (or onsite conditions)
LoR	Limit of Reporting. Laboratory detection limit for the reporting of results for a particular geochemical test.
MPA	Maximum Potential Acidity. Calculated by multiplying the total sulfur or sulfide-sulfur (CRS) content of a sample by 30.6 (stoichiometric factor) and expressed as kg H_2SO_4 per tonne.
NAF	Non-Acid Forming. Geochemical classification criterion for a sample that will not generate acid conditions.

NAF_{BARREN}	Non-acid forming and barren of sulfur (i.e. less than or equal to 0.1% sulfur).
NAPP	Net Acid Producing Potential, expressed as kg H_2SO_4 per tonne. Calculated by subtracting the ANC from the MPA.
NMD	Neutral mine drainage typically caused by exposure of sulfide minerals in mine waste materials to oxygen and water and then neutralisation by gangue minerals. Typically characterised by neutral pH and elevated concentrations of salts, sulfate and metals.
Ore	Material that has been mined with sufficient value to warrant processing.
Overburden	The waste rock material found overlying the first ore horizon within the stratigraphic profile.
PAF	Potentially Acid Forming. Geochemical classification criterion for a sample that has the potential to generate acid conditions.
PC Titrator	Potentiometric Compact Titrator. PC Titrators are specially designed for routine applications and simple operation, allowing basic titration analysis from a single device.
pH	A measure of hydrogen ion (H^+) concentration.
PSD	Particle size distribution.
Retained acidity	Acidity withheld by a sample and not initially measured in 1:5 (soil:water) extract.
S	Sulfur.
SD	Saline Drainage. Water that is elevated in dissolved salts (e.g., Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-}), but may have acidic, neutral, or alkaline pH.
Slaking	Disintegration of unconfined soil or rock after exposure to air and subsequent immersion in water.
Sodic	Sodic soil and rock materials are characterized by a disproportionately high concentration of sodium (Na) in their cation exchange complex and are innately unstable, exhibiting poor physical and chemical properties, which impede water infiltration, water availability, and ultimately plant growth.
SO_4^{2-}	Sulfate.
Soluble acidity	Acidity measured using a 1:5 (soil:water) extract.
Static test	Procedure for characterising the geochemical nature of a sample at a single point in time. Static tests may include measurements of mineral and chemical composition of a sample and the Acid Base Account.
TS	Total sulfur content of a sample generally measured using a 'LECO' analyser expressed as total sulfur%.
w:w	Weight to weight ratio.
w:v	Weight to volume ratio.

1 Requirement for the work program

1.1 The project

AARC Environmental Solutions Pty Ltd (AARC) is contracted by Vecco Industrial Pty Ltd (Vecco) to coordinate consulting services to obtain an Environmental Authority for the Vecco Critical Minerals Project (VCMP). The VCMP is 70 km north of Julia Creek in northwest QLD (**Figure 10-1, Attachment B**). RGS Environmental Consultants Pty Ltd (RGS) was commissioned by AARC (on 29 September 2021) to complete Stage 1 and Stage 2 of a soil and mine waste assessment for rehabilitation material, mine waste, ore, and residue.

1.2 Purpose

The purpose of this technical report is to provide the required technical information to support the EA approvals process and inform development of the Progressive Rehabilitation and Closure Plan (PRCP) for the VCMP.

This technical report documents the soil quality, geochemical and physical properties of the rehabilitation material, overburden and mine waste streams that will be produced at the mine.

1.3 Objectives

The objectives for this soil and mine waste and final void assessment include the following tasks.

- Review existing project information.
- Provide a sampling plan to Vecco to enable their geologists to provide RGS with samples from their RC resource drilling program.
- Submit provided topsoil, subsoil, overburden, ore and basement geological samples for soil quality, geochemical and physical analyses for an acid, saline and metalliferous drainage assessment.
- Submit provided residue and process samples for soil quality, geochemical and physical analyses.
- Compile the soil fertility, and geochemical and physical data from the analytical program data into a database.
- Produce graphs and tables to interpret results.
- Present preliminary findings at client meetings to inform PFS and FS engineering studies.
- Produce this technical report.
- Provide conclusions and recommendations.

1.3.1 Mined and processed materials from this project

Mined materials and process materials that will be managed during the development of this project may include the following.

- **Rehabilitation material**
  - These are beneficial materials that can be utilised for landform design, cover systems and water management features. These materials:
  - have favourable fertility, geochemical and physical attributes such as;
    - extremely weathered units such as topsoil (O and A soil horizons), and subsoil (B and C soil horizons) that are defined in the geology model as Quaternary Alluvium (**Section 1.4.1**)
    - oxidised and fully weathered to weathered units such as saprolite and saprock including the Wondoola Beds, Allaru Mudstone and Toolebuc Limestone units (**Section 1.4.1**).
- **Cover material** are beneficial rehabilitation units utilised for the final phases of rehabilitation that may be selectively placed within the upper profile of the rehabilitated landform in a cover system. for this project it is proposed to reinstate the original soil profile over the backfilled mined materials.
- **Mine waste** typically includes deleterious overburden strata and the basement unit.
- **Process residues** such as residue or reject streams.

1.3.2 Acid and metalliferous drainage

In Australia, the term Acid and Metalliferous Drainage (AMD) is a term incorporating acidic to alkaline pH drainage, metalliferous drainage, neutral metalliferous drainage, and saline drainage (COA, 2016).

Standard industry terms used to classify the net acid producing potential (NAPP**)** of mined materials include the following.

- AF (Acid Forming) – highly reactive material that can produce acid rapidly (days to weeks).
- PAF (Potentially Acid Forming) - has the potential to produce acid.
- PAF- LC (Potentially Acid Forming - Low Capacity) - has the potential to produce minor amounts of acid.
- NAF (Non-Acid Forming) - will not produce acid but may leach salts and some metals due to the presence of low sulfide bearing material.
- NAF_{BARREN} (Non-Acid Forming-Barren) - will not produce acid or leach salts due to the absence of sulfide minerals (typically less than 0.2% total sulfur).
- AC (Acid Consuming) – has some acid neutralising capacity (ANC) that will contribute to ongoing acid neutralisation e.g. calcite in Basalt.

General industry terms that can be used to describe water quality at mines include the following.

- Acid Mine Drainage.
- Acid Rock Drainage.
- Acid and Metalliferous Drainage.
- Neutral Mine Drainage.
- Saline Drainage.
- Mine Impacted Water.

Water on mines includes surface water and groundwater. Groundwater can be considered as water that is present in non-mined ground that has the potential to enter pits (operational pits, backfilled pits or decommissioned pits). After groundwater enters a pit, it will become mine impacted water. Mine impacted water could leave a pit and enter the groundwater system in the receiving environment or become surface water that may then be pumped from the pit. Surface water is present in dams, creeks, and process plants. Seepage from landforms can drain to groundwater or it may appear as resurgent seepage to surface water.

The term mine impacted water is used as a general term to describe water which contacts disturbed ground and that may include water in:

- Seepage from waste rock dumps or low-grade ore stockpiles (in-pit or ex-pit);
- Operating pits;
- Decommissioned pits; and
- Back-filled pits.

Mine impacted water can be classified as having:

- Acid, neutral or alkaline pH;
- Variable concentrations of major ions (salts e.g. calcium, magnesium, potassium, sodium, chloride, sulfate, boron or fluoride); and
- Variable concentrations of metals (e.g. Al, Fe, Mn and Zn) or metalloids (e.g. Mo, Se and V) with the concentrations often linked to pH.

Potential sources of acid in mine impacted water at mine sites can include the following.

- Oxidation of sulfide minerals such as pyrite that produce sulfuric acid (INAP, 2009).
- Rainfall and leaching of cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}) and sodium (Na^{+}) that reduce soil pH by atmospheric carbonic, nitric or sulfuric acid.

Potential sources of salts in mine impacted water at mine sites that can include the following.

- Oxidation of sulfide minerals, the production of sulfuric acid and subsequent neutralisation reactions that mobilise major ions such as sulfate (SO_4^{2-}) and calcium.
- Chemical weathering of adjacent soil and rock by sulfuric acid that releases major ions such as sodium, potassium, magnesium and chloride.
- The mobilisation of sodium chloride (NaCl) or sodium bi-carbonate ($NaHCO_3$) that are present within geological units and groundwater and then released in fluxes as mined materials are extracted (blasted), processed (crushed) and placed into mine landforms.

Potential sources of metals (e.g. Al, Fe, Mn, and Zn) and metalloids (oxyanions such as Mo, Se and V) in water at mine sites can include elements present:

- As ancillary minerals within primary sulfide minerals like pyrite or marcasite;
- In the solid phase of geological units in a range of minerals; and
- In pore water.

Pathways by which AMD is mobilised

AMD is mobilised by water and is transported from the source materials along aqueous physical pathways into the receiving environment. The salts, metals and metalloids in aqueous phases can be taken up by aqueous flora and fauna via aqueous biophysical pathways.

Salts, metals, and metalloids present as exchangeable or less soluble fractions (e.g., carbonate or oxide fractions) can also be relocated via physical pathways in the aqueous environment as suspended sediment or bedload sediment.

Salts, metals, and metalloids present in soluble or exchangeable fractions within mined material or process waste can also be taken up by plants via terrestrial biophysical pathways.

Wind borne erosion is another pathway whereby salts, metals and metalloids can be moved from the source to the receiving environment.

1.3.3 Progressive rehabilitation and closure plan (PRCP) requirements

The need to comply with the PRCP guideline (DES, 2020) has influenced the program of work recommended to be completed for the VCMP.

In the PRCP guideline, geochemical and chemical analysis is referenced on pages 18, 27, 28, 29, 30 and 66 and physical analysis is referenced on pages 27, 28 and 66.

For the PRCP, the number of samples needed to inform life of mine planning decisions varies, and is (in part) a subjective process that considers the following:

- Volume of mine waste being produced
- Number of open pits being mined
- Depth of open pits
- Variation in soil types and regolith properties
- Variability of the geochemical and physical properties of each rock type within and between open pits
- Number of major rock types
- Mining method

In order to address PRCP Guideline requirements, RGS has ensured there is adequate coverage within the pit to characterise and classify soil and each major lithological or stratigraphic unit in the overburden, ore body, and basement.

The need for comprehensive **soil quality**, **geochemica**l and **physical** testing is clearly defined in the PRCP Guideline i.e., the waste characterisation report should achieve the following outcomes:

- Sampling regime meets best practice standards, is spatially representative of all material being mined (i.e., the ore body, exposed pit walls and overburden) and representative of all lithologies.
- Be capable of confidently classifying mine and processing waste streams based on environmental risk and managements requirements.
- Be capable of generating block models and estimating the volume of mine waste based on waste type (i.e., level of environmental risk).
- Provide recommendations for the management and mitigation of mine and processing waste streams to manage environmental risk and achieve proposed rehabilitation methods and objectives.

The sampling and analysis plan for the open cut pit at VCMP addresses the following.

- Potential for acid, neutral and alkaline pH drainage and saline and metalliferous drainage (AMD).
- The fact that not all NAF materials are the same:
  - NAF material can range in its physical properties from being sand or clay to fresh volcanic rock that will resist weathering for millennia, and it is this aspect of material characterisation that becomes critical when stable constructed mine landforms are being designed.
  - NAF material may be non-acid forming (NAF), but may contain elevated sodium chloride and sulfur content and have the potential to leach saline drainage.
- Physicochemical properties of all the materials from the topsoil to the deepest mined surface to address sodic potential; porosity and permeability; erosion; and water holding potential.
- The potential for co-disposal of processing waste materials within overburden at open pits.
- The impact of backfilling mine waste into mined voids and the effect this can have on the porewater quality that accumulates in the backfilled material as the water level recovers. RGS has found that backfilled mine and processing waste placed into voids can become anoxic or reducing and (depending on the materials) can have positive or negative outcomes on water quality.

1.3.4 Quality, standards, regulation, legislation, and guidelines

This factual report complies with applicable legislation, regulation, guidelines, and standards. The project also considers the implications of the evaluation of residual risk that is being defined by the Queensland Government. The geochemical and physical characterisation assessment program described herein has been developed and refined to be consistent with requirements of the documents in this Section.

RGS is responsible for verifying adherence to applicable legislation, regulation, guidelines, and standards. In Queensland this includes the following.

- DES (2014). Department of Environment and Science. Rehabilitation requirements: as appropriate for mining resource activities: ESR/2016/1875 • Version 2.01 • Effective 23 May 2014.
- DSITI (2017). Using monitoring data to assess groundwater quality and potential environmental impacts. Version 1. Department of Science, Information Technology and Innovation (DSITI), Queensland Government, Brisbane.
- *The Mineral Resources and Energy (Financial Provisioning) Act 2018* amended the *Environmental Protection Act 1994* and the *Environmental Protection (Rehabilitation Reform) Amendment Regulation 2019* implements key elements of the Mined Land Rehabilitation Policy. This includes introducing the new requirements for a Progressive Rehabilitation and Closure Plan (PRC plan) progressive rehabilitation and closure plan guideline ESR/2019/4964 • Version 2.00 • Last reviewed: 17 MAR 2021.P

Commonwealth and International requirements may include the following:

- Australian Standards.
- AMIRA (2002) ARD Test Handbook - Prediction and Kinetic Control of Acid Mine Drainage; AMIRA International. Project P387A Prediction & Kinetic Control of Acid Mine Drainage, Ian Wark Research Institute and Environmental Geochemistry International Pty Ltd.
- Australian Water Quality Guidelines (2018) that supersede the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) (ANZECC).

- Commonwealth of Australia Leading Practice Sustainable Development Program (LPSDP) for the Mining Industry: Rehabilitation (2016a).
- Commonwealth of Australia Leading Practice Sustainable Development Program for the Mining Industry: Prevention of Acid and Metalliferous Drainage (2016b).
- Commonwealth of Australia Leading Practice Sustainable Development Program (LPSDP) for the Mining Industry: Mine Closure (2016c).
- Environmental Protection (Water) Policy 2009 (EPP (Water)). The EPP (Water) achieves the object of the Environmental Protection Act 1994 (EP Act) to protect Queensland's waters while supporting ecologically sustainable development.
- Global Acid Rock Drainage Guide, http://www.gardguide.com/index.php/Main_Page, International Network for Acid Prevention (INAP), (2022).
- Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials, MEND Report 1.20.1, December 2009.

1.3.5 Vecco rehabilitation goals and objectives

The VCMP will be required to produce rehabilitation goals and outcome objectives for the EA. The final landform after closure will be required to be:

- safe to humans and wildlife;
- stable;
- non-polluting; and
- able to sustain an agreed post-mining land use.

The VCMP strategy for the final landform is to implement progressive rehabilitation over the life of mine. 70% of the mined pit will be backfilled to RL132, which will be approximately 0 to 2 m above the natural topographic surface. The remaining 30% of the void will be backfilled to RL 142 with slopes of 10%. One out-of-pit dump (30.2 ha) will be developed in the initial box-cut but will transit into the in-pit dump when room becomes available. It is anticipated that 1.7 M loose cubic meters (lcm) of material will require re-handling at the cessation of mining (Boyd 2022) to backfill the void to natural surface level.

1.4 Proposed mining operation

Exploration of the Toolebuc Formation in Julia Creek began in the 1970s but was primarily focussed on drilling for shale oil. Other metals were assayed as part of the XRF testing conducted by Oilcorp in 2012. Vecco accessed the preserved Oilcorp cores in 2015 and found positive results for vanadium. In addition to vanadium ore, high purity alumina (HPA) and rare-earth elements (REE) were later added as products that could be extracted during the process circuit. The Vecco exploration program began in 2018 and included 4C size diamond core holes with metalliferous assays, as well as geological and geophysical surveys.

EPM 25254 contains the target vanadium ore deposit, and an access route has been planned to enter and leave the site (**Figure 1-2)**. The proposed mining leases and proposed final landform (inset) are also shown. Refinement of the plan in 2022 developed the mine sequence plot, mineral resource estimates and revised the out of pit waste rock dumps (WRD) (**Figure 1-1**).

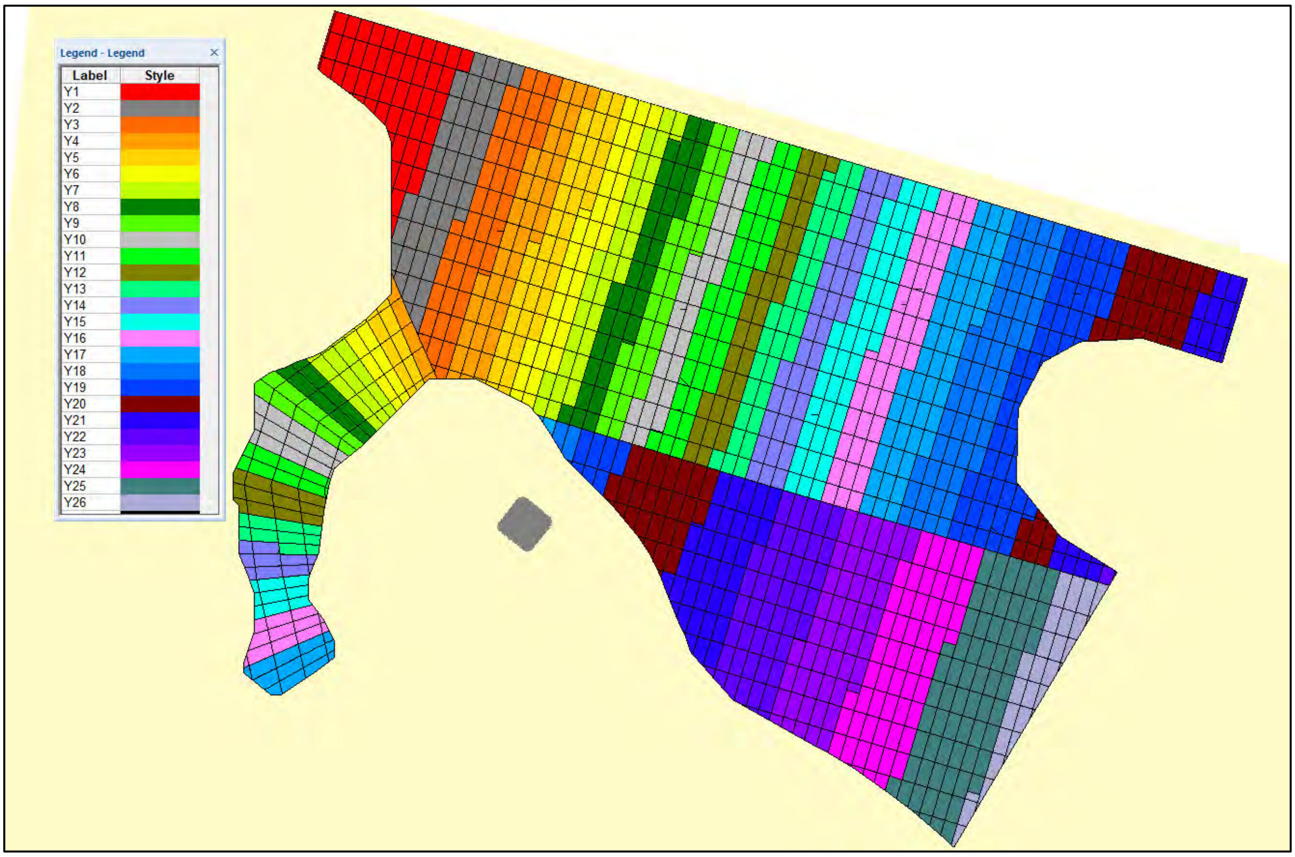


Figure 1-1: Revised 2022 sequence plot for VCMP

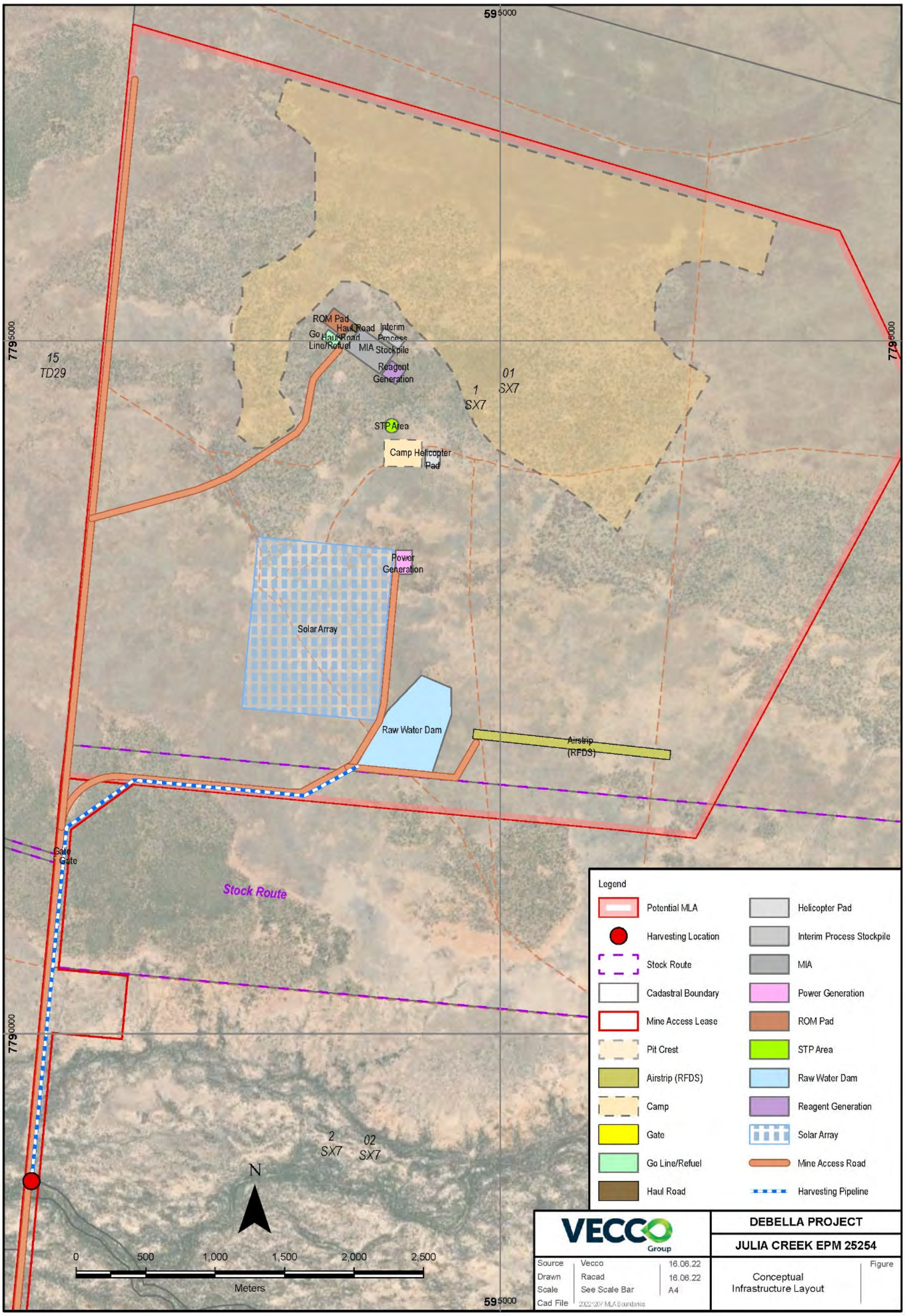


Figure 1-2: VCMP proposed site layout

1.4.1 Soil and geology

The targeted orebody is in the Toolebuc Formation, a thin but laterally persistent geological unit of Upper Albian age from the Early Cretaceous period. It occurs within a thick section of fine-grained clastics in the Eromanga Basin, Queensland. The Toolebuc Formation strata is known to contain a limestone unit that is rich in Mesozoic vertebrate fossils around the towns of Richmond, Julia Creek, Hughenden and Boulia. The Toolebuc Formation shows little evidence of diagenesis other than physical compaction, hence the high preservation rate of fossils. However, the formation is heterogeneous, and the limestone is subordinate to calcareous and bituminous siltstone, black labile sandstone, and shale which are of greater significance in this mine material characterisation assessment.

The vertical mining sequence (**Table 1-1)** is described by Boyd (2022) as follows:

- The **Quaternary Alluvium** (QA) comprising of **topsoil** with a thickness of 0.5 m is stored and preserved for the rehabilitation process and **subsoil** with a thickness of 1.5 m is stored and preserved for the rehabilitation process.

  Topsoil / subsoil profiles and vegetation communities in the project area include:

  - **Grey Dermosols** with **Grey Vertosols** occurring on gently inclined or near-level plains within an old alluvial landscape. This SMU is distributed throughout the majority of Study Area as regions of palaeo-drainage and flood channels. The soil consists either of a sandy surface, or self-mulching sandy clay surface, with clay content increasing with depth. Vegetation is predominantly feathertop wiregrass and Mitchell grass tussock grassland.

  - **Alluvium**: with reddish brown, clay loam sandy soil unit occupying the central region of the study area, on gently inclined or near-level rises. The profile consists of only a B horizon with sandy clay loam to medium clay texture throughout. Vegetation associated with this unit includes bloodwood and Corymbia spp. woodlands.

  - **Arenosol**: Reddish brown, deep, sandy soil unit occupying the southern region of the study area, on gently inclined or near-level plains. The profile generally exhibits little or no A horizon material and therefore often comprises a B horizon with a sandy texture throughout. Vegetation associated with this unit includes wild plum (Terminalia platyphylla) and beefwood (Grevillea striata), with western bloodwood (Corymbia terminalis) and whitewood (Atalaya hemiglauca) associated in the upper canopy, and Melaleuca spp. in the sub-canopy.

- **Wondoola Beds** (WDB) consist of soil, clay, sand and gravel with an average thickness of 9.5 m and a maximum of 14 m. QA and WDB are backfilled into the mined void as waste.
- **Mudstone Horizon:** Allaru Mudstone (ALM) consists of blue-grey mudstone composed of clay-sized particles with some siltstone beds. It has an average thickness of 8.5 m, with a maximum of 17.7 m at the south end of the pit. ALM is mined as waste material.
- **Limestone:** The Toolebuc Formation horizon (TLBA) contains low vanadium grades. TLBA thickness is 5.0 m (average), ranging to 8.4 m (maximum) in the northeast end of the pit. TLBA contains calcium oxide (CaO) up to 44.6%. Quantities of TLBA may be required for processing and neutralising acidic materials. The majority of TLBA is considered waste and handled accordingly.
- **Mineral Resource:** The weathered Arrolla Shale (TLBB and TLBD) are considered mineral resource. Both horizons combined have an average thickness of 4.6 m, with a maximum of 6.3 m on the southwest side of the pit.
- **Floor:** The transition material between the Toolebuc Formation and Wallumbilla Formation (TLBE) is considered poor quality for vanadium but will be mined for REE. The basement is also a blue-grey mudstone unit (WLA).

Table 1-1: Geological units and material classifications

Geological Unit	Code	Description	Material classification
Quaternary alluvium	QA	Soils and clays	Soil
Wondoola Beds	WDB	Unconsolidated sands, clay and gravels	Overburden
Allaru Mudstone	ALM	Mudstone with minor interbedded siltstone and infrequent sandstone	Overburden
(Limestone roof)	TLBA	St Elmo Coquina, banded shelly limestone. Minor bituminous shale.	Limestone
Toolebuc Formation	TLBB	Wilat's Crossing Shale, laminated bituminous shale. Minor to common limestone bands. Manfred Coquina at base.	Orebody
Toolebuc Formation	TLBD	Arrolla Shale, finely laminated bituminous shale.	Orebody
Toolebuc Formation	TLBE	Arrolla Shale lower transition, inferior oilshale transition to Wallumbilla Formation.	Orebody (low grade)
Wallumbilla Formation	WLA	Blue to grey mudstone with minor siltstone and fine-grained carbonaceous sandstone.	Basement

1.4.2 Pit depth

The Arrolla Shale horizons (TLBB and TLBD) within the Toolebuc Formation are defined as the mineral resource. The pit floor is defined as the maximum RL value of either the base of weathering or the floor of the TLBD horizon. The topography of the Vecco mining area is near horizontal (RL128 to RL132). Prospective mineral resource horizons are at shallow depths below the surface. The depth to the pit floor is 15 to 30 mbgl. No identified watercourses, natural drainage channels or roads are impacted by the pit design (Boyd 2022).

1.4.3 Mining method

The open pit will be mined using conventional strip mining methods with excavators and trucks. All mined material will be weathered and unconsolidated, and therefore blasting will not be required. The mined pit will be progressively backfilled with overburden and residue through the predicted 26-year operating mine life (Boyd 2022). A small ex-pit waste dump will be developed early in the mine life until a void is developed to backfill into. The ex-pit dump and backfilled void will be covered in 1.5 m of subsoil and 0.5 m of topsoil to reinstate the pre-mine soil profile. All external slopes will be at a maximum grade of 1:10 to minimise erosion.

1.4.4 Processed mine waste streams – residue

Processed residue will be produced on site and will be returned to the base of the open pit. The ratio of overburden to residue is expected to be approximately 5:1 (volume) (Boyd 2022). The residue will be a combined stream of ore processes to recover vanadium, residue processed to recover high purity alumina (HPA) and ore processed to recover rare earth elements (REE). The combined residue stream is planned to be co-disposed into the mined pit and covered with Toolebuc Limestone, Allaru Mudstone, Quaternary Alluvium and the original subsoil and topsoil profile.

1.5 Existing data review

1.5.1 Total sulfur and sulfide sulfur assay data

RGS reviewed data from the 2018 drill hole assay database to develop an understanding of the geochemical properties within the deposit within EPM 25254. The total sulfur (TS) and sulfide sulfur concentrations (%) from 34 drill holes in the 2018 drilling program were classified by lithology.

- Allaru Mudstone (ALM)
- Toolebuc Formation – St Elmo Coquina (TLBA)
- Toolebuc Formation – Willat's Crossing Shale (TLBB)
- Toolebuc Formation – Arrolla Shale (TLBD)

- Toolebuc Formation – Arrolla Shale Lower Transition (TLBE)
- Wallumbilla Formation (WLA)

1.5.1.1 Overburden and limestone (ALM and TLBA)

Allaru Mudstone (ALM) samples have negligible TS concentrations at 0.01 to 0.03%. Sulfide sulfur concentrations were < 0.01% CRS.

Toolebuc Formation (TLBA) had low to high TS. Assay data within 8 out of 12 drill holes containing TLBA had < 0.1% TS. Assay data in three drill holes had < 1% TS, and assay data in one drill hole (DEB010) had up to 1.96% TS.

1.5.1.2 Orebody (TLBB and TLBD)

TS concentrations in TLBB and TLBD are 0.03 to 4.69% and show similar spatial distribution to TLBA. Drill holes in the south-eastern area of the survey zone (e.g., DEB032, DEB18_32, and DEB068) had high TS and sulfide sulfur values. TLBD had 3.89 to 4.69% TS in this area.

In the central area, sulfide sulfur was considerably lower than TS in drill holes of the survey zone (e.g., DEB18_36, DEB18_20, DEB002, and DEB004), indicating the presence of less reactive TS forms, such as gypsum ($CaSO_4$).

1.5.1.3 Basement (TLBE and WLA)

TS and sulfide sulfur concentrations in TLBE and WLA range from 2.65 to 4.66%, with the exception of DEB18_38 which has 0.13% TS. Although there were less data points for these lithological units, overall, these TS and sulfide concentrations fall into the higher risk category.

Overall, TS and sulfide sulfur concentrations were observed to gradually increase with depth through the stratigraphic profile (**Figure 1-3**).

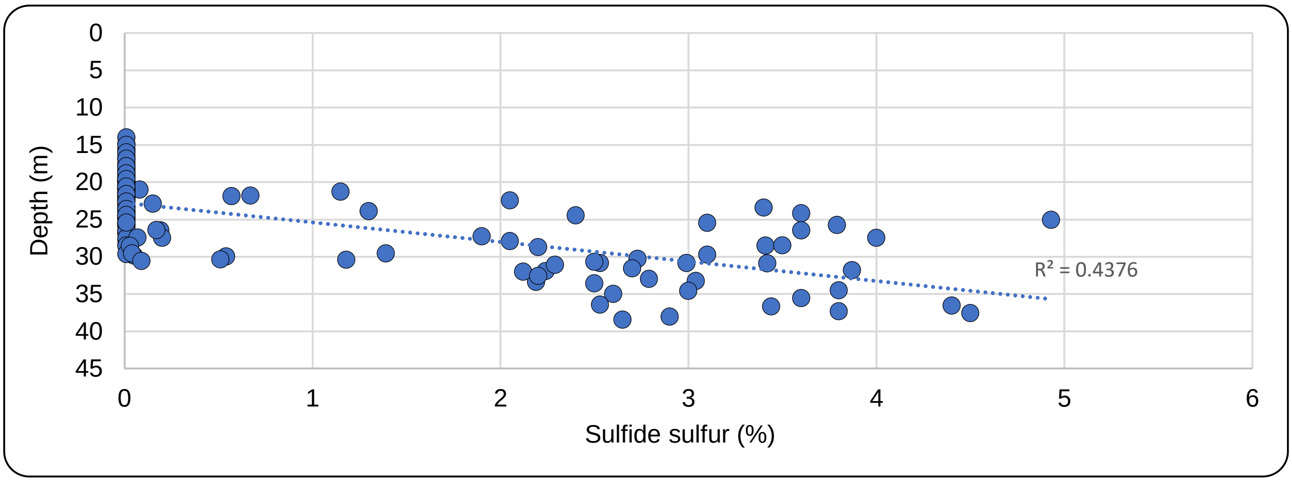


Figure 1-3: Relationship between sulfide sulfur and depth for assay data

1.5.2 Major, minor and trace element assay data

Major, minor and trace elements (n=50) analysed in the metalliferous assays are in **Figure 1-4** and **Figure 1-5.** Concentrations of In, Li, Se and Tl were also measured but were below detection limit and are not shown. The trace element concentrations verify that the soil is naturally mineralised e.g., As, Cd, Cu, Mo, Ni, U, and Zn. Outlier concentrations of some REE (e.g., Ce, Dy, Gd, Nd, Sm, Y (**Figure 1-4**) and Er, Eu, Ho, Lu, Py, Tb, Tm, Yb (**Figure 1-5**)) were noted. The values provide baseline concentrations to compare against disturbed materials.

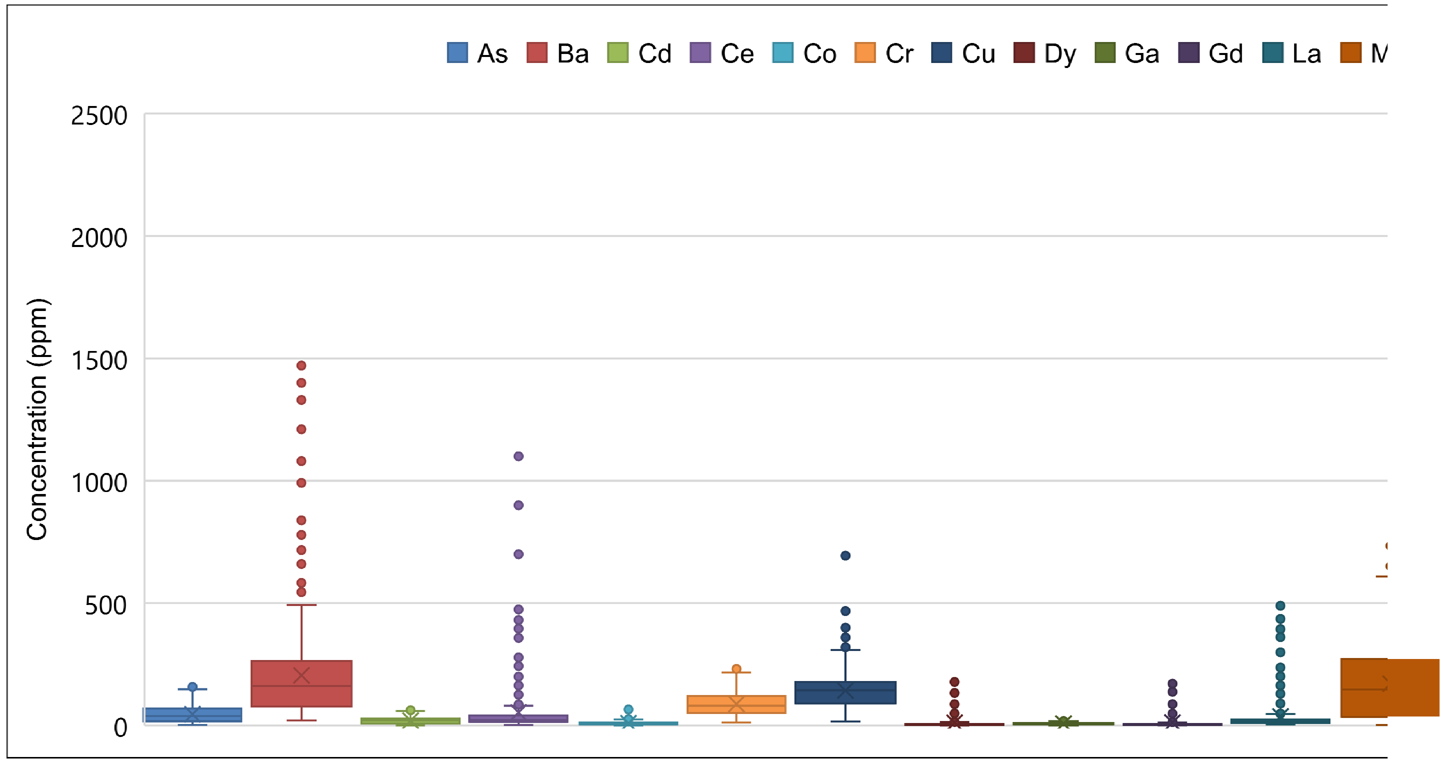


Figure 1-4: Trace element assay data concentrations (As – Zr)

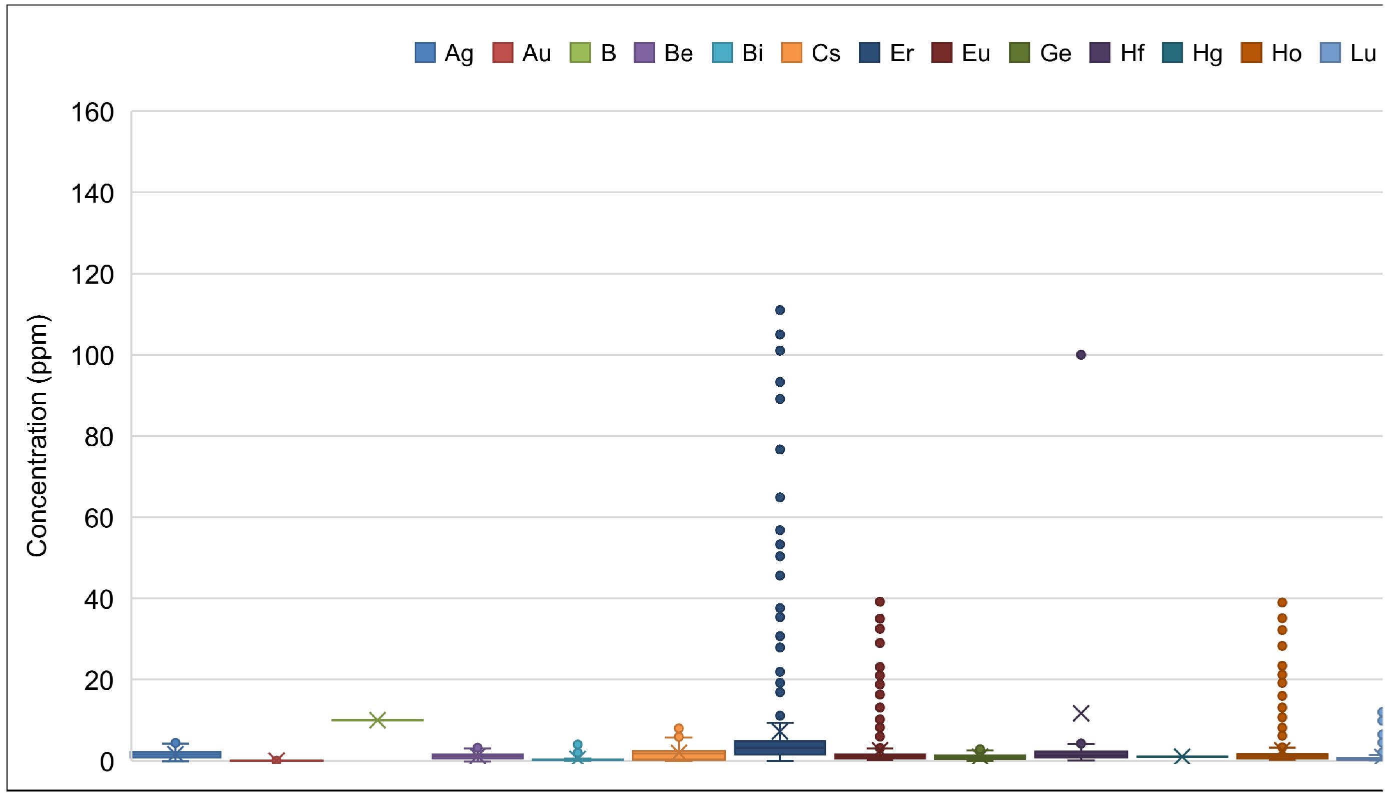


Figure 1-5: Trace element assay data concentrations (Ag – Yb)

1.5.3 Acid neutralising capacity estimate from assay data

RGS has reviewed previous data from the metalliferous assays in the 2018 drilling program and used this information to estimate the acid neutralising capacity (ANC) for materials in the 34 drill holes.

The ANC calculations rely upon actual results from the geochemical analyses (**Section 4**), which is used as a comparative tool to verify the relationship between ANC and CaO concentrations.

1.5.3.1 Assumptions in ANC calculation

The following assumptions have been used in the ANC calculation:

- ANC values for individual samples were averaged to give an assumed composite ANC;
- CaO concentrations x 0.7146 = Ca concentrations based on the molecular weight;
- Maximum potential acidity (MPA) = 30.625 x sulfide sulfur concentration;
- eNAPP = MPA – eANC and eNPR = eANC / MPA.

1.5.3.2 Approach

The approach for the ANC calculation was as follows:

1. The average ANC value for soil and rock composites (n=18) was tabulated against Mg% and Ca% for each composite from the 2-acid digest multi-element (ME) analyses.
2. Three graphs were plotted from this data:
    - Ca% Vs ANC
    - Mg% Vs ANC
    - Ca% Vs Mg%
3. It was observed that average composite ANC values did not correlate well with Mg%.
4. However, average composite ANC values correlated well with measured Ca% concentrations for the same composites (R^2 = 0.9967) (**Figure 1-6**).

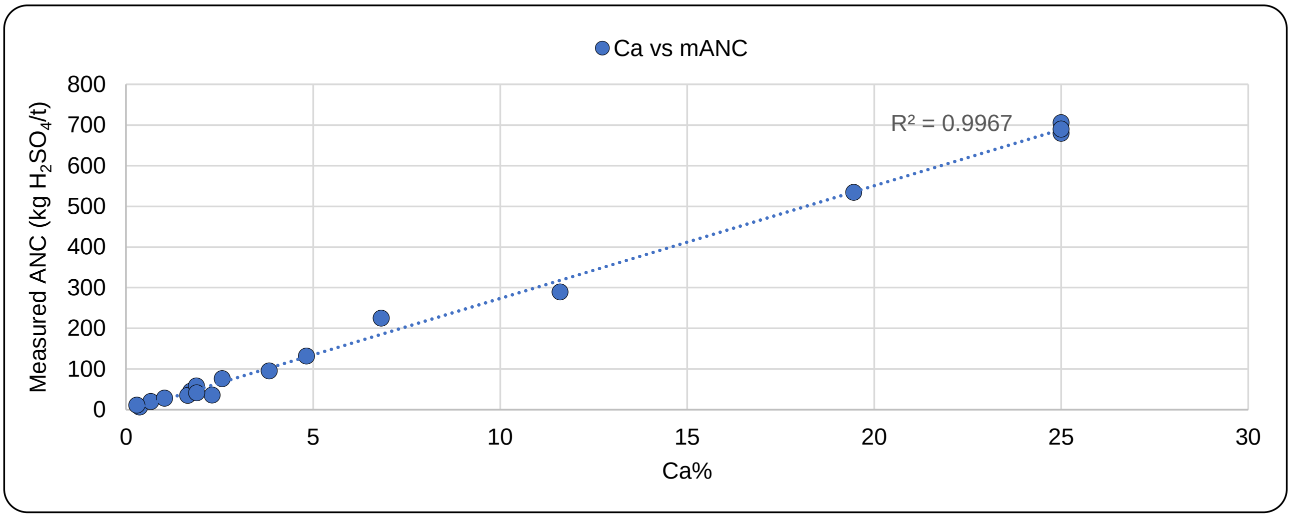


Figure 1-6: Correlation between Ca% and measured ANC values for ME composites

5. Based on the comparison of Ca concentrations and measured average composite ANC (mANC) values, the least squares linear regression estimates eANC = 27.53 ± 0.30 x Ca%.

6. The sum of residuals (-36.20 kg $H_2/SO_4/t$) suggests that the estimated ANC (eANC) may slightly underestimate ANC relative to mANC.
7. Using the regression formula, the Ca% concentrations for assay sample data (n=356) were used to calculate eANC.
8. Sulfide sulfur data (where available, n=141) for the assay data, was used to calculate MPA and hence effective net acid production potential (eNAPP) for these samples.
9. Estimated net production ratio (eNPR) is calculated from the ratio of eANC / MPA where sulfide sulfur data is available (n=141).

1.5.3.3 Results

When applied to the assay sample data, the ANCT(n=356) ranges from 15.55 to 1080.3 kg H_2SO_4/t (median 596.2 kg H_2SO_4/t) (**Table 1-2**).

Calculating the eNAPP (n=141) from the ANC and MPA values, the values for eNAPP range from -1080 to -6.64 kg H_2SO_4/t (median -534.9 kg H_2SO_4/t). All of the eNAPP are negative, verifying that the samples have excess neutralising capacity over acid generation (**Figure 1-7**).

The eNPR (n = 141) is also calculated from MPA and ANC, and ranges from 1.32 to 3527.5 (median 1124.4). If the eNPR is ≥ 2, and the sample has eNAPP ≤ -5, the sample is considered non-acid forming (NAF).

A NAF geochemical classification is true for all of the assay data points (n=141), with the exception of one sample with eNPR = 1.32. This sample is from DEB18_36_09 at a depth of 21.82 m and occurs in the TLBD unit. Overall, 99.2% of the assay data points with sulfide sulfur measurements are classified as NAF.

Table 1-2: Summary of eANC calculations for assay data

Analyte	n	Source	Minimum	Median	Maximum
CaO%	356	Assay data	0.79	30.30	54.90
Ca%	356	Calculated from CaO%	0.56	21.66	39.24
eANC (kg H_2SO_4/t)	356	Ca% and linear regression formula	15.55	596.2	1080.3
MPA (kg H_2SO_4/t)	141	Sulfide sulfur calculation	0.31	0.31	150.98
eNAPP (kg H_2SO_4/t)	141	eNAPP = MPA - eANC	-1080.0	-534.9	-6.64
eNPR	141	eNPR = ANC / MPA	1.32	1124.4	3527.5

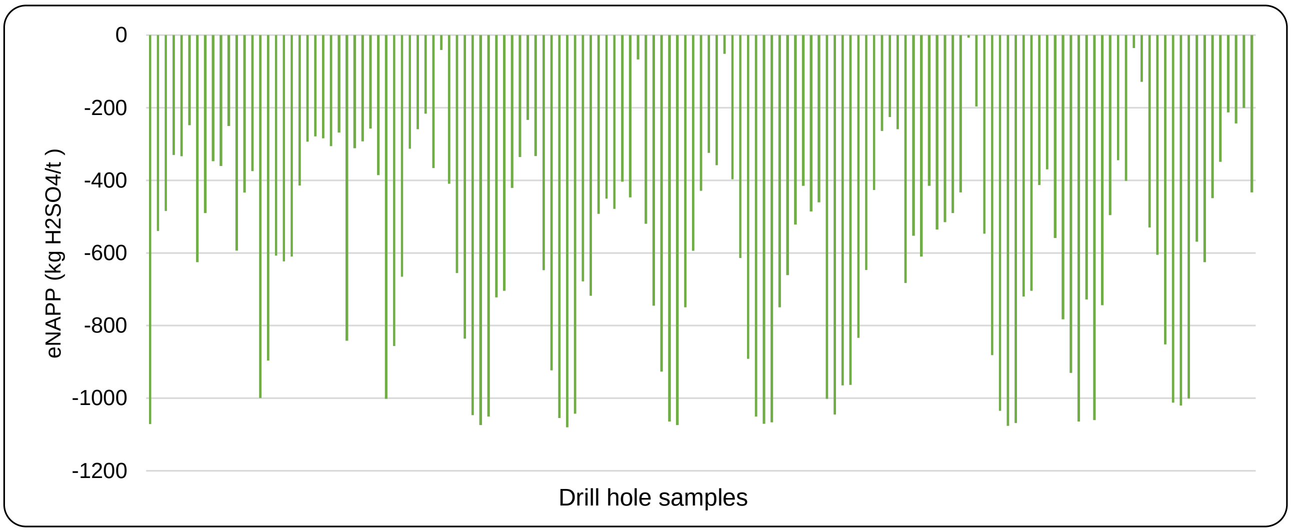


Figure 1-7: NAPP values for assay data from drill hole samples

1.5.4 Geotechnical assessment

In July 2022, J & S Drilling Pty Ltd were appointed by Vecco to carry out a drilling, sampling, and testing program in accordance with a scope of work provided by ATC Williams Pty Ltd (ATCW). Three boreholes (DEB21_03R, DEB22_18R, and DEB22_50) were drilled using rotary coring methods, with depths from 15.1 m to 30.5 m. Stratigraphic units intercepted were from Quaternary alluvium at surface, to the Wallumbilla Formation, at the basement of the ore body. The purpose of the drilling program was to collect samples for preliminary geotechnical investigations to provide information on suitable construction and foundation materials (ATCW, 2022). Borehole logs are in **Section 10.3**.

1.5.4.1 Atterberg Limits

Results for Atterberg Limits on samples from the 3 boreholes indicated there is a wide variance of Plasticity Index (PI) and Liquid Limit (LL) values, ranging from PI 10% for residue (low plasticity silt) to PI 48% for mudstone (high plasticity clay) (**Figure 1-8**). The residue is a geochemically neutralised waste product from processing TLBA (limestone) with TLBD (orebody) (ATCW, 2022).

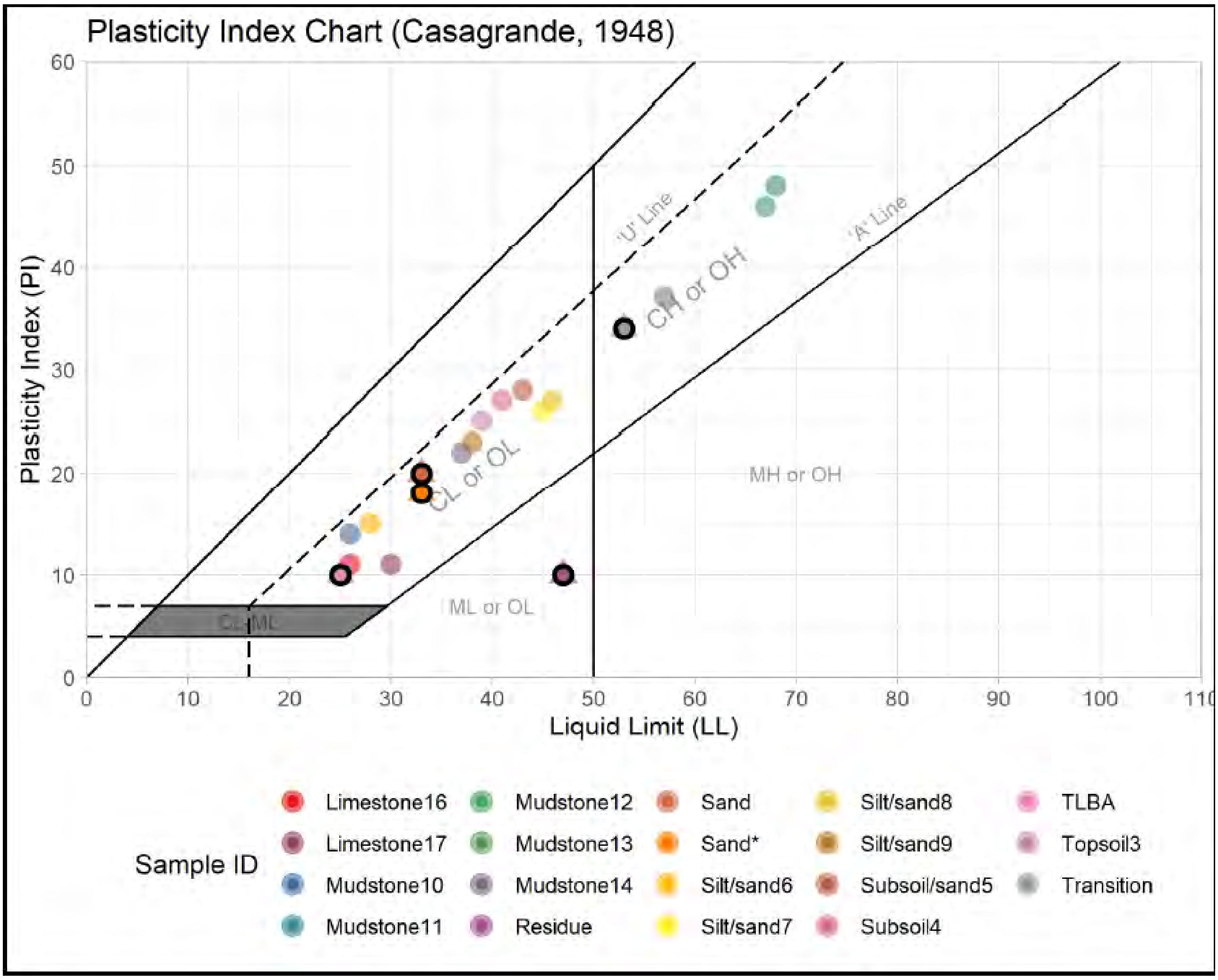


Figure 1-8: Atterberg limit results for borehole samples

1.5.4.2 Particle size distribution

Particle size distribution (PSD) curves (**Figure 1-9**) are shown for different material types and verify that:

- Mudstone typically has between 30 to 50% clay;
- The residue is low in clay (<10%) but over 50% silt;

- Limestone (TLBA) is well graded with approximately 25% silt and clay; and,
- Silt/sand units contain between 50 to 80% silt and clay.

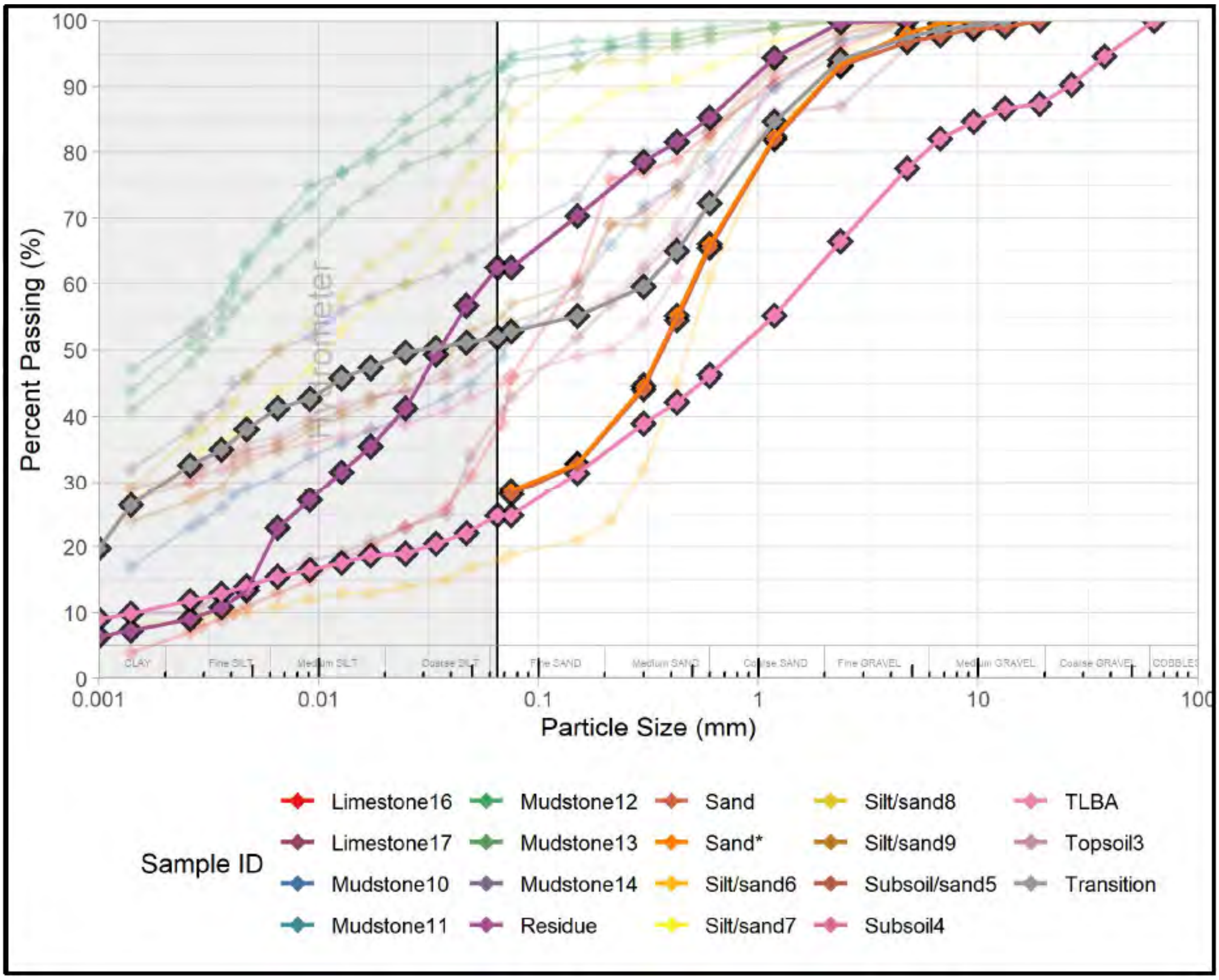


Figure 1-9: Particle size distribution curves for borehole samples

1.5.4.3 Particle density

Particle densities ranged from 2.51 g/cm^3 for Allaru Mudstone and Wondoola Beds up to 2.73 g/cm^3 for residue and limestone (TLBA).

1.5.4.4 Emerson Class

Samples of all material types (n=18) underwent Emerson Class analysis. 44% of samples were stable with carbonate or gypsum present. 11% were stable but had little carbonate or gypsum, 28% were potentially dispersive, and 17% were dispersive. The Emerson Class result did not always correspond to lithology. Topsoil, subsoil, and samples that were from TLBA or close to it were least likely to be dispersive. Dispersive lithologies were typically mudstone or sand.

1.5.4.5 Conclusions

Residue has low plasticity and does not contain enough clay to be suitable as a low permeability layer. Materials from the Wondoola Beds (unconsolidated sands, silts, and gravels) are low density and may be dispersive so would not be suitable as a construction material. Limestone (TLBA) has favourable characteristics as a foundation unit, however if this material is being utilised for geochemical neutralisation and is unavailable, carbonate rich Allaru Mudstone from directly above TLBA is the next best substitute.

2 Sample program

RGS was provided with 3 batches of samples from Vecco. Batch 1 included 86 samples from three bore holes, Batch 2 included 66 samples and Batch 3 included 191 samples: 343 samples in total.

2.1 Summary

Table 2-1 summarises the sample program, which includes individual solid samples (n=173), individual pulp samples (n=191) and composites (n=47). There are a total number of 413 samples in the soil quality, geochemical, and physical assessment.

Table 2-1: Sample program summary

Batch 1 & Batch 2				
Batch	**Lithology / description**	**Sample type**	**Matrix**	**Number**
1	Soil, regolith and rock samples	Individual	Solid or slurry	86
2	Soil, regolith and rock samples	Individual	Solid	66
			Sub-total	**152**
1	Residue	Individual	Solid or slurry	12
1	Process water	Individual	Water	1
2	Residue or HPA residue	Individual	Solid	5
2	Process water or supernatant	Individual	Water	3
			Sub-total	**21**
1	Soil, regolith and rock samples	Composite	Solid or slurry	21
2	Soil, regolith and rock samples	Composite	Solid	12
1	Residue	Composite	Slurry	2
2	Residue	Composite	Solid	1
1	Soil, regolith and rock samples	KLC composite	Solid	6
1	Residue	KLC composite	Solid	2
2	Residue or HPA residue	KLC composite	Solid	3
			Subtotal	**47**
3	Orebody and basement samples	Individual	Solid pulp	191
			Subtotal	**191**

2.2 Soil, regolith, and rock samples

2.2.1 Batch 1 soil, regolith and rock samples

The first batch of soil, regolithrock samples (n=86) were collected from three bore holes (DEB21_05, DEB21_12, and DEB21_17) (**Figure 2-1)**. The bore holes were 35 m to 44 m in depth and 15 to 45 samples were collected in each hole. The samples represent the geological units and material types in **Table 1-1** including soil (QA), overburden (WDB and ALM), limestone (TLBA), orebody (TLBB to TLBD), and basement (TLBE and WLA). 7 to 25 samples were collected from each lithological unit (**Table 2-2)**. The sampling program provided adequate coverage for each material type.

The mass of each sample was 2.6 kg to 20 kg. Orebody samples from the Toolebuc Formation were wet and 0.5 kg to 1 kg. Basement samples were moist or wet and 0.8 kg to 7 kg.

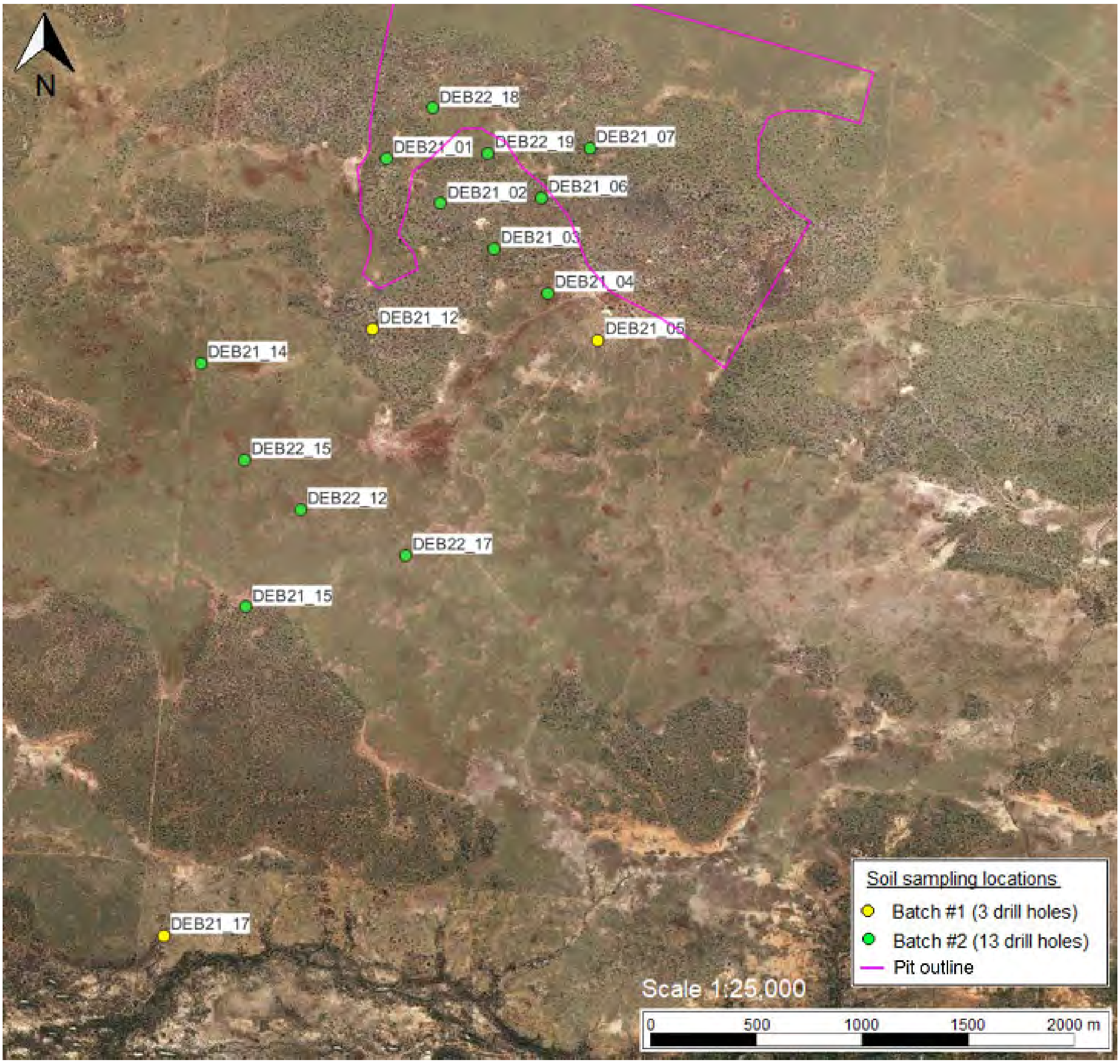
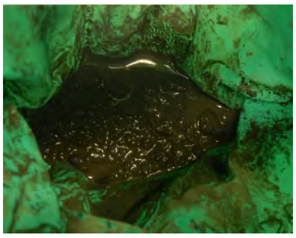


Figure 2-1: Batch 1 and batch 2 bore hole sampling locations

Table 2-2: Summary of soil and rock samples – Batch 1

Soil and rock samples – Batch 1				
Lithological unit	Bore hole	Number of samples	Sample appearance	Total
Soil Quaternary alluvium (QA)	DEB21_05	2		7
	DEB21_12	2		
	DEB21_17	3		
Silt/Sand	DEB21_05	3		11

Quaternary Wondoola Beds (WDB)	DEB21_12	1		
	DEB21_17	7		
Mudstone ALM Cretaceous Allaru Mudstone (ALM)	DEB21_05	0		25
	DEB21_12	6		
	DEB21_17	19		
Limestone roof Cretaceous Allaru Mudstone (TLBA)	DEB21_05	1		12
	DEB21_12	5		
	DEB21_17	6		
Orebody Cretaceous Toolebuc Formation (TLBB-TLBE)	DEB21_05	5		19
	DEB21_12	8		
	DEB21_17	6		
Mudstone Floor WLA Cretaceous Wallumbilla Formation (WLA)	DEB21_05	4		12
	DEB21_12	4		
	DEB21_17	4		
			Total	**86**

2.2.2 Batch 2 soil, regolith and rock samples

The second batch of soil and rock samples (n=66) were collected from thirteen bore holes from the 2021 drilling program (DEB21_01, DEB21_02, DEB21_03, DEB21_04, DEB21_06, DEB21_07, DEB21_14 and DEB21_15) and 2022 drilling program (DEB22_12, DEB22_15, DEB22_17, DEB22_18, and DEB22_19) **(Figure 2-1)**.

Bore holes were 11 m to 30 m in depth, and only lithologies above the orebody (QA to ALM) were targeted and 5 to 7 samples were collected from each bore hole. The samples represent the geological units and material types in **Table 2-3** including topsoil, subsoil, and overburden (sand and mudstone). 13 to 15 samples were collected from each lithological unit (**Table 2-3)**. Batch 2 samples were collected from 1 m intervals, excluding the relatively thick sand and mudstone ALM when intervals were 4 m to 16 m. Samples were extracted as dry auger or drill chips and were contained in heavy duty plastic bags. The mass of each sample was 0.5 kg to 15 kg. The additional bore hole samples from Batch 2 improved the spatial coverage for shallow material types.

Table 2-3: Summary of soil and rock samples – Batch 2

Soil and rock samples – Batch 2				
Lithological unit	**Bore hole**	**Number of samples**	**Sample appearance**	**Total**
Topsoil Quaternary alluvium (QA))	DEB21_01 to DEB22_19	1 sample from each bore hole		13
Subsoil Quaternary alluvium (QA)	DEB21_01 to DEB22_19	1 sample from each bore hole		13
Sand Quaternary Wondoola Beds (WDB)	DEB21_01 to DEB22_19	1 sample from each bore hole		13
Sand-Mudstone Transition Quaternary Wondoola Beds - Cretaceous Allaru Mudstone	DEB21_01 to DEB22_19	1 sample from each bore hole		13
Mudstone ALM Cretaceous Allaru Mudstone (ALM)	DEB21_01 to DEB22_19	1 sample from each bore hole + 2 additional in DEB22_15		14
			Total	**66**

2.2.3 Batch 3 soil, regolith and rock samples

The third batch of regolith and rock samples (n=191) were provided as pulps from 15 bore holes from the May 2022-Sep 2022 drilling programs within the proposed pit shell and targeted deeper stratigraphic units (**Table 2-4).**

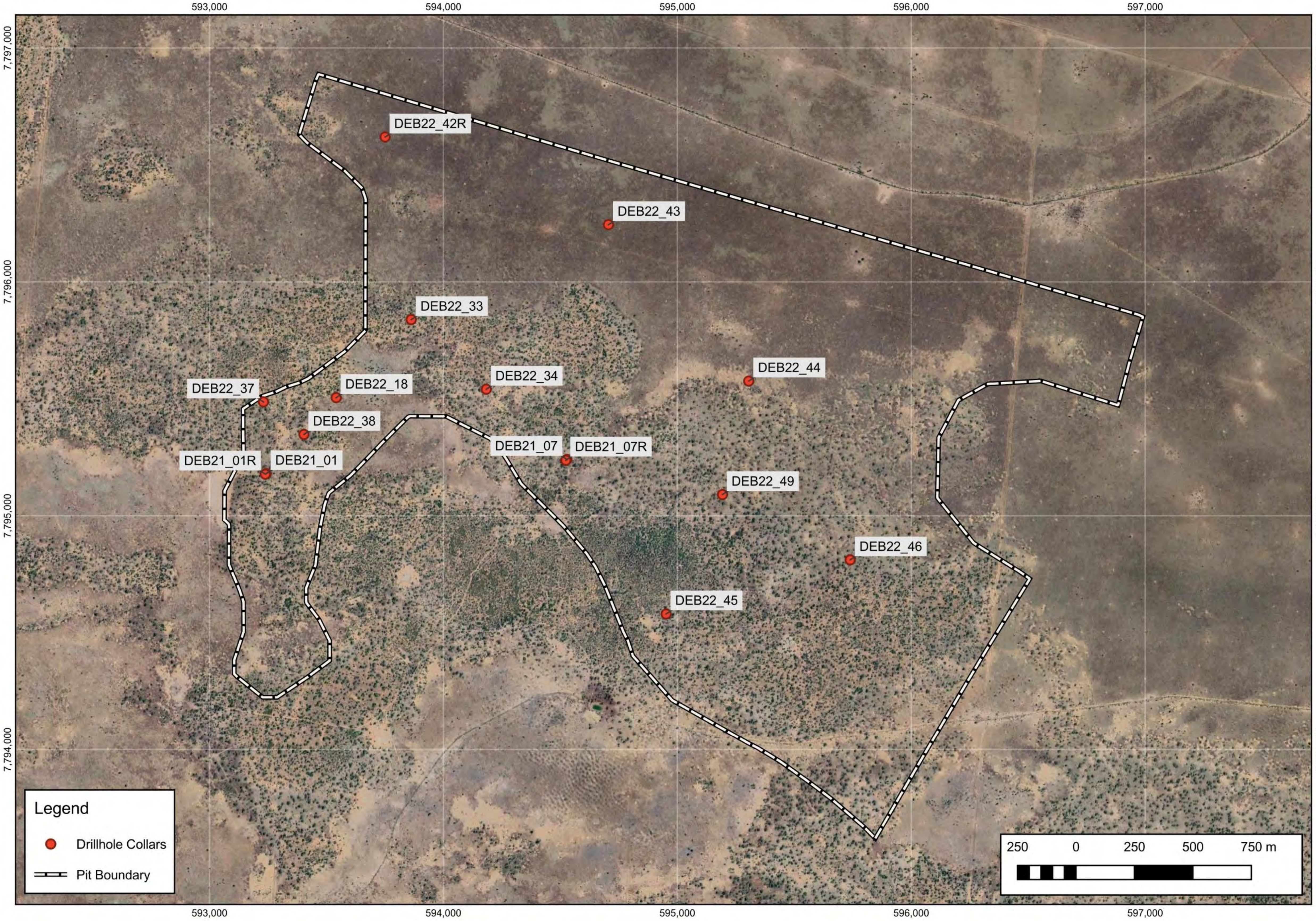


Figure 2-2: Batch 3 bore hole locations

Table 2-4: Summary of soil, regolith and rock samples - Batch 3

Soil and rock samples – Batch 3			
Lithological unit	**Bore hole**	**Number of samples**	**Total**
Mudstone ALM Cretaceous Allaru Mudstone (ALM)	DEB21_01 DEB21_01R DEB21_07 DEB21_07R DEB22_18 DEB22_33 DEB22_34 DEB22_37 DEB22_38 DEB22_42R DEB22_43 DEB22_44 DEB22_45 DEB22_46 DEB22_49	1 sample from 6 selected bore holes	6
Limestone Roof Early Cretaceous Toolebuc Formation – St Elmo Coquina (TLBA)		1 to 4 samples from each bore hole	47
Orebody - TLBB Early Cretaceous Willat's Crossing Shale		1 to 3 samples from each bore hole	36
Orebody – TLBD Early Cretaceous Arrolla Shale		1 to 5 samples from each bore hole	51
Orebody – TLBE Early Cretaceous Arrolla Shale Lower Transition		1 to 2 samples from 13 selected bore holes	16
Mudstone Floor WLA Early Cretaceous Wallumbilla Formation (WLA)		1 to 5 samples from each bore hole	35
		Total	**191**

2.3 Residue samples

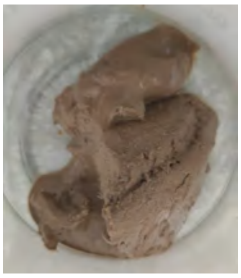
Residue samples were provided in 2 batches.

2.3.1 Batch 1 residue

Residue samples were received by RGS in November 2021 (**Table 2-5** and **Table 2-6**).

The washed residue cake (n=4) arrived at RGS in small plastic bags of approximately 500 g mass: the washing refers to the solids being leached with water post processing to remove process liquor. Washed residue slurry (n=2) and twice washed residue slurry (n=6) were contained in buckets, which had a mass of 5 kg to 10 kg each. The residue slurry is a process residue. A sample of process water was also received (RW01). The total number of Batch 1 process residue samples (n=13) included both residue and process water.

Table 2-5: Batch 1 residue samples

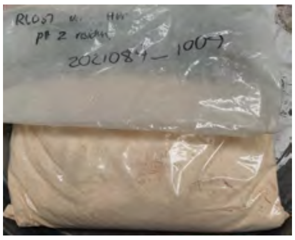
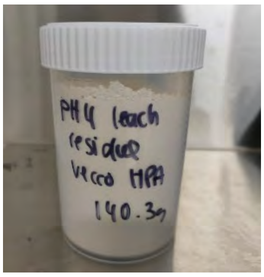
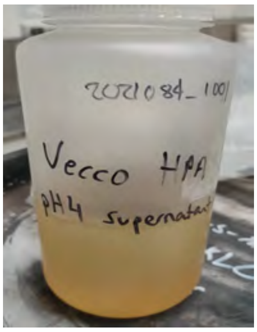
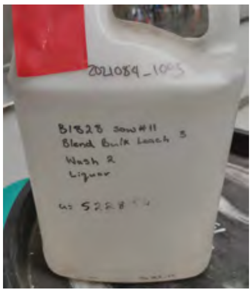
Residue and process residue samples – Batch 1				
Residue stream	**Client ID**	**Number of samples**	**Sample appearance**	**Total**
Residue cake Washed	1A_WO_BL	1		4
	1B_WO_BL_Cake 1	1		
	1B_WO_BL_Cake 2	1		
	1B_WO_BL_Cake 3	1		
Residue slurry Once washed	B2_WO_FR	1		2
	B3_WO_FR	1		
Residue slurry Twice washed	BL1-3_WT_WWC_1	1		6
	BL1-3_WT_WWC_2	1		
	BL1-3_WT_WWC_3	1		
	BL1-3_WT_WWC_4	1		
	BL1_3_WT_WWT_B2034-5	1		
	BL1_3_WT_WWT_B2034-6	1		
Process water pH 1 Bulk leach	RW01	1		1
			Total	**13**

2.3.2 Batch 2 residue

Eight additional residue samples (Batch 2) were received by RGS in June 2022 and consisted of:

- High purity alumina residue (HPA) process residue (n=2) and HPA process water (n=1). These samples were provided to RGS for metallurgical recovery analyses and are not proposed to be representative of post processed residue quality.
- Calcite neutralised vanadium residue supernatant (n=2), and calcite neutralised solid vanadium residue (n=3) (**Table 2-6**). This is the processed vanadium residue stream that will be backfilled into the mined pit.

Table 2-6: Batch 2 residue samples

Residue and process residue samples – Batch 2				
Residue stream	**Client ID**	**Number of samples**	**Sample appearance**	**Total**
HPA Raw process residue pH 2	RL087_Vecco_HPA_pH 2_Residue	1		1
HPA raw process residue pH 4	pH 4 leach residue HPA Vecco	1		1
HPA raw process Water pH 4	Vecco_HPA_pH4_Supernatant	1		1
Vanadium supernatant Treated	B1828_SOW#11_Blend Bulk Leach_2R_Wash 2_Liquor	1		2
	B1828_SOW#11_Blend Bulk Leach_3_Wash 2_Liquor	1		
Vanadium residue Treated	B1828_SOW#11_Blend Bulk Leach_2R-1/2_Wash 2_Final residue	1		3
	B1828_SOW#11_Blend Bulk Leach_2R-2/2_Wash 2_Final residue	1		
	B1828_SOW#11_Blend Bulk Leach_3-1/2_Wash 2_Final residue	1		
			Total	**8**

2.4 Composite samples

2.4.1 Soil, regolith, and rock composite samples

Selected soil, regolith and rock samples from Batch 1 (n=86) were mixed together based on similar lithology, depth, and geochemical properties (e.g., EC, TS) to create composite samples (n=19) (**Table 2-7**). The number of samples in each composite ranged from 2 to 19 and was dependent on individual sample mass. The individual orebody samples had low mass and were all mixed together to form a single composite (11.0 kg). The soil composite samples had the highest sample mass (47.6 kg). A soil composite (C021) was created by mixing all remaining samples together for bulk physical analyses (such as permeability and California bearing ratio (CBR)) that require a large sample mass.

Table 2-7: Soil and rock composites – Batch 1

	Soil and rock composites – Batch 1				
#	Composite ID	Lithology	Depth	Number of samples in composite	Composite mass
1	**2021080_C003**	Soil – Topsoil	0 – 0.5 m	3	47.6 kg
2	**2021080_C004**	Soil - Subsoil	0.5 – 1 m	3	46.3 kg
3	**2021080_C005**	Subsoil / Sand	1 – 2 m	2	26.1 kg
4	**2021080_C006**	Sand	2 – 8 m	2	49.4 kg
5	**2021080_C007**	Silt (Sand)	3 – 5 m	2	10.9 kg
6	**2021080_C008**	Silt (Sand)	5 – 8 m	3	21.6 kg
7	**2021080_C009**	Sand / Mudstone	2 – 10 m	3	19.5 kg
8	**2021080_C010**	Mudstone ALM	11 – 17 m	3	9.3 kg
9	**2021080_C011**	Mudstone ALM	12 – 23 m	5	17.4 kg
10	**2021080_C012**	Mudstone ALM	14 – 24 m	6	17.1 kg
11	**2021080_C013**	Mudstone ALM	9 – 25 m	6	12.3 kg
12	**2021080_C014**	Mudstone ALM	12 – 28 m	5	14.4 kg
13	**2021080_C015**	Limestone roof	17 – 23 m	6	12.4 kg
14	**2021080_C016**	Limestone roof	28 – 31 m	3	5.7 kg
15	**2021080_C017**	Limestone roof	31 – 34 m	3	14.6 kg
16	**2021080_C018**	Orebody	23 – 39 m	19	11.0 kg
17	**2021080_C019**	Mudstone WLA	31 – 35 m	8	9.3 kg
18	**2021080_C020**	Mudstone WLA	40 – 44 m	4	2.9 kg
19	**2021080_C021**	All samples	0 – 44 m	86	40.0 kg

Similarly, selected soil and rock samples from Batch 2 (n=58) were mixed together to create a second batch of composite overburden samples (n=12) (**Table 2-8**). The number of samples in each composite ranged from 2 to 10 and was dependent on individual sample mass. Some samples (n=8) from DEB 22_15 and DEB 22_19 were excluded from the Batch 2 composites due to insufficient mass. The limited sample mass available for these 8 samples was utilised in the ABA screen. The composites in Batch 2 represent the upper units of the stratigraphic profile, from the topsoil to the Mudstone ALM overburden unit. The boreholes reached a maximum of 30 m in depth, and did not include the deeper limestone, orebody, and Mudstone WLA units.

Table 2-8: Soil, regolith and rock composites - Batch 2

	Soil and rock composites – Batch 2				
#	Composite ID	Lithology	Depth	Number of samples in composite	Composite mass
1	**2021084_C001**	Soil – Topsoil	0 – 1 m	9	35.5 kg
2	**2021084_C002**	Soil – Topsoil	0 – 2 m	3	13.7 kg
3	**2021084_C003**	Soil - Subsoil	0.5 – 3 m	10	49.7 kg
4	**2021084_C004**	Soil - Subsoil	1 – 2 m	2	9.0 kg
5	**2021084_C005**	Sand	2 – 11 m	5	23.1 kg
6	**2021084_C006**	Sand	2 – 12 m	6	29.2 kg
7	**2021084_C007**	Sandstone-Mudstone Transition	7 – 12 m	3	9.5 kg
8	**2021084_C008**	Sandstone-Mudstone Transition	6 – 9 m	5	16.6 kg
9	**2021084_C009**	Sandstone-Mudstone Transition	8 – 13 m	4	12.2 kg
10	**2021084_C010**	Mudstone ALM	7 – 30 m	3	11.7 kg
11	**2021084_C011**	Mudstone ALM	7 – 23 m	4	17.0 kg
12	**2021084_C012**	Mudstone ALM	7 – 22 m	4	18.3 kg

Note: Some Batch 2 samples were excluded from composites due to insufficient mass.

2.4.1.1 Residue composite samples

The Batch 1 individual residue samples (n=12) excluding the process water were mixed together into composites (n=2) based on whether they were washed or twice washed (**Table 2-9**). The washed residue samples (n=6) included some solid residue cake, which was manually mixed into the composite with a rod to ensure homogeneity (m=8.1 kg). The twice washed residue samples (n=6) were residue slurry only and when mixed together had higher moisture and higher overall mass (m=15.1 kg) than the washed residue. A mechanical stirring rod was used to combine the samples in slurry form.

Table 2-9: Residue composites – Batch 1

	Residue composites – Batch 1				
#	Client ID	Composite ID	Description	Number of samples in composite	Composite mass
1	1A_WO_BL	**2021080_C001**	Washed residue	6	8.1 kg
	1B_WO_BL_Cake 1				
	1B_WO_BL_Cake 2				
	1B_WO_BL_Cake 3				
	B2_WO_FR				
	B3_WO_FR				
2	BL1-3_WT_WWC_1	**2021080_C002**	Twice washed residue	6	15.1 kg
	BL1-3_WT_WWC_2				
	BL1-3_WT_WWC_3				
	BL1-3_WT_WWC_4				
	BL1_3_WT_WWT_B2034-5				
	BL1_3_WT_WWT_B2034-6				

The solid fraction of the Batch 2 treated residue residue samples (n=3) were combined to produce a bulk composite (**Table 2-10**). The Batch 2 residue samples were crumbly and slightly moist but were not a slurry like the untreated residue in Batch 1.

Table 2-10: Residue composites – Batch 2

Residue composites – Batch 2				
Client ID	Composite ID	Description	Number of samples in composite	Composite mass
B1828_SOW#11_Blend Bulk Leach_2R-1/2_Wash 2_Final residue	**2021084_C101**	Treated residue	3	17.6 kg
B1828_SOW#11_Blend Bulk Leach_2R-2/2_Wash 2_Final residue				
B1828_SOW#11_Blend Bulk Leach_3-1/2_Wash 2_Final residue				

2.4.1.2 KLC composites

The initial Batch 1 kinetic leach column (KLC) composites (KLC 1 - KLC 8) were made by combining composites of similar lithology together (**Table 2-11**). Each KLC contained the same composite mass (m = 2.5 kg). Soil samples (C003 to C006) were excluded from the KLC composites.

The residue composites (C001 and C002) underwent a series of neutralisation experiments. The treated twice washed residue composite (C101T) was placed into both KLC 7 and KLC 8, but the columns were leached under different moisture regimes (unsaturated and saturated). The KLC method is described in **Section 2.5.1**.

Table 2-11: KLC composites – Batch 1

KLC composites – Batch 1				
KLC ID	Lithology / description	Moisture regime	KLC composition (2021080_)	Number of samples in KLC composite
KLC 1	Sand / Silt	Unsaturated	C007 + C008 + C009	8
KLC 2	Mudstone ALM (TS ≤ 0.1%)	Unsaturated	C010 + C011 + C012	14
KLC 3	Mudstone ALM (TS ≥ 0.1%)	Unsaturated	C013 + C014	11
KLC 4	Limestone roof	Unsaturated	C015 + C016 + C017	12
KLC 5	Orebody	Unsaturated	C018	19
KLC 6	Mudstone Floor WLA	Unsaturated	C019 + C020	12
KLC 7	Treated twice washed residue	Unsaturated	C101T	6
KLC 8	Treated twice washed residue	Saturated	C101T	6

When the Batch 2 treated residue from the pilot plant became available, KLC 7 and KLC 8 were discontinued and were replaced with analogous columns utilising the new samples (KLC 9 and 10). Another column (KLC 11) was included to kinetically leach the HPA residue, however, due to limited sample mass, this could only be performed under an unsaturated moisture regime (**Table 2-12**).

Table 2-12: KLC composites – Batch 2

KLC composites – Batch 2				
KLC ID	Lithology / description	Moisture regime	KLC composition (2021084_)	Number of samples in KLC composite
KLC 9	Pilot plant treated residue	Unsaturated	C101	3
KLC 10	Pilot plant treated residue	Saturated	C101	3
KLC 11	HPA Residue pH 2	Unsaturated	1004	1

2.5 KLC method

2.5.1 KLC set up and operation

The kinetic leach column (KLC) program is carried out at the RGS laboratory. Analyses of the collected leachate are performed at ALS.

For this project, RGS used 150 mm diameter PVC columns cut to a height of 300 mm (**Figure 2-3**). This column size was chosen as it is appropriate for the available sample mass. The base of the column is lined with 20 mm of glass beads that are overlain with filter paper to prevent clogging of the outlet taps. The KLC composites (m=2.5 kg for KLC 1 - 8 and m=4.0 kg for KLC 9 - 10) are sieved to < 20 mm and placed in the column.

Unsaturated (free leach) samples KLC 1 - KLC 7 and KLC 9 are allowed to oxidise and simulate exposed environmental conditions such as the surface of waste rock dumps. The saturated columns (KLC 8 and KLC 10) are filled to capacity with de-ionised (DI) water and capped with a lid to maintain zero headspace. This type of column subjects the sample to environmental conditions expected when the residue are submerged in a residue storage facility (TSF). The saturated columns are fitted with an Eh probe which measures whether the redox potential is positive (oxidising conditions) or negative (reducing conditions).

KLC 11 used the same column size but a smaller mass of sample (1.0 kg) which was limited by the small quantity of HPA residue sample. All other aspects are identical to KLC 1 – KLC 10.

2.5.1.1 Unsaturated (free leach) columns

The unsaturated soil and rock KLC samples (KLC 1 – KLC 6) began a monthly leaching program in April 2022 and have been subjected to 12 leach events at the time of writing (**Figure 2-3**). The unsaturated treated residue sample (KLC 7) began a similar program but was delayed a few weeks by the residue neutralisation experiments and then discontinued after four leach events. The unsaturated pilot plant treated residue sample (KLC 9) and HPA residue (KLC 11) have undergone six leach events at the time of writing and have been discontinued, as the long term behaviour of these samples is clearly defined (**Figure 2-4**).

In all KLC samples prior to the unsaturated column leach event, the outlet tap is closed. A measured volume of DI water was added to the columns in Week 1 and Week 2: after this 1 L of DI water was added for each leach cycle. The DI water is allowed to react with the sample for 24 hours and then the outlet tap is opened. The leachate is collected in a plastic container. All KLC sample parameters and criteria are recorded.

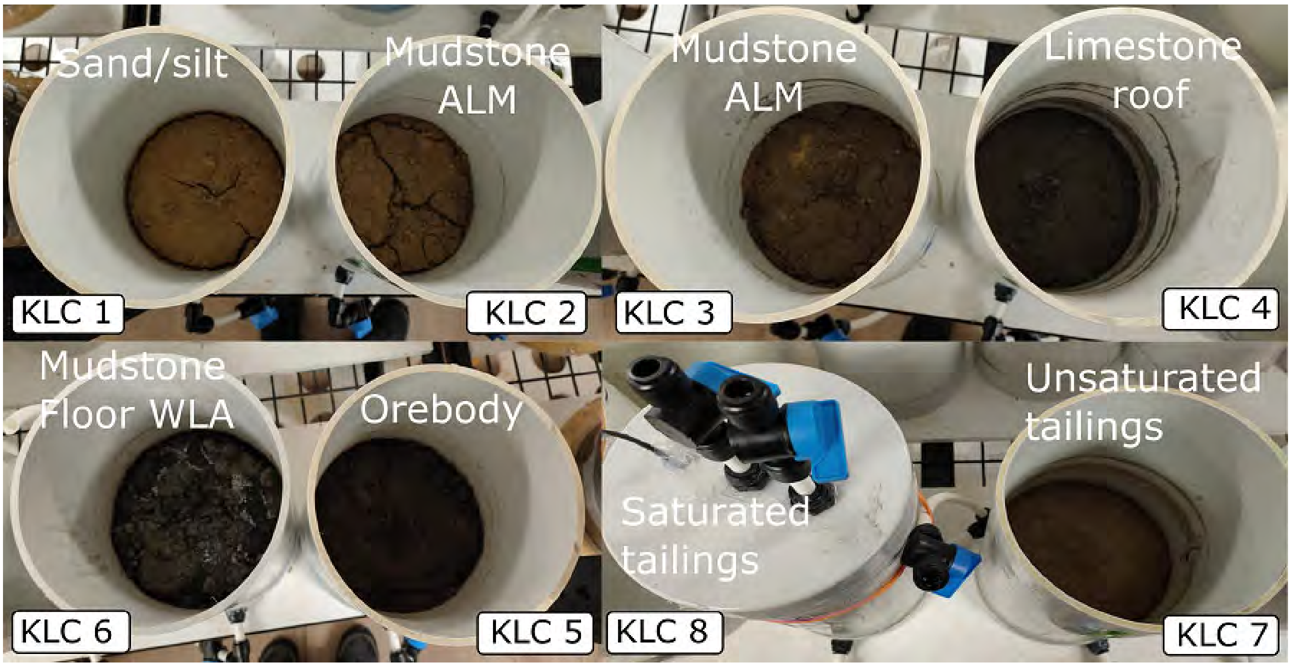


Figure 2-3: KLC set up for Vecco Vanadium (KLC 1 – KLC 8)

Figure 2-4: KLC set up for Vecco Vanadium (KLC 9-11)

2.5.1.2 Saturated columns

Prior to leaching, the pore volume of the sample in the saturated residue columns (KLC 8 and KLC 10) is calculated by measuring the mass difference between a saturated sample and an oven dried sample of known volume. The pore volume for KLC 8, the treated residue sample (C101T) is 600 mL in the 2.5 kg sample. For each monthly leach event, the outlet tap is opened, and one pore volume is collected. The outlet tap is then closed and the saturated KLC is topped up with DI water to ensure there are no air gaps at the roof of the column. Leach events for the saturated columns continue for four pore volumes, collecting one pore volume per leach event. Both KLC 8 and KLC 10 have completed this leaching program.

The Eh probe is permanently inserted into the saturated column. Changes in the Eh are expected to occur rapidly when the residue sample first becomes saturated but should stabilise over time. When KLC 8 and KLC 10 first began operating, the Eh probe was measured at 1-hour intervals for the first day. After that, the Eh probe was measured daily for the following week. Over the course of the next month, the Eh probe was monitored weekly, and from then on it was checked once a month.

2.5.2 Column settlement method

The column settlement experiment is done to verify how bedload and suspended sediment settle in solution. The results are cross referenced with ESP and Emerson Class results to determine whether the materials are truly dispersive.

The procedure is described below.

1. 100 g of soil or rock sample (sieved to < 2 mm) is placed into a 1 L glass measuring cylinder and topped with DI water to a combined volume of 1 L.
2. A lid is placed over the top of the cylinder and the contents shaken thoroughly to ensure there are sediments at the base of the cylinder.
3. The cylinder is placed on a stable surface and the contents are allowed to settle. Photographs are taken at 0, 8, 24, and 48 hours to show settlement progression.

3 Analytical program

The analytical program for the soil, regolith, rock, residue, and HPA residue samples is in **Table 3-1**. The number of analyses has been split into different sample types to provide clarity. All analyses have been completed as of January 2023. The external laboratory (or RGS laboratory) at which the analyses are performed has been specified, along with their method codes.

Table 3-1: Analytical program for Vecco Vanadium

				Soil and rock individual samples	Soil and rock composite samples	Residue individual samples	Residue process water and supernatant	Residue composite samples	HPA residue samples and HPA process water	Batch 3 pulp samples	Soil, rock, and residue kinetic leach columns
				001-086 (Batch 1) 001-066 (Batch 2)	C003-C021 (Batch 1) C001-C012 (Batch 2)	1001-1012 (Batch 1) 1005, 1006, 1007 (Batch 2)	RW01 (Batch 1) 1002, 1003 (Batch 2)	C001-C002 (Batch 1) C101 (Batch 2)	1001, 1004, 1008 (Batch 2)	Pulp samples	KLC1-KLC11 (4 or 12 leach events)
Static geochemcial analyses	**ALS Code**	**Method Code**	**Number of analyses**	**152**	**31**	**15**	**3**	**3**	**3**		**11**
Moisture Content			44	44							
pH and EC (1:5)	IN-4S	APHA 4500 H+ - B and APHA 2510 B	171	152		15		2	2		
NAPP (includes ANC, Total S)	ASS1	III. Coastech Research (Canada)	171	152		15		2	2	191	
Chromium Reducible Sulfur (22B)	EA026	Ahern et al (2004)	78	61		15			2	191	
Titratable Actual Acidity (23F)	EA029a TAA	Ahern et al (2004)	7			3		2	2		
Major, minor and trace elmental analysis (Total) (48 elements)	ME-MS41 - 2 acid aqua regia digest		33	12	18			2	1		
TRH / BTEXN	EP080	USEPA SW 846 - 8260B	44	44							
Soil fertility analyses	**ALS Code**	**Method Code**	**Number of analyses**								
Exchangeable Cations ECEC, ESP + NT8S Nutrients (TN, TP, TKN, NO$_2$, NO$_3$, NH$_3$ and NO$_x$) + Chloride (1:5), pH (CaCl$_2$) Colwell P and K, DTPA extractable Fe, Cu, Zn and Mn, Organic Matter and Organic Carbon by Walkley Black	AG-3	APHA 4500-NH$_3$ B, APHA 4500 NO$_3$- B, APHA 4500 NO$_3$- – I/NO$_2$- -B, Thermo Scientific Method D08727 and NEMI: 9171, APHA 4500 Norg – D,	44	24	18			2			
Shale Flask Extraction 1:3 and 16 hr leach for water soluble elements	**ALS Code**	**Method Code**	**Number of analyses**								
pH and EC (1:3)	IN-4S	APHA 4500 H+ - B and APHA 2510 B	41		30	3	3	2	3		
Acidity as CaCO3 only	ED038P CaCO$_3$	APHA 2310 B	41		30	3	3	2	3		
Cations - Dissolved: Calcium, Magnesium, Sodium, Potassium	NT-01	APHA 3120B, APHA 3125B	33		30		1	2			
Anions: Major (Cl, SO$_4$, Alkalinity), Fluoride	NT-02A	APHA 3120B, APHA 3125B	33		30		1	2			
Total trace metals by ICP/MS (including digestion)	ME-02W	USEPA 6020 ICP/MS	18		18						
Dissolved trace metals by ICP/MS (including digestion)	EG020F (ME-02)	USEPA 6020 ICP/MS	41		30	3	3	2	3		
Mercury	EG035F	APHA 3112 Hg-B CV/FIMS	40		30	3	2	2	3		
Kinetic Leach Column testing	**ALS Code**	**Method Code**	**Number of analyses**								
pH and EC (1:3)	EA005P + EA010P	APHA 4500 H+ - B and APHA 2510 B	11								11
Acidity as CaCO3 only	ED038P CaCO$_3$	APHA 2310 B	11								11
Cations - Dissolved: Calcium, Magnesium, Sodium, Potassium	NT-01	APHA 3120B, APHA 3125B	11								11
Anions: Major (Cl, SO$_4$, Alkalinity), Fluoride	NT-02A	APHA 3120B, APHA 3125B	11								11
Trace metals by ICP/MS (including digestion)	EG020F (ME-02)	USEPA 6020 ICP/MS	11								11

Mercury	EG035F	APHA 3112 Hg-B CV/FIMS	11								11
TRH/BTEXN	W-04		7								7
Dissolved Organic Carbon	EP002		11								11
Physical Parameters (Trilab Brisbane)	**Code**	**Method Code**	**Number of analyses**								
Grading with Hydrometer (includes Particle Density)	Based on method	AS 1289.3.6.1 , AS 1289.3.6.3	17		14			2	1		
Atterberg Limits - Standard Oven Preparation	Based on method		14		14						
Soaked California Bearing Ratio (CBR) - includes Standard MDD	Based on method		1		1						
Permeability (falling head) - includes MDD Standard 90%	Based on method		11		6						5
Compaction Curve - additional remoulding ratio 95%	Based on method		11		6						5
Pinhole Dispersion (including STD compaction)	Based on method		1		1						
Emerson Class No.	Based on method	AS1289.3.8.1	40	24	14			2			
Shrink and Swell Index	Based on method		1		1						
Physical Parameters (RGS In-House)	**Code**	**Method Code**	**Number of analyses**								
Column Settlement	RGS In-House		14		14						
X-Ray Diffraction (XRD) (Levay & Co)	Code	Method Code	Number of analyses								
XRD Analysis - sample containing clay	Based on method		6					1			5
SWCC Testing (Soil Water Group)	**Code**	**Method Code**	**Number of analyses**								
Soil Water Characteristic Curve (10 Point)	Based on method		13		12			1			

4 Results

4.1 Static acid base account results

This section contains figures and tables for the acid base account (ABA) suite for soil (n=55), rock (n=97), and residue (n=17) for Batch 1 and Batch 2 individual and composite samples that represent the deposit (not the ore within the pit shell): because of the consistency in the geological and geochemical properties of the deposit the Batch 1 and Batch 2 results are appliable to the nature of the material in the pit shell. The Batch 3 samples (n=191) are from within the proposed pit shell.

4.1.1 Batch 1 and Batch 2

- $pH_{1:5}$ results for soil and rock are in **Figure 4-1**.
- $pH_{1:5}$ results for untreated and treated residue and HPA residue are in **Figure 4-2**.
- Electrical conductivity ($EC_{1:5}$) results for soil and rock are in **Figure 4-3**.
- $EC_{1:5}$ results for residue and HPA residue are in **Figure 4-4**.
- Total sulfur (TS) results for soil and rock are in **Figure 4-5**.
- TS results for soil and rock are in **Figure 4-6**.
- TS and chromium reducible sulfur (CRS) for soil and rock are in **Figure 4-7.**
- TS and CRS for residue and HPA residue are in **Figure 4-8.**
- Net acid production potential (NAPP) values for soil and rock are in **Figure 4-9** and **Figure 4-10**.
- NAPP values for residue and HPA residue are in **Figure 4-11.**
- The relationship between maximum potential acidity (MPA) and acid neutralising capacity (ANC) is shown in **Figure 4-12**.
- The relationship between MPA and ANC for residue and HPA residue is in **Figure 4-13**.
- The geochemical classifications for soil and rock samples are in **Table 4-1** and **Table 4-2**.

ABA results are interpreted in **Section 5**.

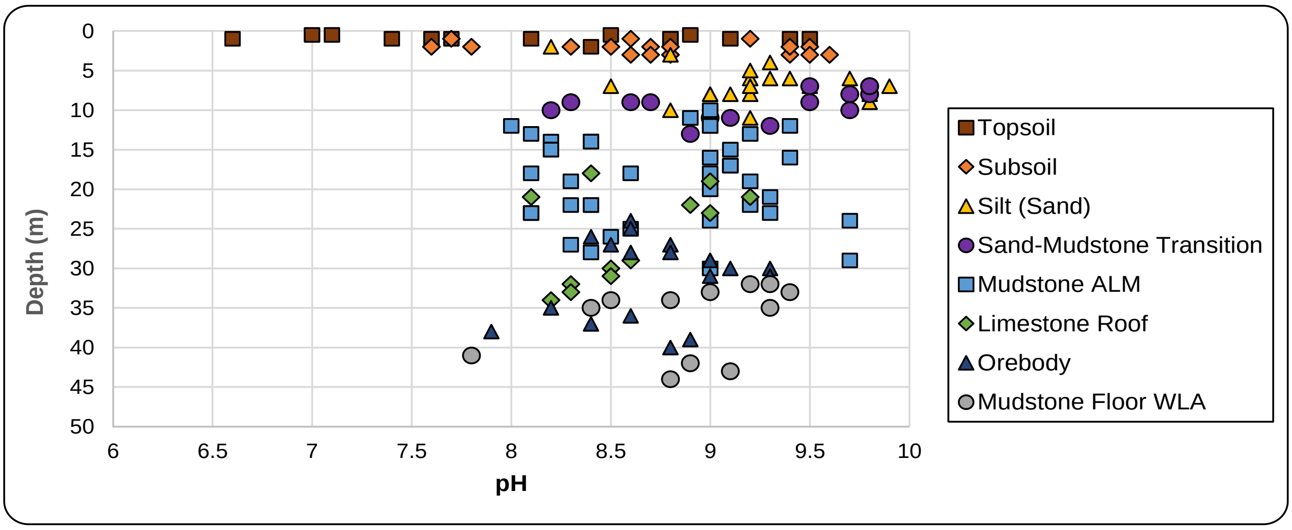


Figure 4-1: $pH_{1:5}$ for soil and rock

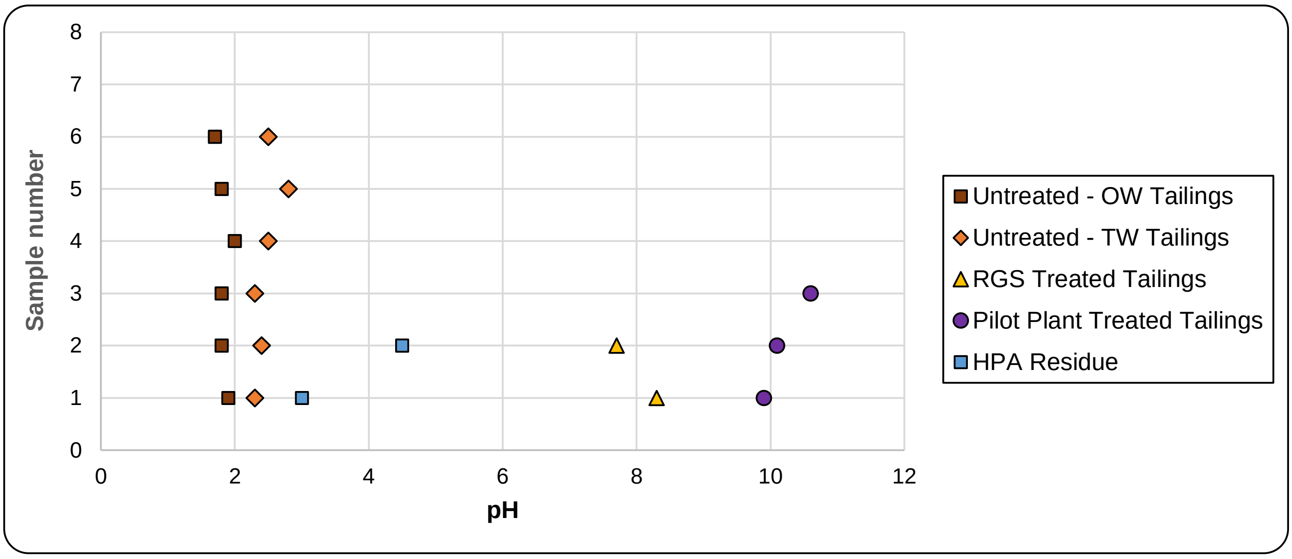


Figure 4-2: $pH_{1:5}$ for residue and HPA residue

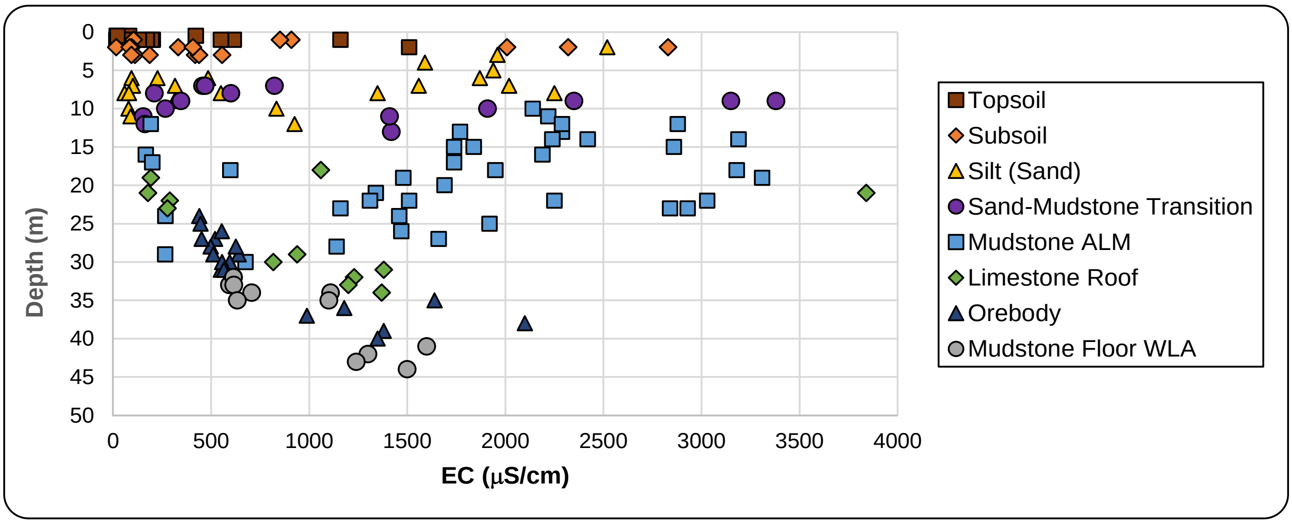


Figure 4-3: $EC_{1:5}$ for soil and rock

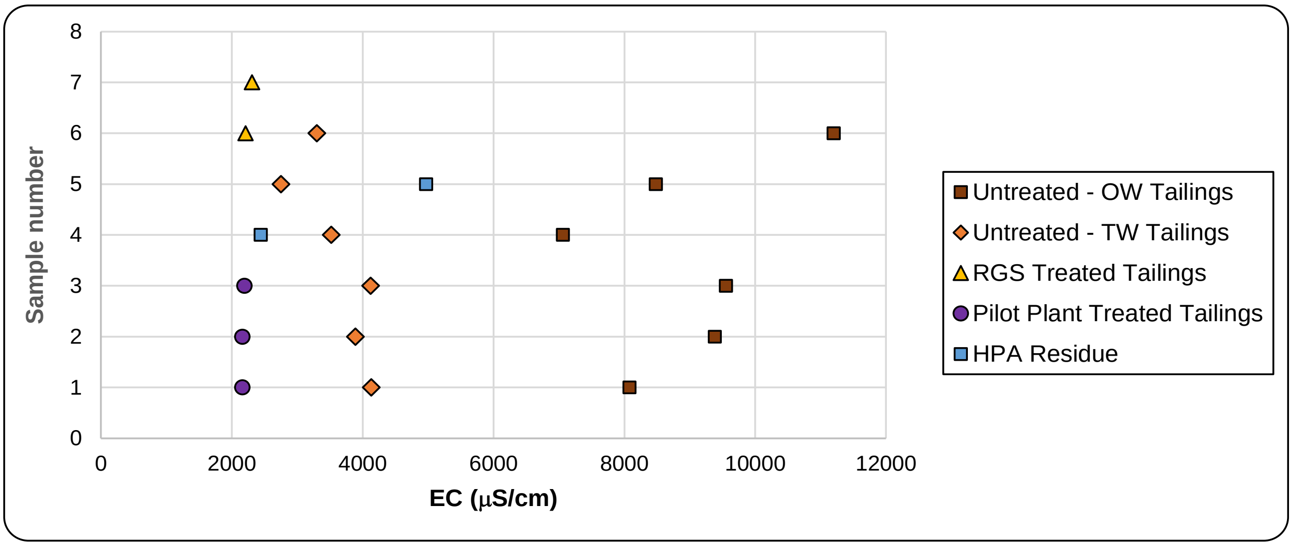


Figure 4-4: $EC_{1:5}$ for residue and HPA residue

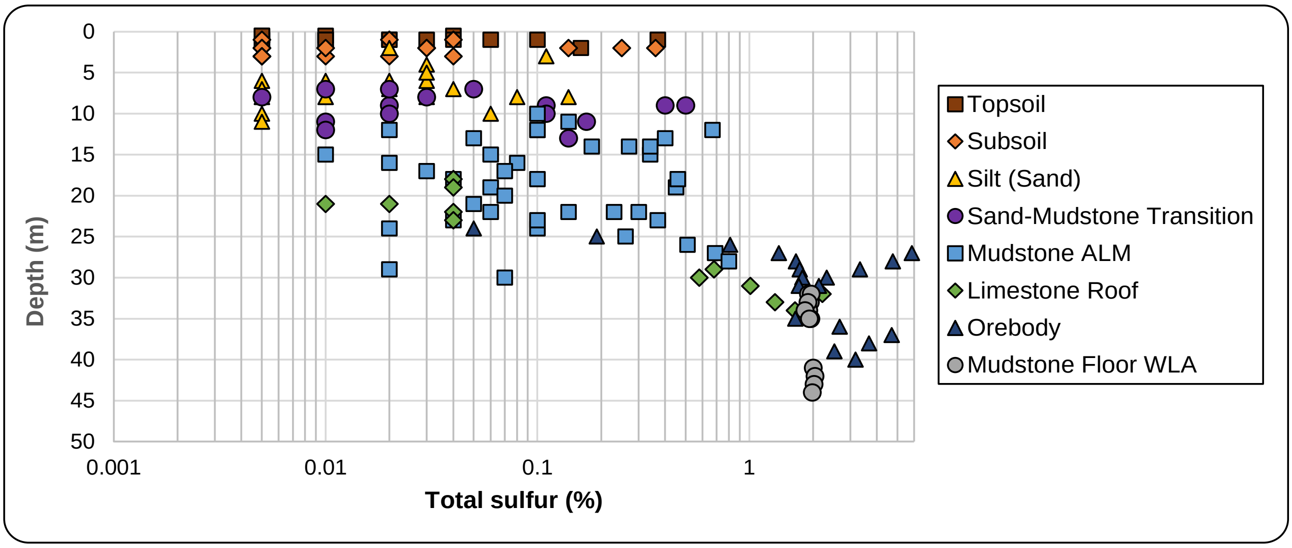


Figure 4-5: Total sulfur for soil and rock

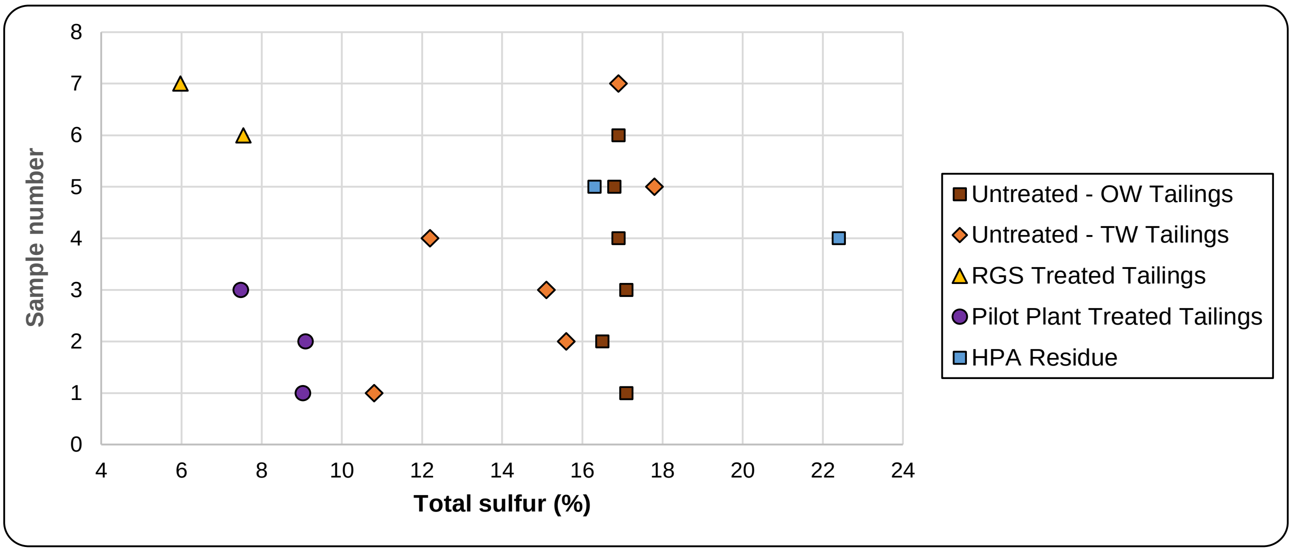


Figure 4-6: Total sulfur for residue and HPA residue

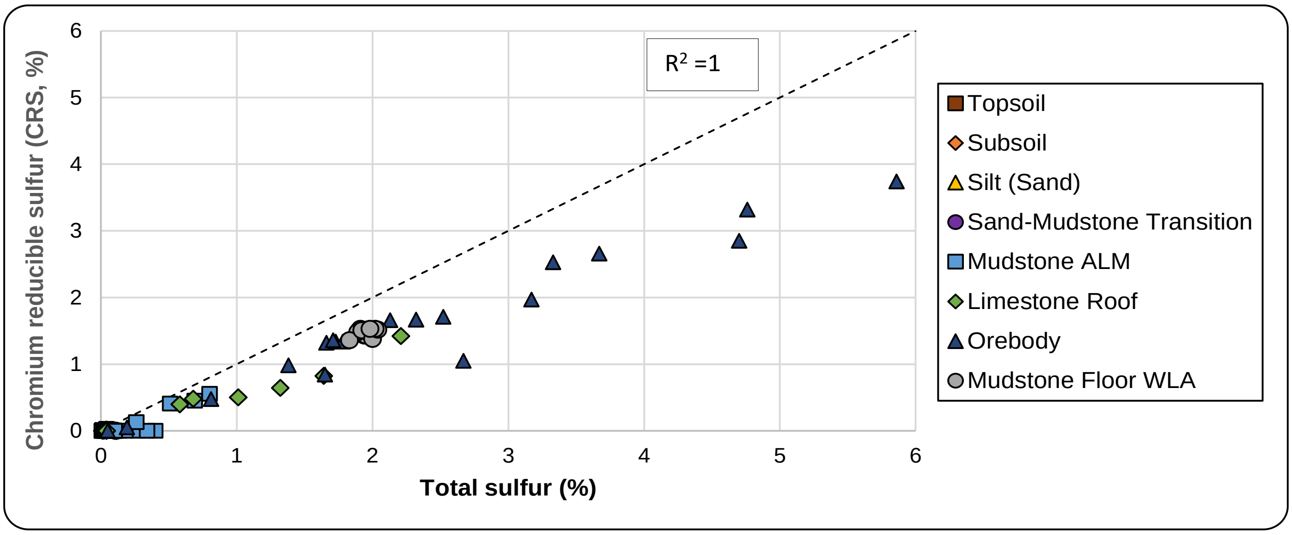


Figure 4-7: Relationship between TS and CRS for soil and rock

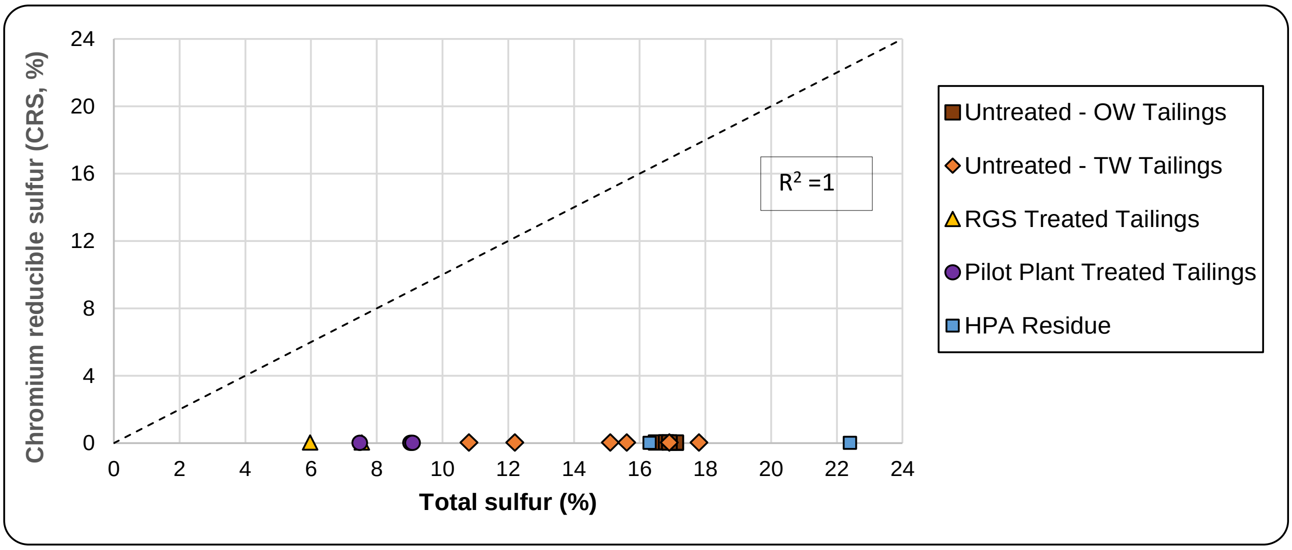


Figure 4-8: Relationship between TS and CRS for residue and HPA residue

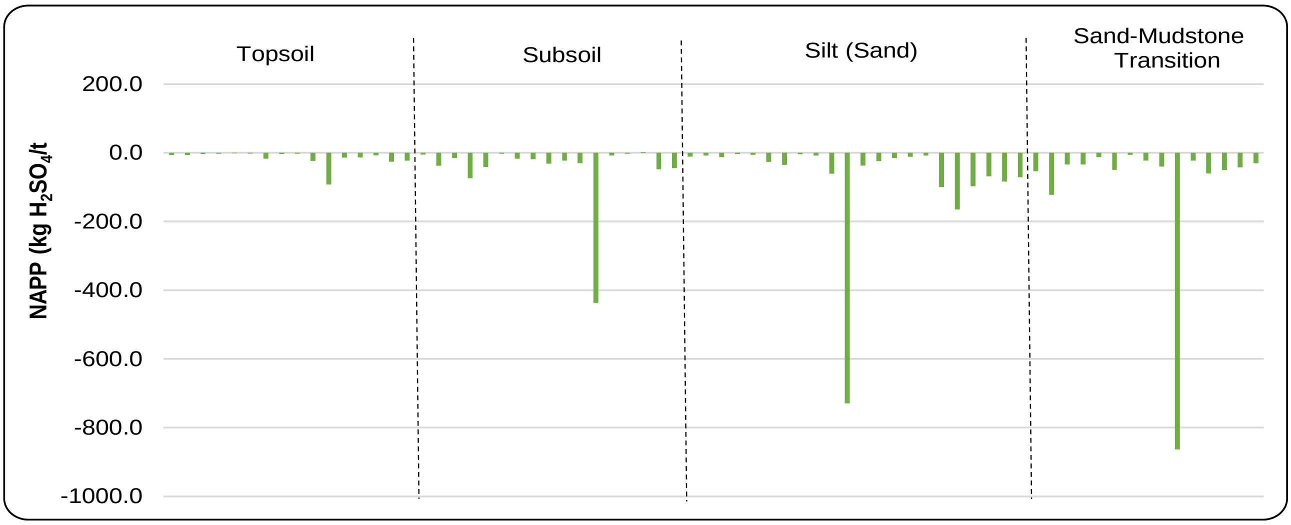


Figure 4-9: NAPP values (calculated from TS) for topsoil, subsoil, silt (sand), and transition material

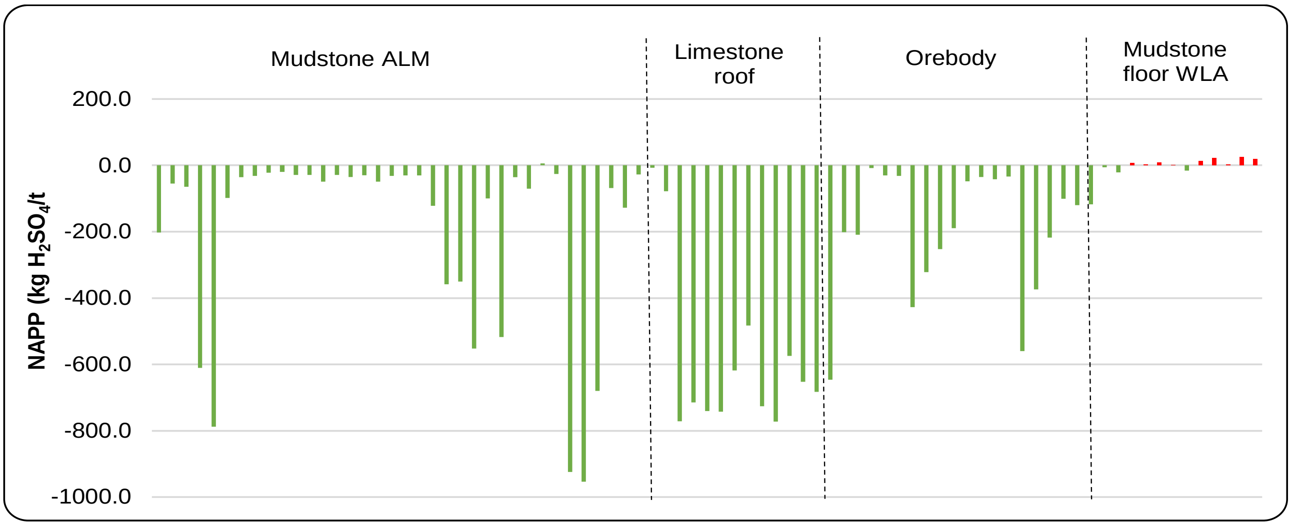


Figure 4-10: NAPP values (calculated from TS) for Mudstone ALM, limestone roof, orebody, and Mudstone floor WLA

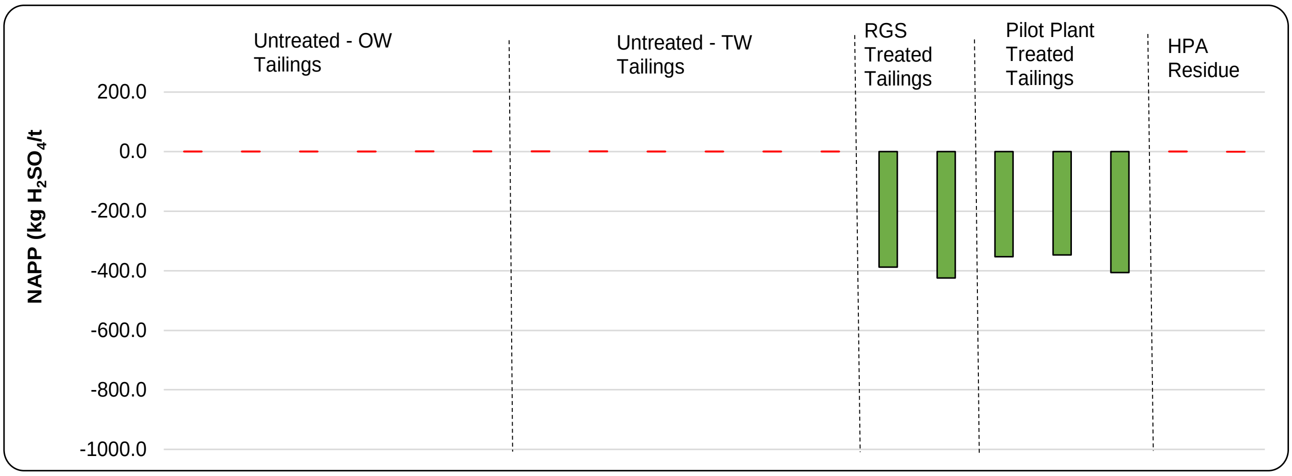


Figure 4-11: NAPP values for residue and HPA residue

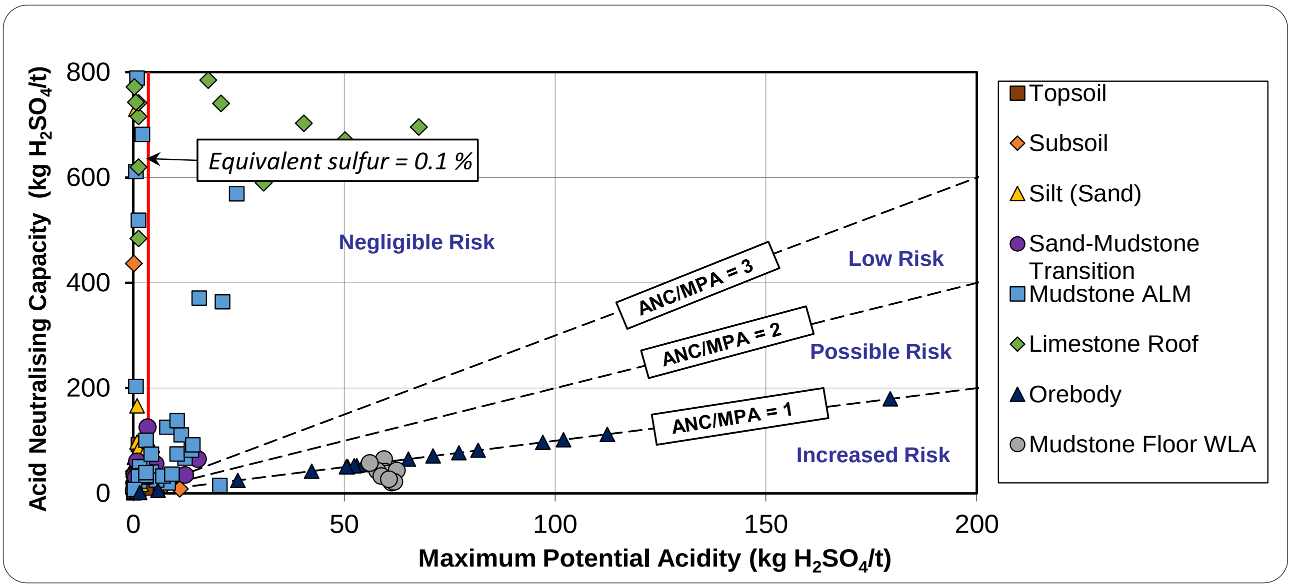


Figure 4-12: Relationship between MPA (calculated from TS) and ANC for soil, regolith and rock

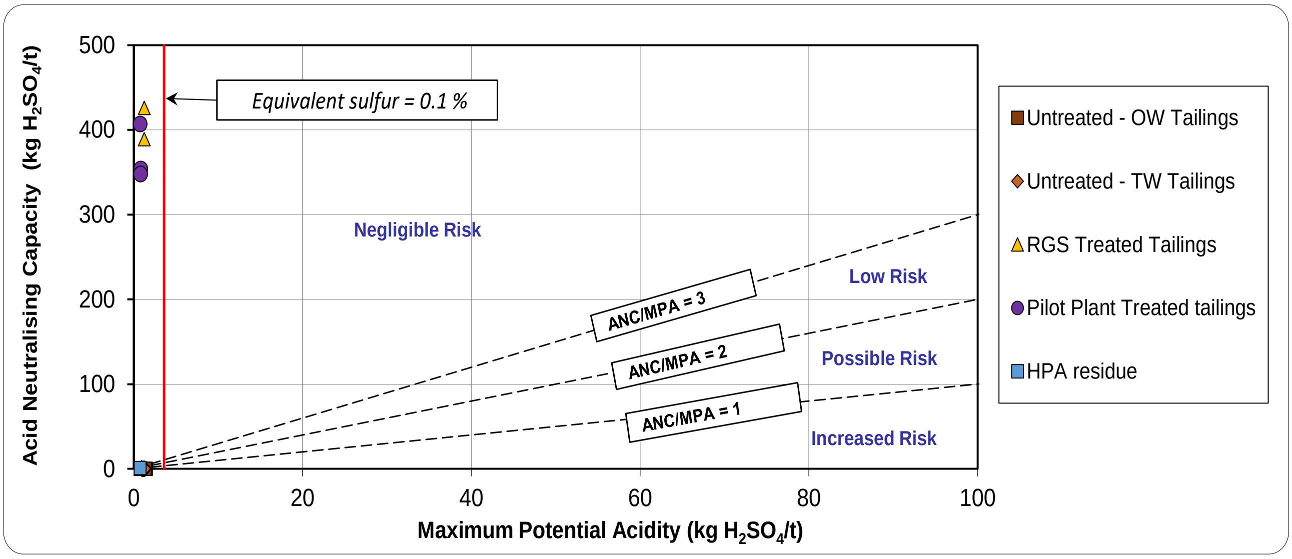


Figure 4-13: Relationship between MPA and ANC for residue and HPA residue

4.1.2 Batch 3

- Total sulfur (TS) results for rock are in **Figure 4-14**.
- TS and chromium reducible sulfur (CRS) for rock are in **Figure 4-15**.
- Net acid production potential (NAPP) values for rock calculated from CRS are in **Figure 4-16.**
- The relationship between maximum potential acidity (MPA) calculated from CRS and acid neutralising capacity (ANC) is shown in **Figure 4-17**.
- The geochemical classifications for rock samples are in **Table 4-2** and **Table 4-3.**

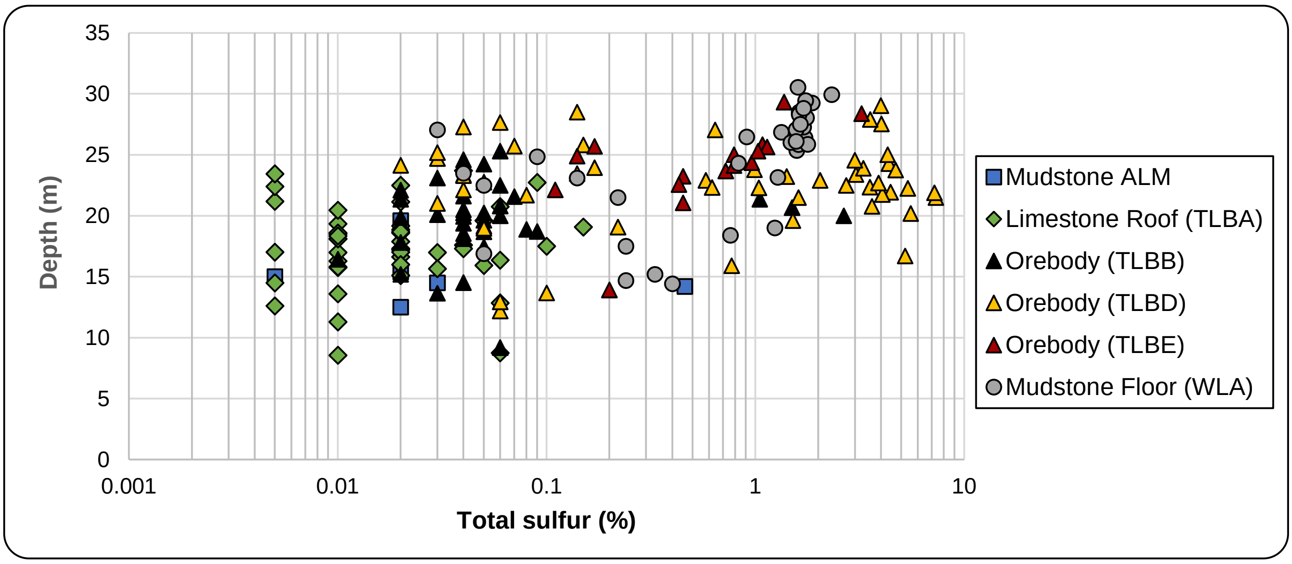


Figure 4-14: Total sulfur for rock

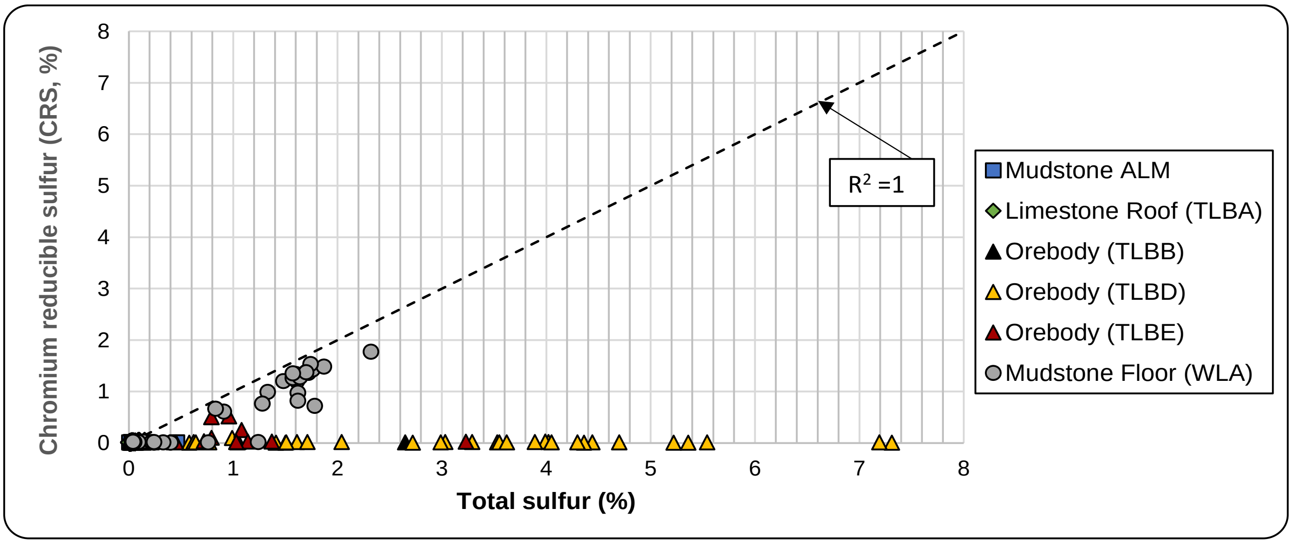


Figure 4-15: Relationship between TS and CRS for rock

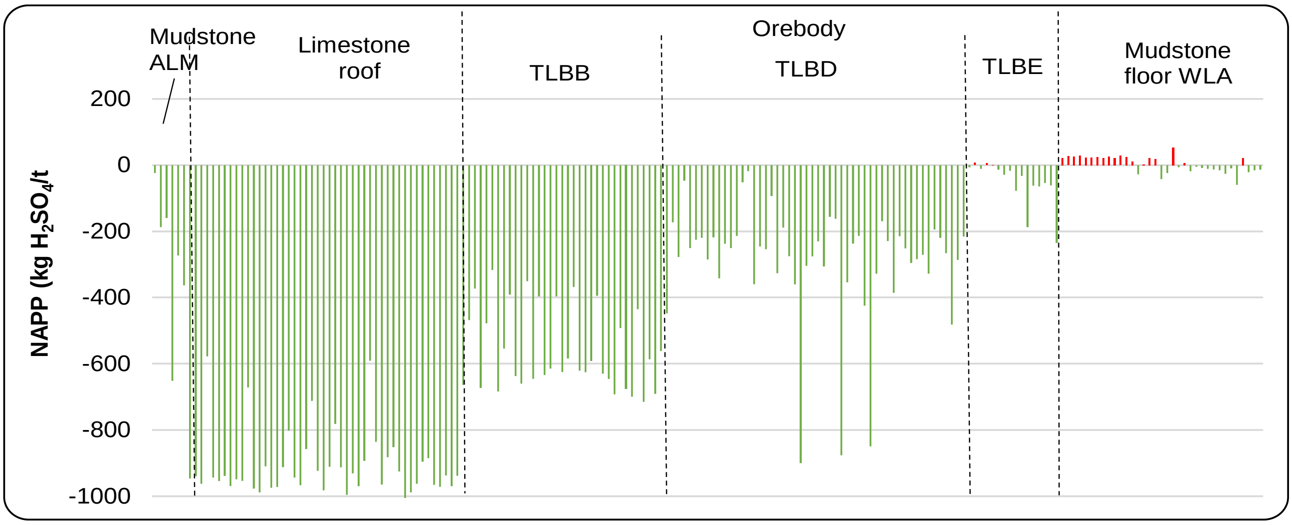


Figure 4-16: NAPP values (calculated from CRS) for rock

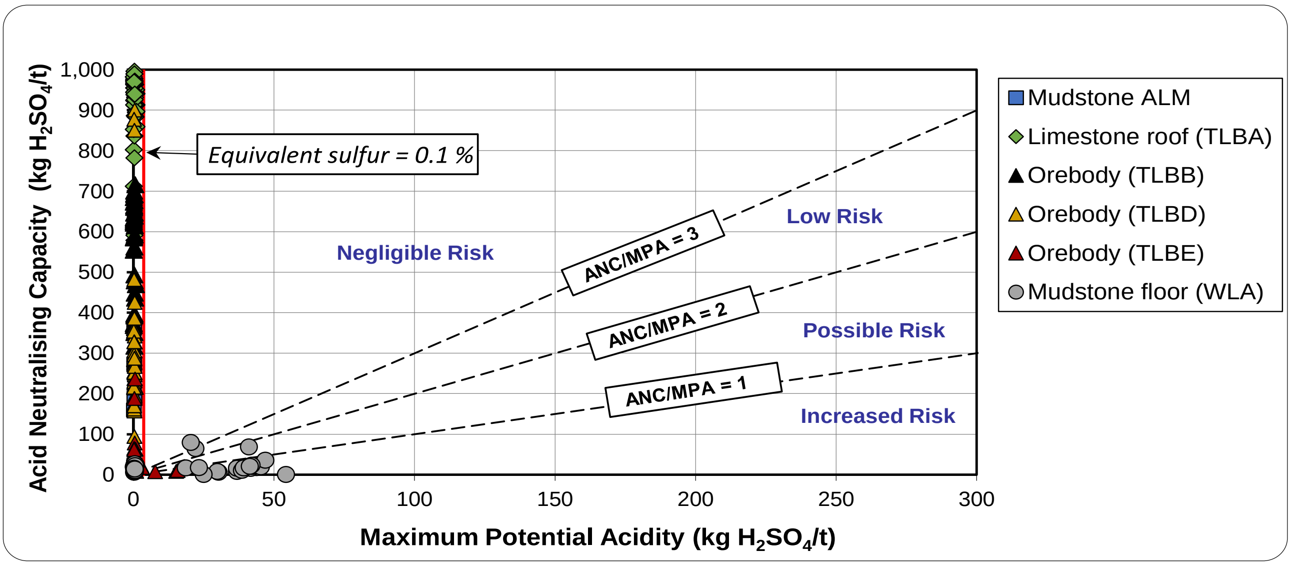


Figure 4-17: Relationship between MPA (calculated from CRS) and ANC for rock

4.1.3 Summary of ABA results

Geochemical classifications for soil, regolith, and rock are in **Table 4-1** to **Table 4-3**.

Table 4-1: Geochemical classifications for Quaternary Alluvium calculated from TS

Geochemical Classification	$NAPP_{TS}$ (kg H_2SO_4/t)	Quaternary Alluvium (topsoil and subsoil samples (n=55)	%
Acid consuming	< -60	11	20%
Non-Acid Forming	-60 to -10	24	44%
Non-Acid Forming (Low Capacity)	-10 to 0	19	34%
Potentially Acid Forming (Low Capacity)	0 to 10	1	2%
Potentially Acid Forming	10 to 30	0	0%
Potentially Acid Forming (High Capacity)	> 30	0	0%

Table 4-2: Geochemical classifications for regolith and rock (calculated from TS)

Geochemical Classification	$NAPP_{TS}$ (kg H_2SO_4/t)	Regolith and rock samples (n=288)	%
Acid Consuming (AC)	< -60	176	61%
Non-Acid Forming	- 60 to -10	55	19%
Non-Acid Forming (Low Capacity)	-10 to 0	10	3%
Potentially Acid Forming (Low Capacity)	0 to 10	9	3%
Potentially Acid Forming	10 to 30	19	7%
Potentially Acid Forming (High Capacity)	> 30	19	7%

Table 4-3: Geochemical classifications for regolith and rock (calculated from CRS)

Geochemical Classification	$NAPP_{CRS}$ (kg H_2SO_4/t)	Regolith and rock samples samples (n=191)*	%
Acid Consuming (AC)	< -60	142	74%
Non-Acid Forming	-60 to -10	22	12%
Non-Acid Forming (Low Capacity)	-10 to 0	5	3%
Potentially Acid Forming (Low Capacity)	0 to 10	5	3%
Potentially Acid Forming	10 to 30	16	8%
Potentially Acid Forming (High Capacity)	> 30	1	<1%

*Samples include Batch 3 only

4.2 Static multi-element results

Static multi-element results for soil (n=12), rock (n=18), residue (n=5), and HPA residue (n=2) individual and composite samples for Batch 1 and Batch 2 are presented here and included as tables in **Section 10.1.2**.

- 0.45µm filtered multi-element results for the Batch 1 process water (RW01) and treated and untreated supernatant water (C101_SN and SW01) (**Table 10-4**,
- **Table** 10-6, and
-
-
- Table 10-8).
- Total (2-acid digest) results for soil, rock, residue, and HPA residue are in **Figure 4-18, Table 10-1** and **Table 10-2**.
- Water soluble shake flask extraction (SFE 16hr &1:3 ratio) results for unfiltered and filtered major element results for soil, rock, residue, and HPA residue are in **Figure 4-19** and **Table 10-3**.
- Water soluble shake flask extraction (SFE 16hr &1:3 ratio) results for unfiltered and filtered trace element results for soil, rock, residue, and HPA residue are in , **Table 10-5**, and
- **Table** 10-7.
- Mineralogical results from x-ray diffraction (XRD) for soil, rock, and residue are in **Figure 4-20**.

It is useful to compare the filtered and unfiltered water soluble SFE data to simulate water quality under different environmental conditions. For example, unfiltered results can be used to define concentrations of metal(loids) in surface runoff, during or immediately after a storm event when sediment is suspended in water.

Column settlement results (**Figure 4-33**) verify that the bedload and suspended sediment will settle within a few hours. The filtered (0.45 μm) results can then be used to verify the quality of clarified water after the sediment has settled.

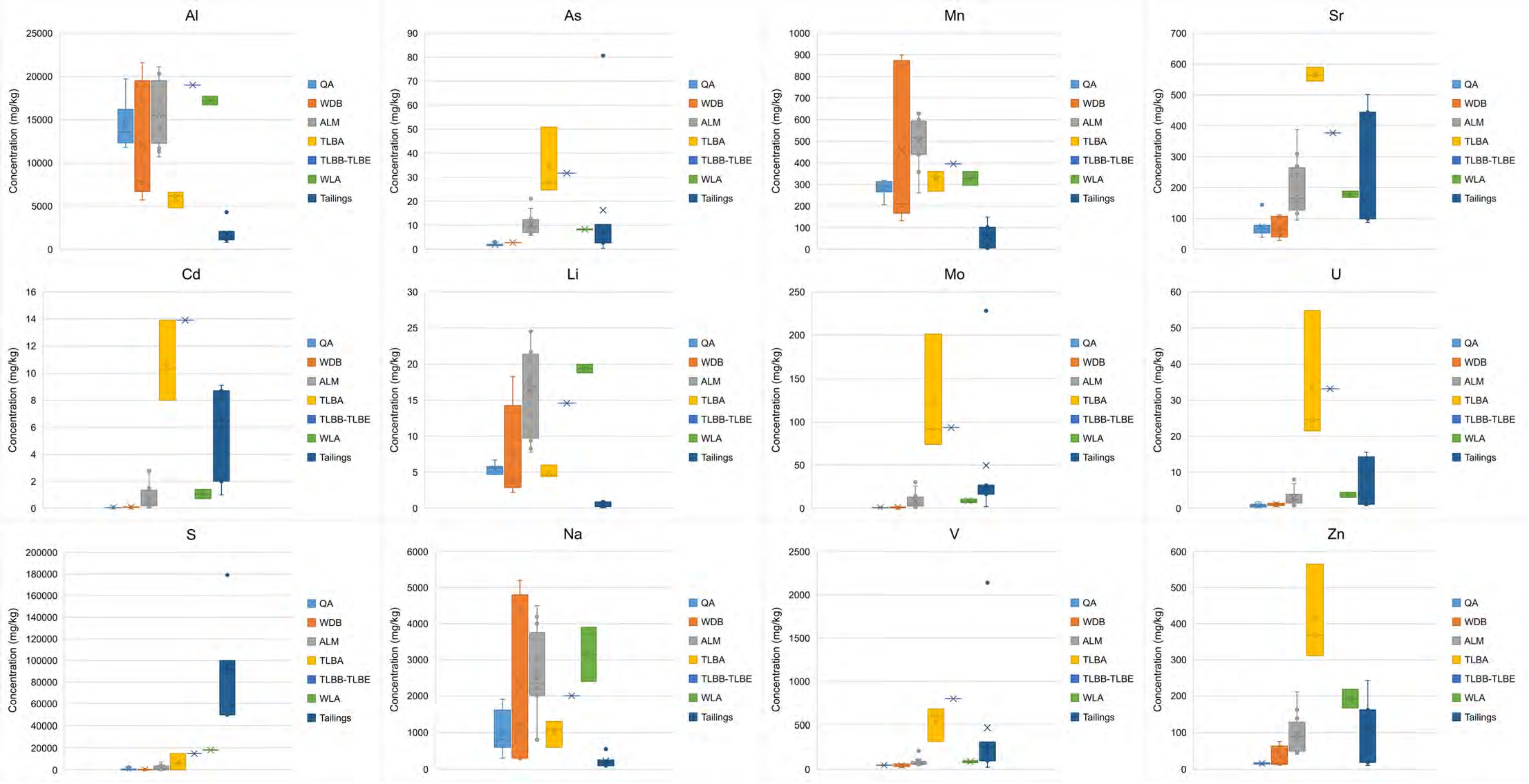


Figure 4-18: 2-acid aqua regia digest results for Soil, Alluvium, Allaru Mudstone, Limestone, Toolebuc TLBB-TLBE, Wallumbilla Formation and Residue

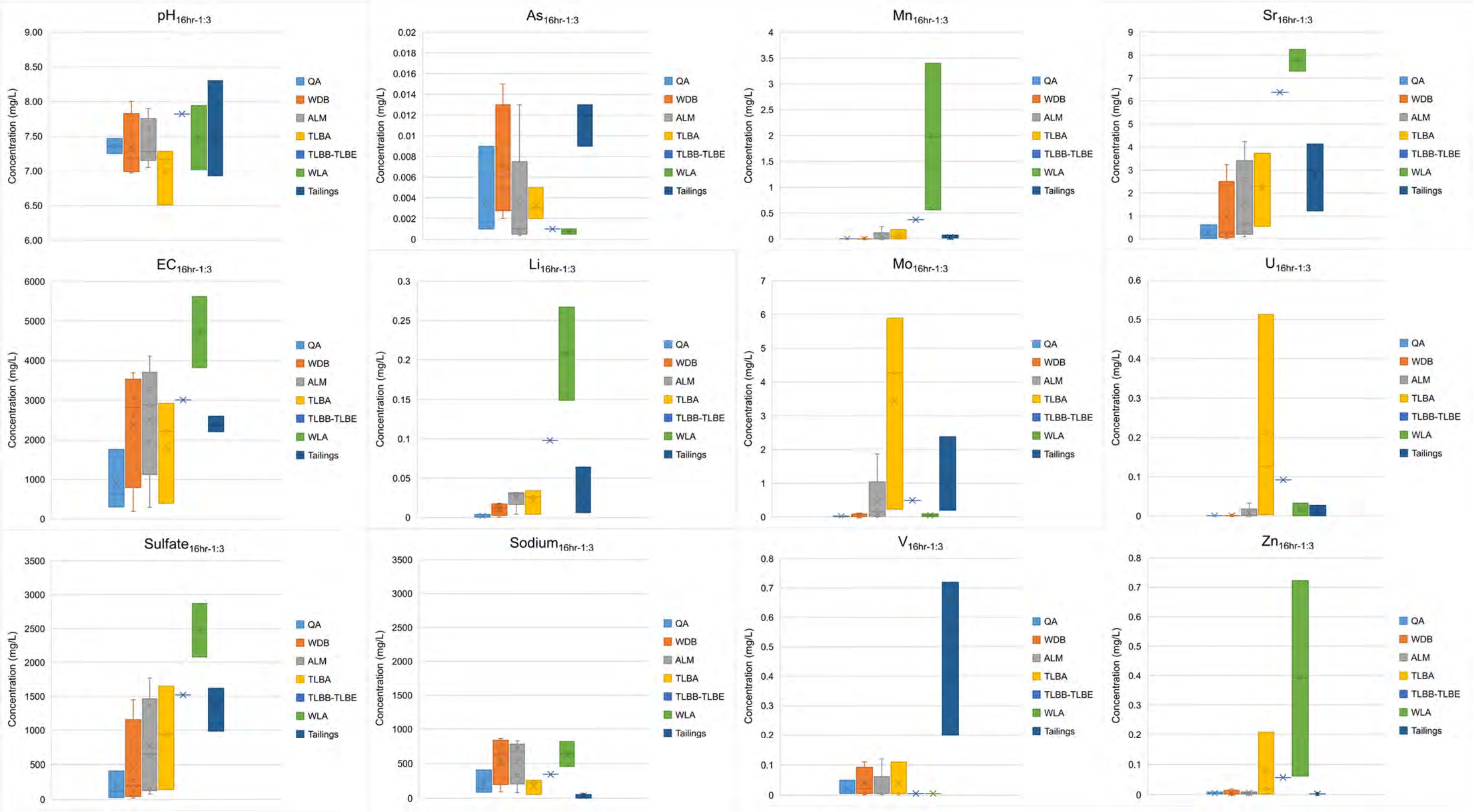


Figure 4-19: Water soluble SFE results for Soil, Alluvium, Allaru Mudstone, Limestone, Toolebuc TLBB-TLBE, Wallumbilla Formation and Residue

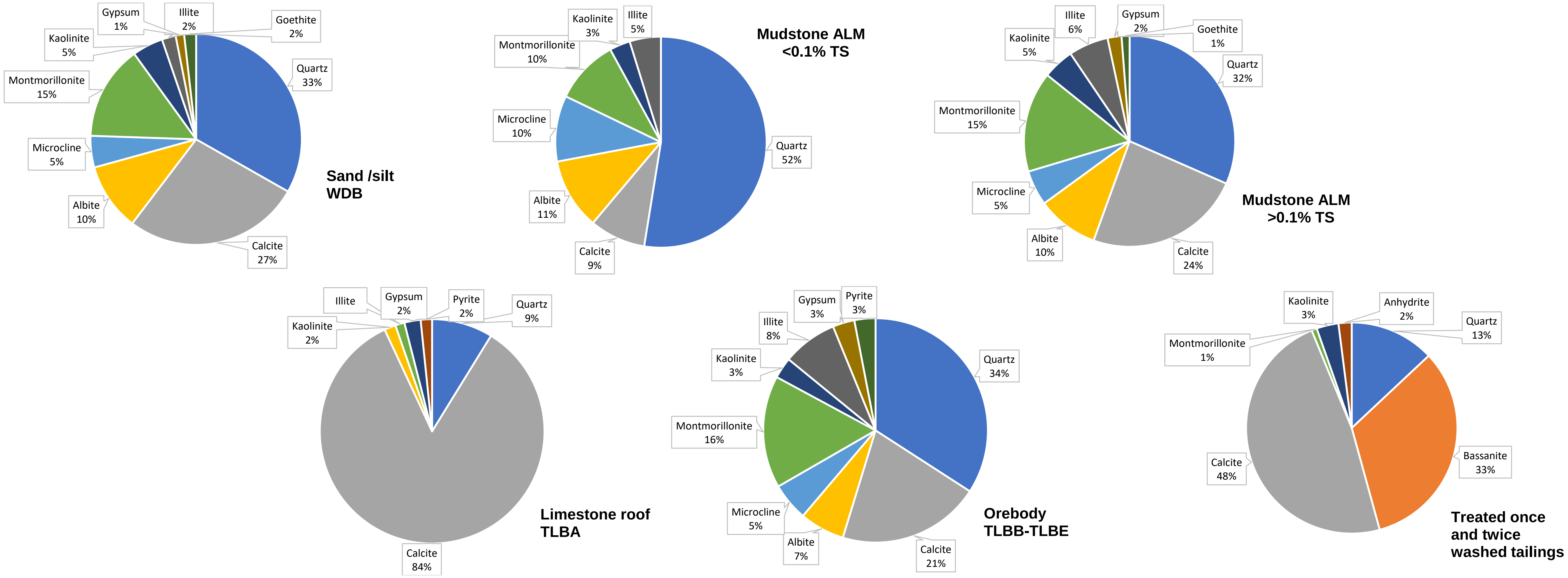


Figure 4-20: Mineralogical (XRD) results for soil, rock, and treated residue

4.3 Kinetic leach column (KLC) multi-element results

This section presents the data from the kinetic leach columns (KLC).

- KLC box plots provide the full range of results for each KLC sample (**Figure 4-21, Figure 4-22** and **Figure 4-23**).
- KLC concentration over time results are in **Figure 4-24**, **Figure 4-25** and **Figure 4-26**.

Interpretation of the KLC results is included in **Section 5**.

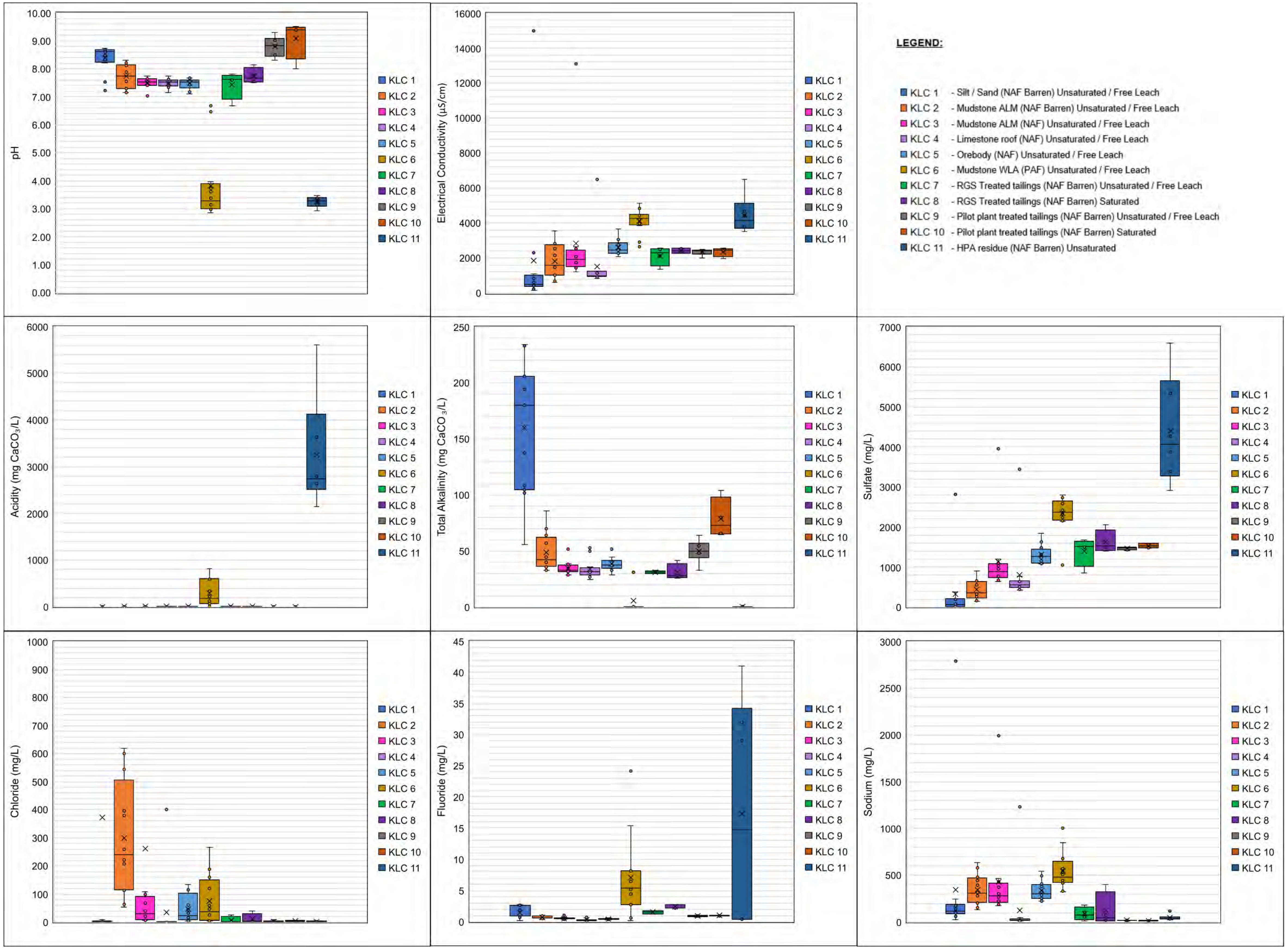


Figure 4-21: KLC box plots - pH, EC, acidity, alkalinity, major anions

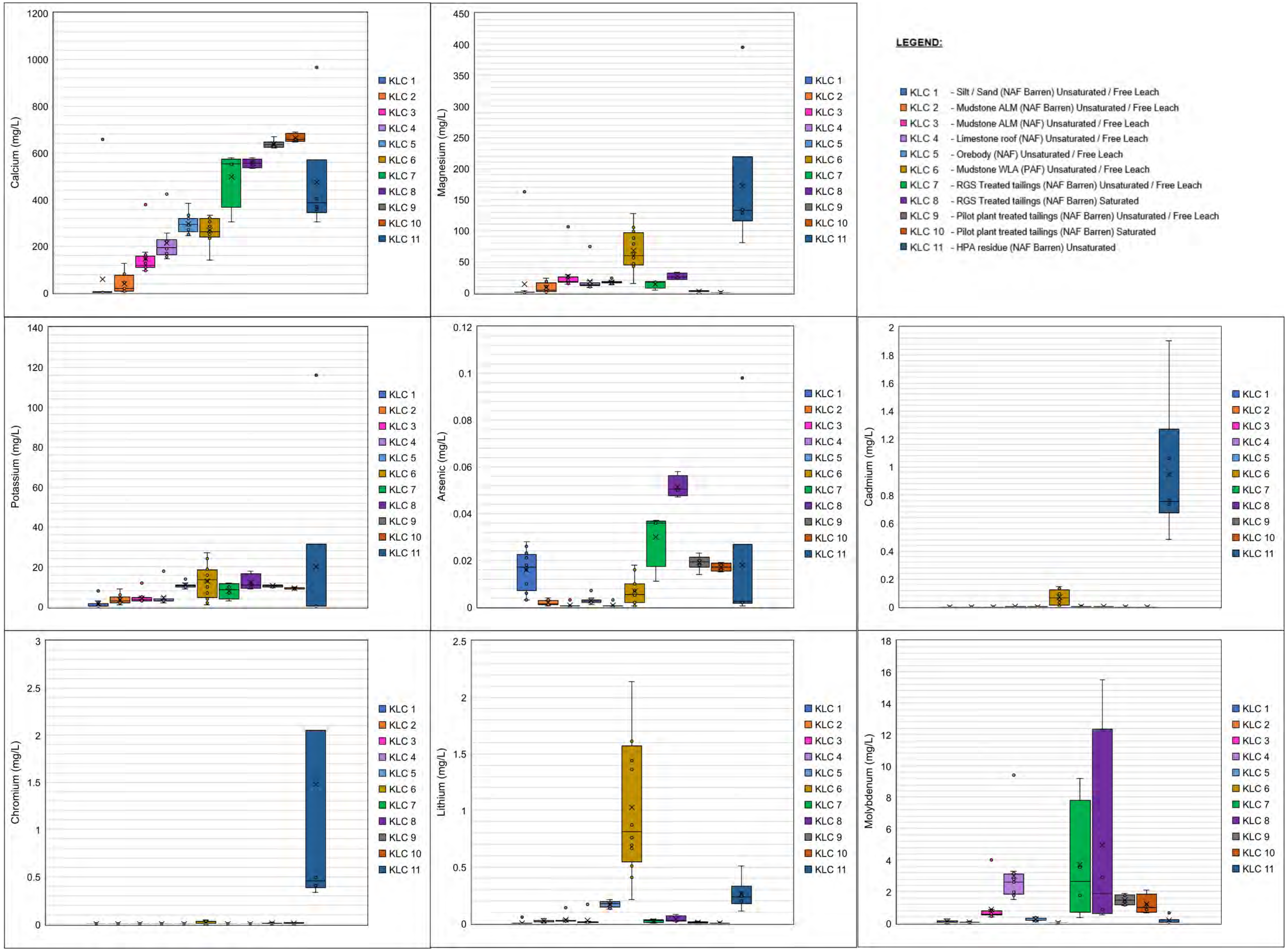


Figure 4-22: KLC box plots - major cations, selected trace elements (As, Cd, Cr, Li, Mo)

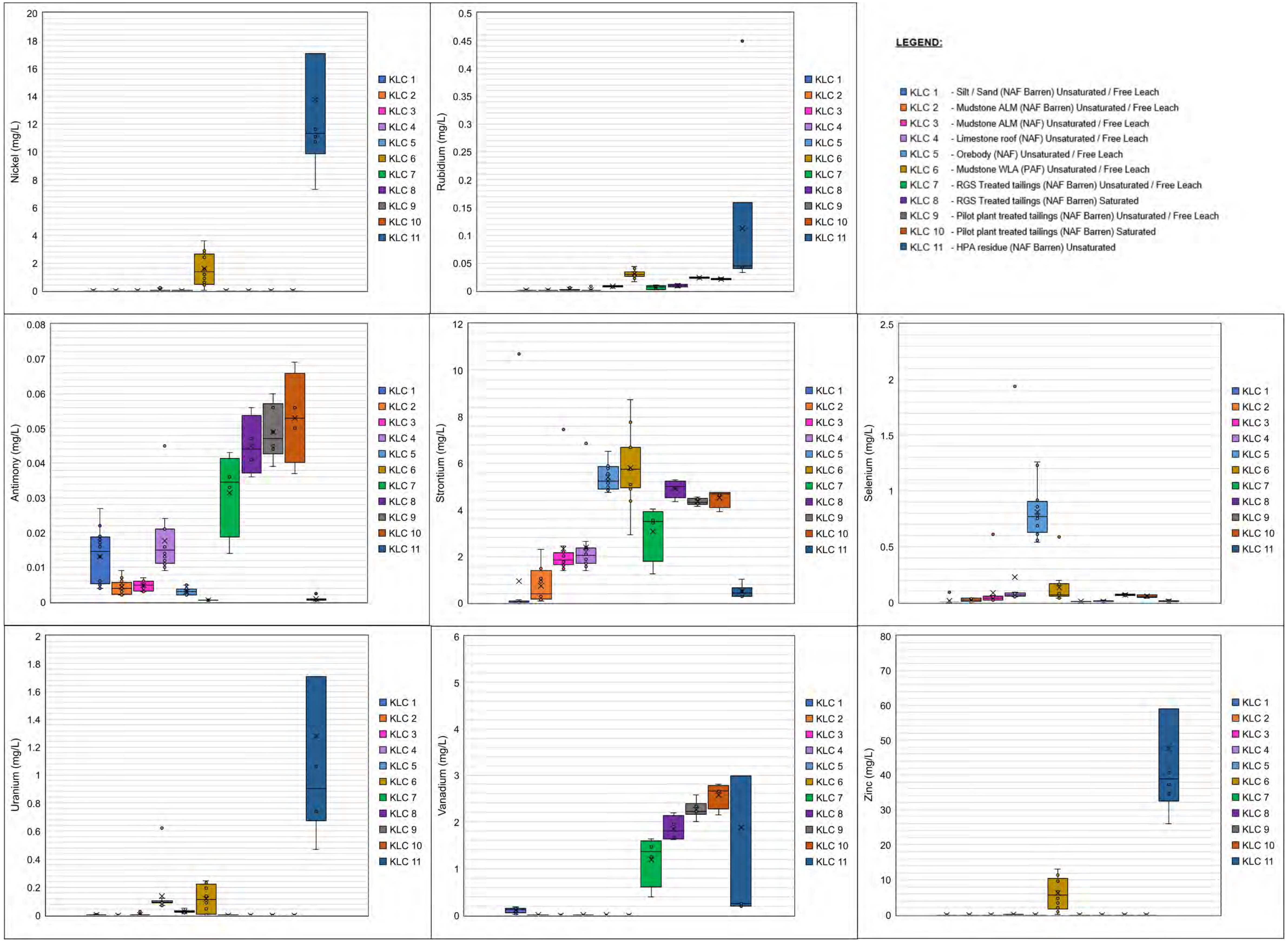


Figure 4-23: KLC box plots - selected trace elements (Ni, Rb, Sb, Se, Sr, U, V, Zn)

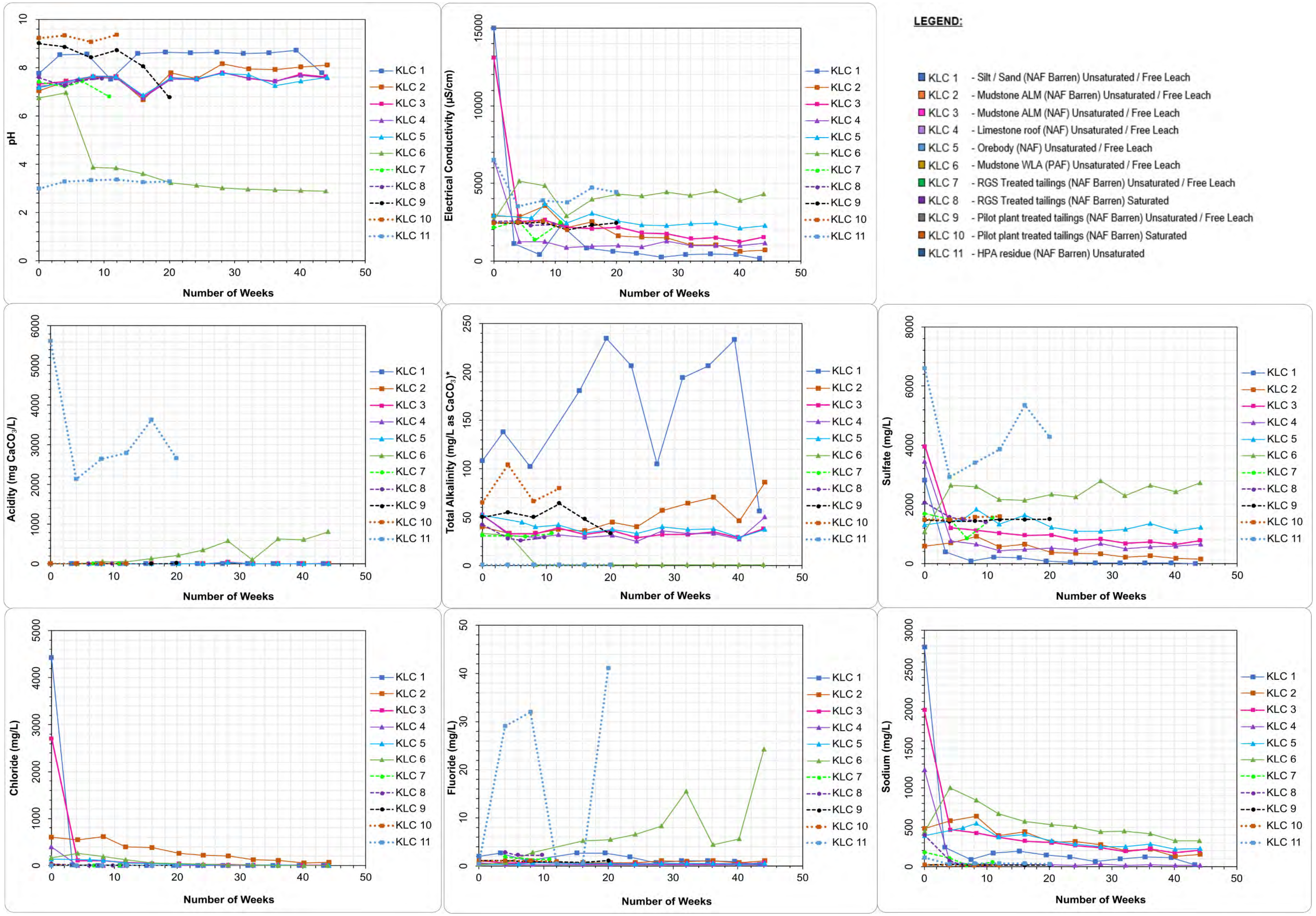


Figure 4-24: KLC concentrations over time for pH, EC, acidity, alkalinity, and major anions

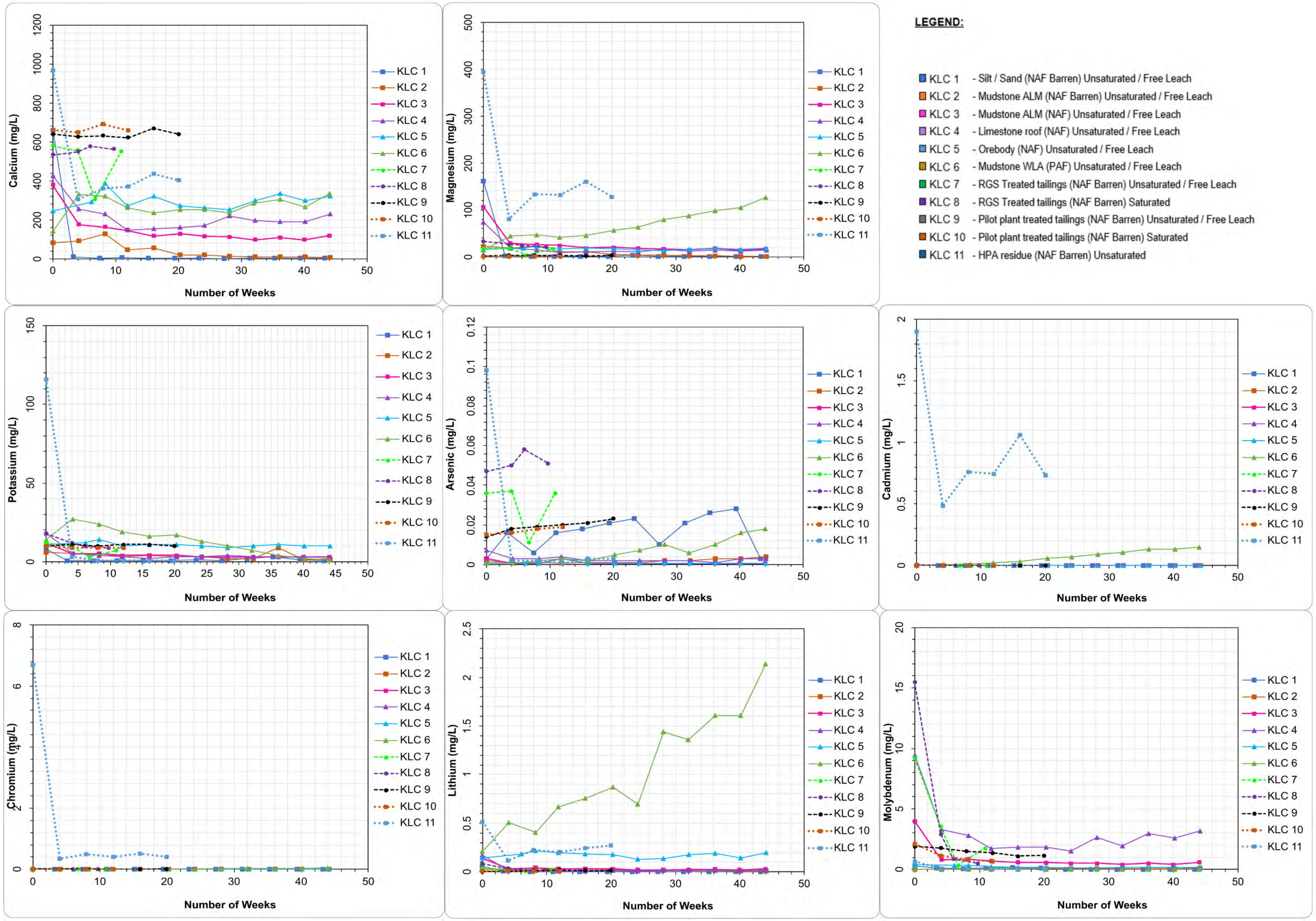


Figure 4-25: KLC concentrations over time for major cations and trace elements (As, Cd, Cr, Li, Mo)

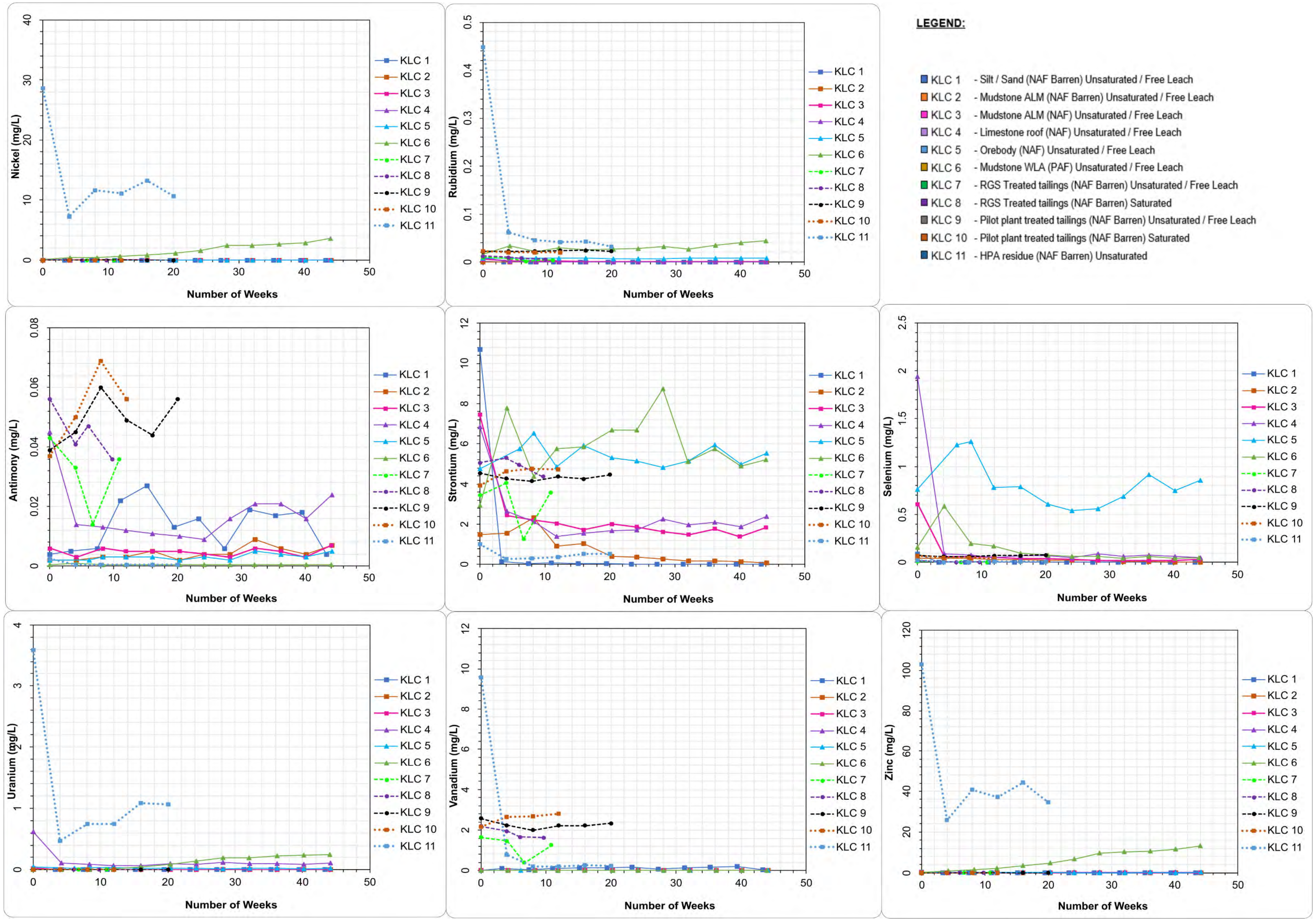


Figure 4-26: KLC concentrations over time for selected trace elements (Ni, Rb, Sb, Se, Sr, U, V, Zn)

4.4 Soil quality results

This section includes graphs and tables of Batch 1 and Batch 2 samples to summarise the geochemical and physical analyses that are relevant to a soil quality assessment.

- Soil moisture content results for Batch 1 are in **Table 4-4**.
- Emerson Class classifications for Batch 1 and Batch 2 samples are in **Table 4-5**.
- Soil salinity classifications for Batch 1 and Batch 2 samples are in **Figure 4-27** based on Regasamy (1984).

Summary tables for topsoil, subsoil, silt/sand, mudstone ALM, and limestone are in **Table 4-6** to **Table 4-8**.

Table 4-4: Soil moisture content for soil, rock, and residue – Batch 1

		Moisture Content (%)		
Composite number	**Lithological unit**	**ALS**	**Trilab**	**Median (%)**
C003	Topsoil	4.2	4.3	4.3
C004	Subsoil	4.1	5.2	4.7
C005	Subsoil /sand	5.3	5.7	5.5
		Median all soil		**4.7**
C006	Silt /sand	1.8	2	1.9
C007	Silt /sand	11	12.9	12
C008	Silt /sand	9.8	11.4	10.6
C009	Silt /sand	6.3	7.4	6.9
		Median all silt/sand		**8.8**
C010	Mudstone ALM	6.3	7.3	6.8
C011	Mudstone ALM	13	14.1	13.6
C012	Mudstone ALM	13.4	15.7	14.6
C013	Mudstone ALM	13.4	15.1	14.3
C014	Mudstone ALM	7.3	9	8.2
		Median all Mudstone ALM		**13.6**
C016	Limestone roof	2.8	2.7	2.8
C017	Limestone roof	3.8	4.5	4.2
		Median all limestone roof		**3.5**
C001	Once washed residue	17.6	---	17.6
C002	Twice washed residue	15.5	---	15.5
		Median all residue		**16.6**

Table 4-5: Emerson class classifications for soil and residue

Batch Number	1	2	2	2	2	2	2	2
Sample No.	C003	0001	0005	0010	0015	0020	0025	0030
Lithological unit	Topsoil	Topsoil	Topsoil	Topsoil	Topsoil	Topsoil	Topsoil	Topsoil
Description	Sandy CLAY - dark grey	Medium CLAY	Medium CLAY	Medium Heavy CLAY	Medium CLAY	Medium CLAY	Sandy Clay LOAM	Sandy Clay LOAM
Emerson Class Number	**4c**	**2**	**2**	**2**	**2**	**2**	**5**	**4**

Batch Number	2	2	2	2	2	1	2	2
Sample No.	0042	0047	0052	0057	0062	C004	0002	0006
Lithological unit	Topsoil	Topsoil	Topsoil	Topsoil	Topsoil	Subsoil	Subsoil	Subsoil
Description	Light Medium CLAY	Sandy Clay LOAM	Medium CLAY	Light Medium CLAY	Medium CLAY	Clayey SAND - pale brown	Medium CLAY	Medium CLAY

Emerson Class Number	**2**	**2**	**3**	**2**	**3**	**1**	**2**	**2**

Batch Number	2	2	2	2	2	2	2	2
Sample No.	0011	0016	0021	0026	0031	0043	0048	0053
Lithological unit	Subsoil	Subsoil	Subsoil	Subsoil	Subsoil	Subsoil	Subsoil	Subsoil
Description	Medium CLAY	Medium CLAY	Light Medium CLAY	Sandy Clay LOAM	Light Medium CLAY	Light CLAY	Sandy Clay LOAM	Light CLAY
Emerson Class Number	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**

Batch Number	2	2	1	1	1	1	1	1
Sample No.	0058	0063	C005	C006	C007	C008	C009	C010
Lithological unit	Subsoil	Subsoil	Subsoil /sand	Silt /sand	Silt /sand	Silt /sand	Silt /sand	Mudstone ALM
Description	Light Medium CLAY	Sandy Clay LOAM	Clayey SAND - pale brown	Clayey SAND - pale brown	Clayey SILT - pale brown	Clayey SILT - pale brown	Sandy CLAY - pale brown	Sandy Silty CLAY - pale brown
Emerson Class Number	**2**	**2**	**2**	**3**	**3**	**2**	**4c**	**4c**

Batch Number	1	1	1	1	1	1	1	1
Composite No.	C011	C012	C013	C014	C016	C017	C001	C002
Lithological unit	Mudstone ALM	Mudstone ALM	Mudstone ALM	Mudstone ALM	Mudstone ALM	Mudstone ALM	Once washed residue	Twice washed residue
Description	Silty CLAY - brown	Clayey SILT - brown	Clayey SILT - brown	Clayey SILT - grey	Silt - grey	Silt - grey	Dark Greyish Brown LOAM	Dark Greyish Brown LOAM
Emerson Class Number	1	**1**	**2**	**4c**	**4c**	**4c**	**2**	**2**

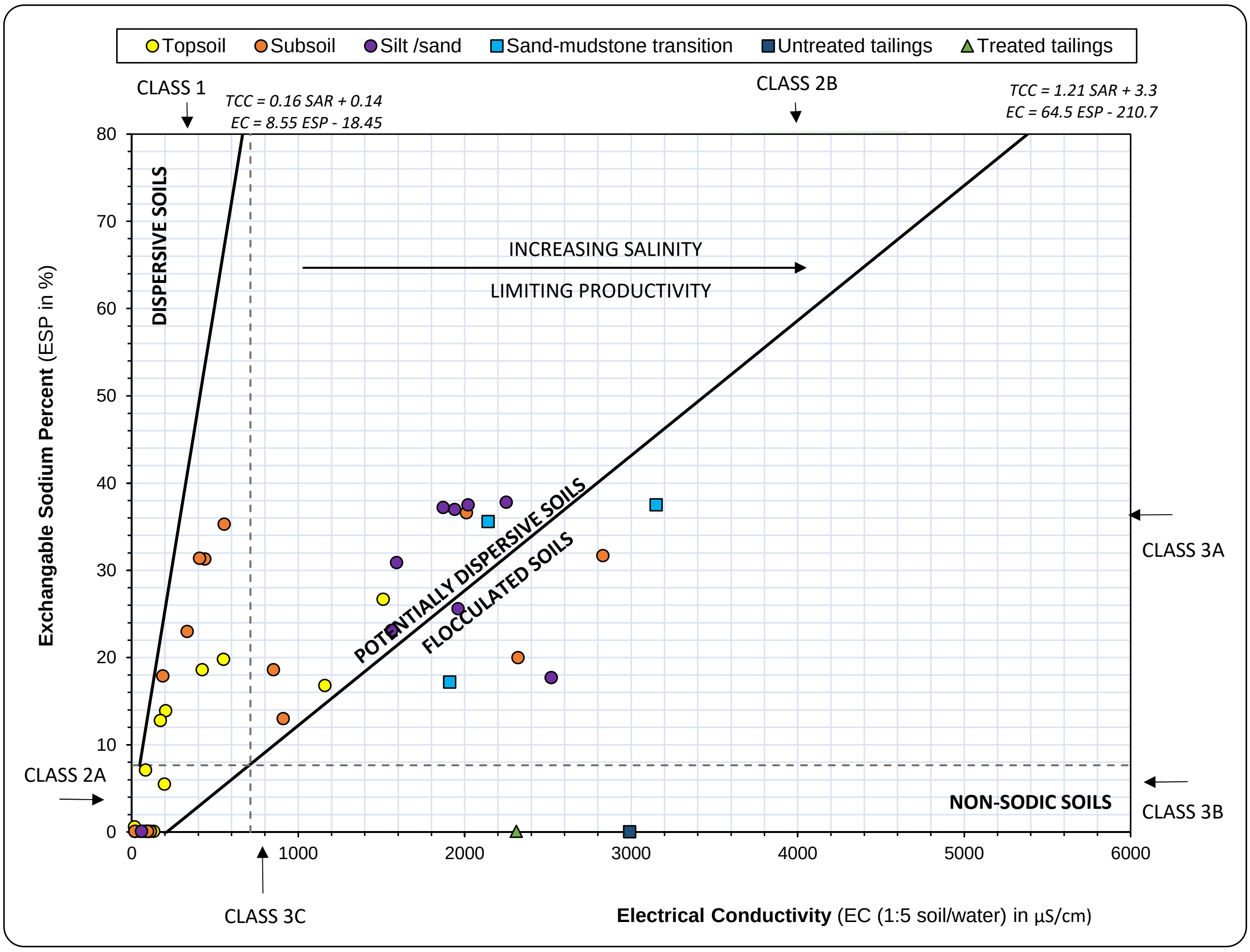


Figure 4-27: Soil salinity classifications based on Rengasamy (1984)

Table 4-6: Summary table of Batch 1 and Batch 2 topsoil and subsoil results

	TOPSOIL			SUBSOIL		
Selected parameter	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**
pH$_{1:5}$	6.6	8.3	9.5	7.6	8.7	9.6
EC$_{1:5}$ (mS/cm)	17	132	1510	18	407	2830
Cation exchange capacity (CEC) (meq/100g)	3.9	6.8	22.7	4.2	11.6	27.1
Exchangeable Sodium Percent (ESP, %)	<0.2	5.5	26.7	<0.2	18.3	36.6
Organic matter	<0.5	<0.5	0.9	<0.5	<0.5	0.5
Total N (%)	80	120	250	<20	60	110
Total P (%)	40	49	52	26	44	90
Plant-available P (%)	<5	<5	12	<5	<5	<5
Plant-available K (%)	<100	<100	181	<100	<100	106
Soil moisture (%)	4.1	4.9	5.6	4.1	6.5	8.0
Salinity classification	2A	2A	2B	2A	2B	3A
Chloride (mg/kg)	<10	10	540	<10	120	1540
Emerson Class	2	2	5	2	2	4
Soil texture (< 2 mm PSD)	Clay	Clay	Sandy clay loam	Clay	Sandy clay loam	Loam
Particle size distribution (< 75 mm) (%)						
- Gravel	---	3	---	1	2	2
- Sand	---	43	---	48	51	53
- Silt	---	21	---	15	18	21
- Clay	---	31	---	30	30	30
Atterberg limits - Plasticity Index (%	---	25	---	27	28	28
Particle density (g/cm^3)	---	2.51	---	2.56	2.59	2.61
Maximum dry density (t/m^3)	---	1.7	---	---	1.7	---
Permeability (<20 mm)						
- ksat 95%	---	3.5 x 10^{-9}	---	---	3.5 x 10^{-9}	---
- ksat 90%	---	6.6 x 10^{-9}	---	---	6.6 x 10^{-9}	---
Volumetric moisture content (cm^3/cm^3)						
- 0 kPa	---	41.73	---	---	42.13	---
- 10 kPa	---	32.42	---	---	33.34	---
- 33 kPa	---	28.42	---	---	26.63	---
- 100 kPa	---	22.12	---	---	19.47	---
- 1,500 kPa	---	15.01	---	---	12.45	---
Derived van Genuchten parameters						
- a (1/cm)	---	0.360	---	---	0.015	---
- N (-)	---	1.149	---	---	1.378	---
- qs (cm^3/cm^3)	---	0.481	---	---	0.421	---
- qr (cm^3/cm^3)	---	0.000	---	---	0.080	---

Table 4-7: Summary table of Batch 1 and Batch 2 silt/sand and Mudstone ALM results

	SILT/SAND			MUDSTONE ALM		
Selected parameter	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**
$pH_{1:5}$	8.2	9.2	9.9	8.0	8.9	9.7
$EC_{1:5}$ (µS/cm)	59	602	3380	168	1770	3310
Cation exchange capacity (CEC) (meq/100g)	8.0	26.8	57.8	---	28.9	---
Exchangeable Sodium Percent (ESP, %)	17.2	34.0	37.8	---	35.6	---
Organic matter	<0.5	<0.5	<0.5	---	<0.5	---
Total N (%)	30	170	310	---	250	---
Total P (%)	54	353	486	---	442	---
Plant-available P (%)	6	6	6	---	6	---
Plant-available K (%)	102	144	152	---	222	---
Soil moisture (%)	2.1	10.5	15.3	4.7	9.2	12.2
Salinity classification	2B	2B	3A	---	---	---
Chloride (mg/kg)	30	2420	2990	---	2230	---
Emerson Class	2	2	4	---	2	---
Soil texture (< 2 mm PSD)	Clay loam	Silty clay loam	Sandy loam	Silty clay	Clay loam	Sandy clay loam
Particle size distribution (< 75 mm) (%)						
- Gravel	0	2	5	0	0	3
- Sand	19	34	77	7	13	48
- Silt	9	36	44	26	39	42
- Clay	9	30	37	23	48	53
Atterberg limits - Plasticity Index (%	15	25	27	14	37	48
Particle density (g/cm^3)	---	2.51	---	---	2.51	---
Maximum dry density (t/m^3)	---	1.7	---	---	1.7	---
Permeability (<20 mm)						
- ksat 95%	---	3.5×10^{-9}	---	---	3.5×10^{-9}	---
- ksat 90%	---	6.6×10^{-9}	---	---	6.6×10^{-9}	---
Volumetric moisture content (cm^3/cm^3)						
- 0 kPa	31.56	39.67	43.57	31.66	40.53	41.89
- 10 kPa	26.30	28.45	31.25	29.67	31.82	31.18
- 33 kPa	19.36	24.54	25.29	26.49	26.62	28.17
- 100 kPa	12.51	21.96	18.67	19.65	18.80	24.56
- 1,500 kPa	6.35	15.17	7.69	8.75	10.35	16.68
Derived van Genuchten parameters						
- a (1/cm)	0.008	0.136	0.024	0.003	0.018	0.083
- N (-)	1.534	1.124	1.275	1.382	1.255	1.125
- qs (cm^3/cm^3)	0.315	0.397	0.434	0.316	0.405	0.419
- qr (cm^3/cm^3)	0.042	0.000	0.000	0.022	0.006	0.000

Table 4-8: Summary table of Batch 1 limestone roof results

	LIMESTONE ROOF		
Selected parameter	**Min**	**Median**	**Max**
$pH_{1:5}$	8.1	8.5	9.2
$EC_{1:5}$ (µS/cm)	178	1000	3840
Cation exchange capacity (CEC) (meq/100g)	---	---	---
Exchangeable Sodium Percent (ESP, %)	---	---	---
Organic matter	---	---	---
Total N (%)	---	---	---
Total P (%)	---	---	---
Plant-available P (%)	---	---	---
Plant-available K (%)	---	---	---
Soil moisture (%)	2.8	5.8	8.9
Salinity classification	---	---	---
Chloride (mg/kg)	---	---	---
Emerson Class	4c	4c	4c
Soil texture (< 2 mm PSD)	Sandy loam	Sandy loam	Sandy loam
Particle size distribution (< 75 mm) (%)			
- Gravel	4	9	13
- Sand	46	52	57
- Silt	31	32	32
- Clay	7	9	10
Atterberg limits - Plasticity Index (%	11	11	11
Particle density (g/cm^3)	---	2.51	---
Maximum dry density (t/m^3)	---	1.7	---
Permeability (<20 mm)			
- ksat 95%	---	3.5×10^{-9}	---
- ksat 90%	---	6.6×10^{-9}	---
Volumetric moisture content (cm^3/cm^3)			
- 0 kPa	42.14	42.46	42.79
- 10 kPa	35.33	31.29	27.25
- 33 kPa	31.06	26.29	21.51
- 100 kPa	20.45	18.54	16.63
- 1,500 kPa	5.38	8.67	11.96
Derived van Genuchten parameters			
- a (1/cm)	0.018	0.033	0.048
- N (-)	1.305	1.336	1.368
- qs (cm^3/cm^3)	0.4219	0.425	0.4280
- qr (cm^3/cm^3)	0.1111	0.100	0.0884

4.5 Physical results

This section includes graphs and tables to present the physical analysis of the soil, rock, residue and HPA residue samples.

- Particle size distribution is in **Figure 4-28** and **Table 4-9**.
- Soil texture classification is in **Figure 4-29** and **Table 4-10**.
- Atterberg limits are in **Figure 4-30, Table 4-11,** and **Table 4-12**.
- Permeability measurements are in **Table 4-13**.
- Pinhole dispersion and shrink swell index are in **Table 4-14** and **Table 4-15**.
- California bearing ratio (CBR) results are in **Table 4-16**.
- Column settlement results are in **Table 4-17**, **Figure 4-31**, **Figure 4-32**, and **Figure 4-33**
- Soil water characteristic curve results with derived van Genuchten parameters are in **Table 4-18**.

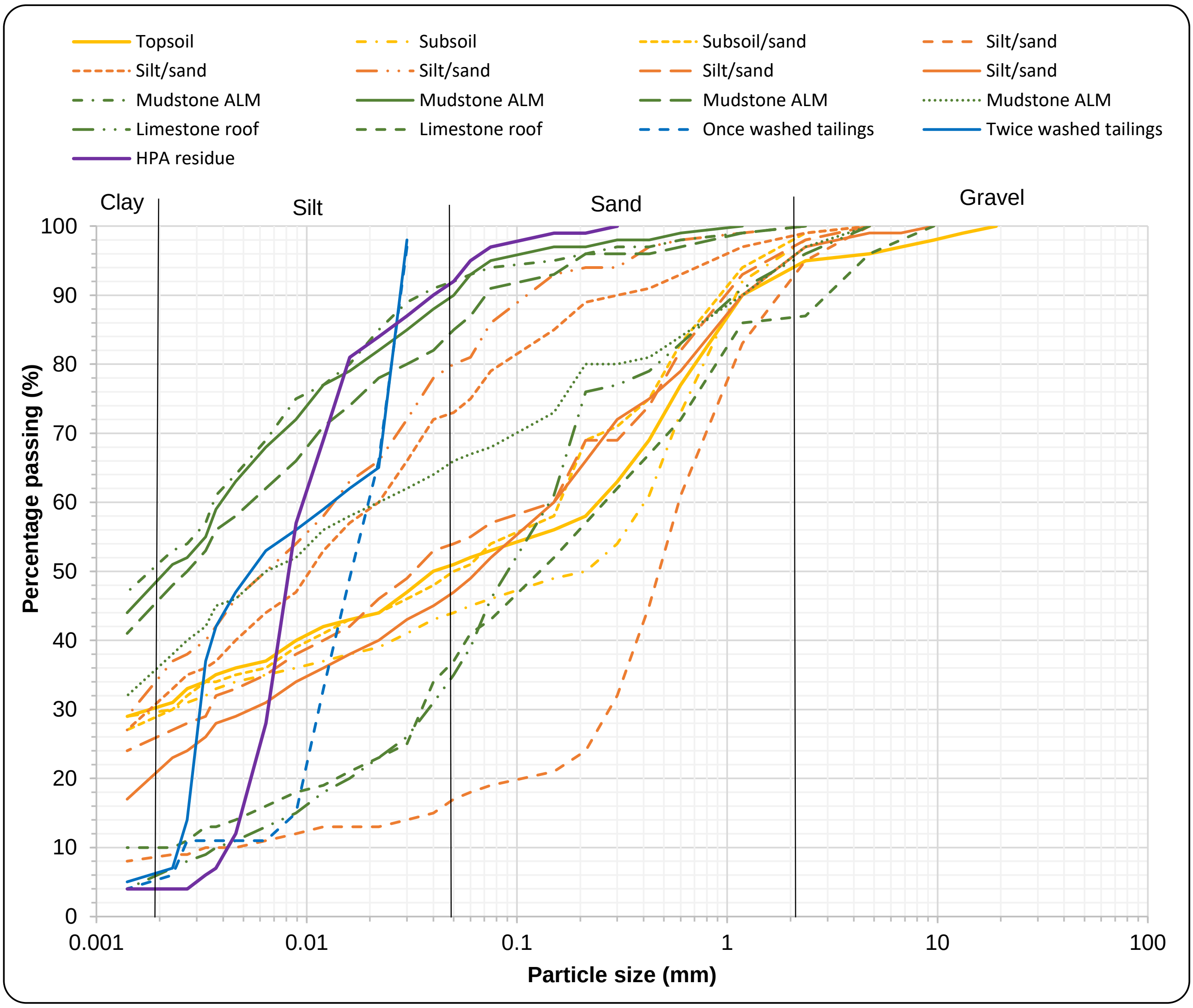


Figure 4-28: Particle size distribution of soil, rock, residue, and HPA residue samples

Table 4-9: Particle size distribution summary

Lithological unit	Clay (<0.04 mm)	Silt (0.004 – 0.062 mm)	Sand (0.062 – 2.0 mm)	Gravel (> 2.0 mm)
Soil	30 – 31%	15 – 21%	43 – 53%	1 - 5%
Silt /sand	9 – 37%	9 – 44%	19 – 77%	0 – 5%
Mudstone ALM	23 – 53%	26 – 42%	7 – 48%	0 – 3%
Limestone roof	7 – 10%	31 – 32%	46 – 57%	4 – 13%
Untreated residue	6 – 7%	93 – 94%	0%	0%
HPA residue	4%	92%	4%	0%

Additional particle size distribution graphs sorted by lithology are in **Section 10 (Attachment B)**.

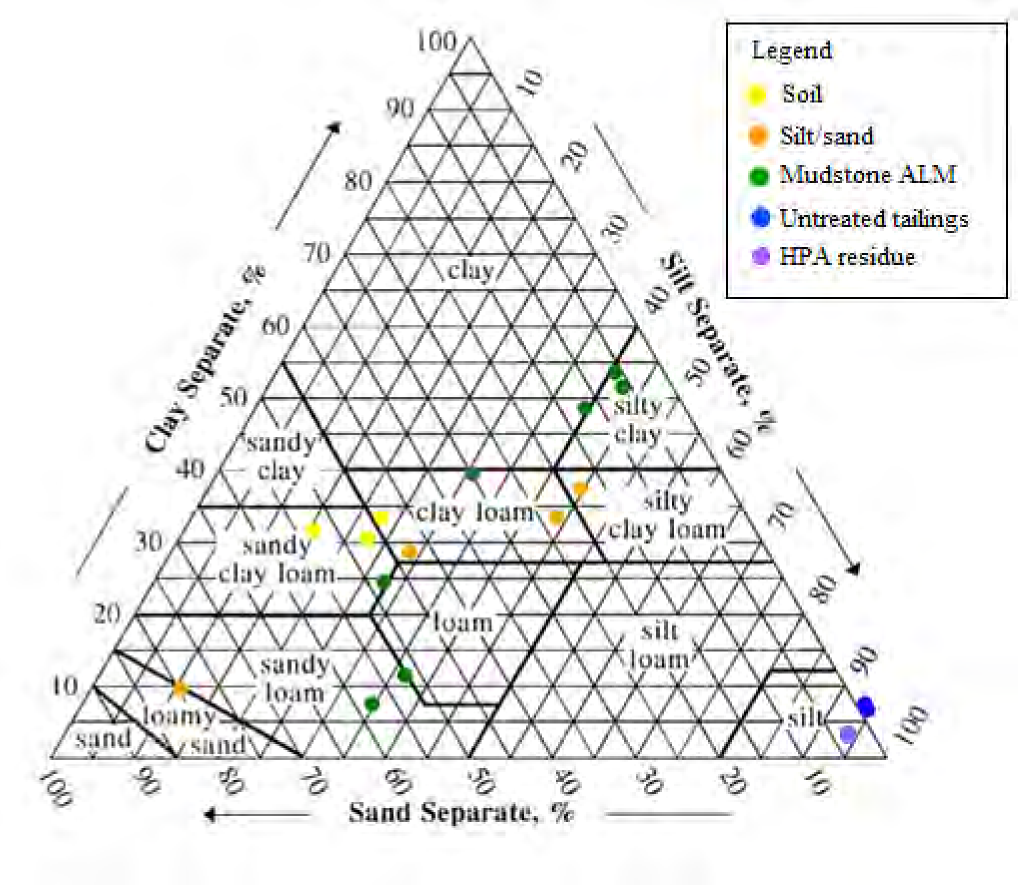


Figure 4-29: Soil texture triangle classification for particles <2.36 mm (excluding gravel)

Table 4-10: Soil texture classification summary

	Soil Texture	
Lithological unit	**Fine**	**Coarse**
Soil	Clay loam	Sandy clay loam
Silt /sand	Silty clay loam	Loamy sand
Mudstone ALM	Silty clay	Sandy clay loam
Limestone roof	Sandy loam	Loam
Untreated residue	Silt	Silt
HPA residue	Silt	Silt

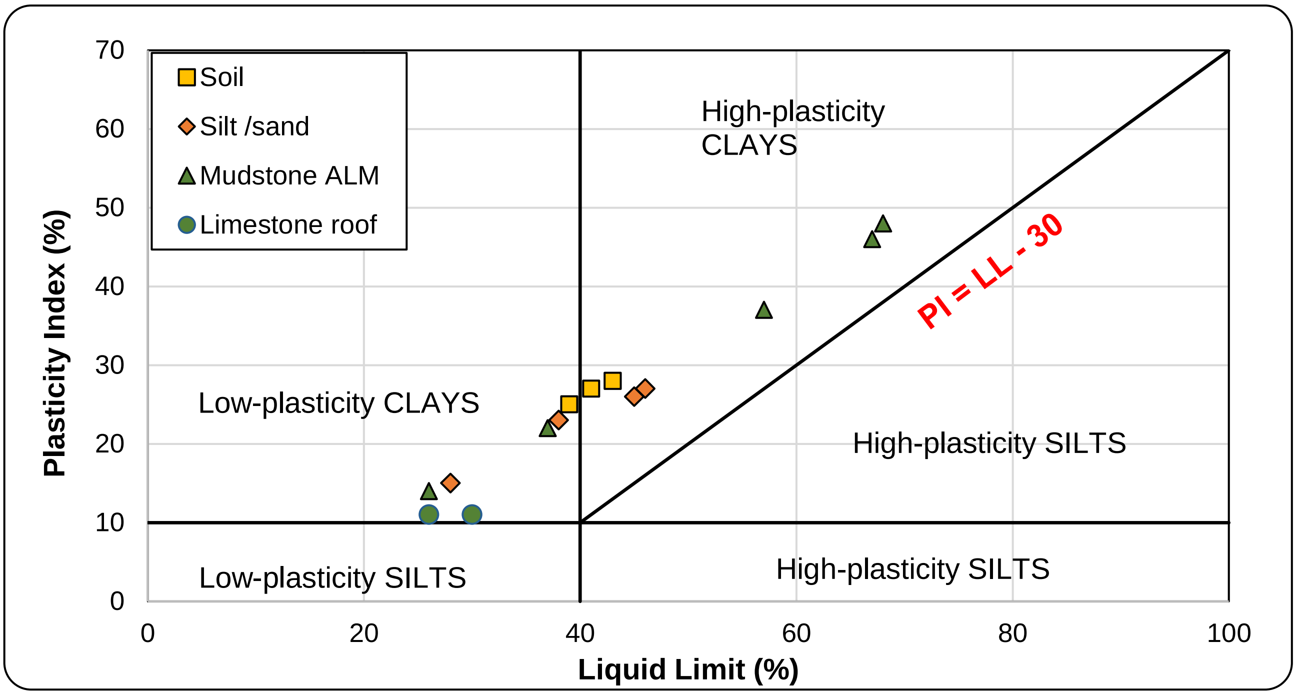


Figure 4-30: AASHTO soil classifications for soil and rock samples

Table 4-11: Atterberg limits for topsoil, subsoil, and silt/sand samples

	C003	C004	C005	C006	C007	C008	C009
Parameter	Topsoil	Subsoil	Subsoil /sand	Silt /sand	Silt /sand	Silt /sand	Silt /sand
Liquid Limit (%)	39	41	43	28	45	46	38
Plastic Limit (%)	14	14	15	13	19	19	15
Plasticity Index (%)	25	27	28	15	26	27	23
Linear Shrinkage (%)	15	14	15	6	12	12	12

Table 4-12: Atterberg limits for Mudstone ALM and limestone roof

	C010	C011	C012	C013	C014	C016	C017
Parameter	Mudstone ALM	Mudstone ALM	Mudstone ALM	Mudstone ALM	Mudstone ALM	Limestone roof	Limestone roof
Liquid Limit (%)	26	68	67	57	37	26	30
Plastic Limit (%)	12	21	21	20	15	15	19
Plasticity Index (%)	14	48	46	37	22	11	11
Linear Shrinkage (%)	6.5	18	18	15.5	11	6	5

Table 4-13: Falling head permeability results for loose as-placed end tipped strata at 90% Proctor and moderate to heavy compaction at 95% Proctor

		kSat 90% (cm/yr)	kSat 95% (cm/yr)
C021	Soil /rock composite	21	11
C013	Mudstone ALM	31	2
C014	Mudstone ALM	29	5
C015	Limestone roof	117	41
C016	Limestone roof	41	4
C017	Limestone roof	38	27

Table 4-14: Pinhole dispersion classification

		Pinhole dispersion classification	Description
C021	Soil /rock composite	ND1	Non-dispersive

Table 4-15: Shrink swell index (Iss) results

		Swell (%)	Shrinkage (%)	Shrink Swell Index (Iss) (%)
C021	Soil /rock composite	3.4	1.9	2.0

Table 4-16: California Bearing Ratio (CBR) compaction results for soil / regolith compsoite

		Max Force	Max Penetration	CBR Penetration	CBR Value	Equivalent to	Comments
Sample	Material	(kN)	(mm)	(mm)	(%)		
C021	Soil / regolith composite	0.36	12.5	5.0	1.5	Clay	Low

Table 4-17: Column settlement results

	C003	C004	C005	C006	C007
Duration	Topsoil	Subsoil	Subsoil /sand	Sand	Silt /sand
0 Hours	E	E	E	E	E
1 Hour	H	M	M	M	M
3 Hours	H	M	M	M	M
7 Hours	H	S	S	S	S
24 Hours	M	N	N	N	N
48 Hours	S	N	N	N	N
Hours to settle	**48+**	**24**	**24**	**24**	**24**

Turbidity: E = Extreme, H = High, M = Moderate, S = Slight, N = Negligible

	C008	C009	C010	C011	C012
Duration	Silt /sand	Sand /mudstone	Mudstone ALM	Mudstone ALM	Mudstone ALM
0 Hours	E	E	E	E	E
1 Hour	S	S	S	S	S
3 Hours	S	S	S	S	S
7 Hours	N	N	N	N	N
24 Hours	N	N	N	N	N
48 Hours	N	N	N	N	N
Hours to settle	**7**	**7**	**7**	**7**	**7**

Turbidity: E = Extreme, H = High, M = Moderate, S = Slight, N = Negligible

	C013	C014	C016	C017	C018
Duration	Mudstone ALM	Mudstone ALM	Limestone roof	Limestone roof	Orebody
0 Hours	E	E	E	E	E
1 Hour	M	M	M	M	H
3 Hours	M	M	M	M	M
7 Hours	N	N	N	M	S
24 Hours	N	N	N	N	N
48 Hours	N	N	N	N	N
Hours to settle	**7**	**7**	**7**	**24**	**24**

Turbidity: E = Extreme, H = High, M = Moderate, S = Slight, N = Negligible

Figure 4-31: Column settlement results (0 - 2 hours)

Figure 4-32: Column settlement results (3 - 5 hours)

Figure 4-33: Column settlement results (7 - 48 hours)

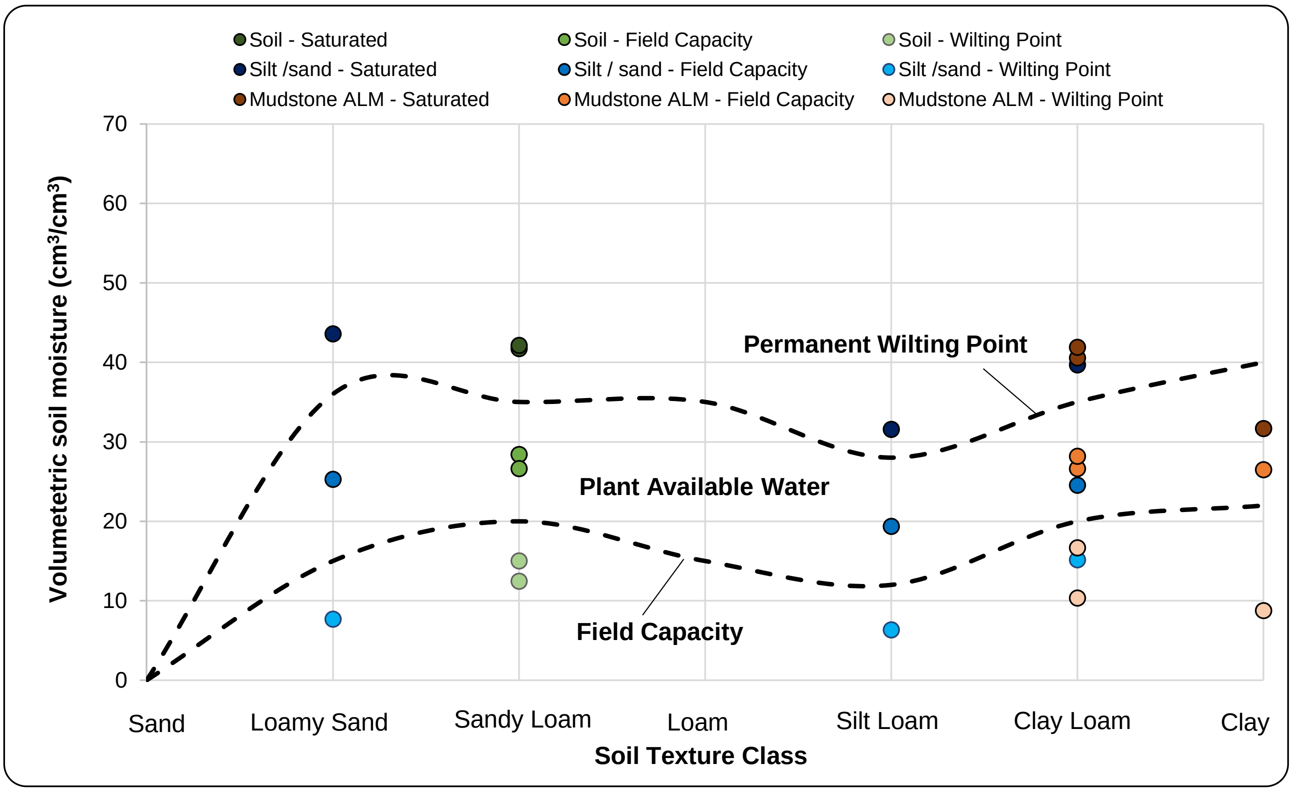


Figure 4-34: Relationship between soil texture class and plant available water for upper units

Figure 4-35: Relationship between soil texture class and plant available water for deeper units

Table 4-18: Soil water characteristic curve results with derived van Genuchten parameters

Comp #	Litho-logical unit	Soil texture classification	Volumetric Moisture Content (cm^3/cm^3)					Derived van Genuchten Parameters			
			0 kPa	10 kPa	33 kPa	100 kPa	1,500 kPa	a (1 /cm)	N (-)	qs (cm^3/cm^3)	qr (cm^3/cm^3)
C003	Topsoil	Sandy Loam	41.7	32.4	28.4	22.1	15.0	0.360	1.149	0.48	0.00
C004	Subsoil	Sandy Loam	42.1	33.3	26.6	19.5	12.5	0.015	1.378	0.42	0.08
C006	Silt /sand	Loamy Sand	43.6	31.3	25.3	18.7	7.7	0.024	1.275	0.43	0.00
C007	Silt /sand	Silt Loam	31.6	26.3	19.4	12.5	6.4	0.008	1.534	0.31	0.04
C009	Silt /sand	Clay Loam	39.7	28.4	24.5	22.0	15.2	0.136	1.124	0.40	0.00
C010	Mudstone ALM	Clay Loam	40.5	31.8	26.6	18.8	10.4	0.018	1.255	0.40	0.01
C012	Mudstone ALM	Clay	31.7	29.7	26.5	19.7	8.8	0.003	1.382	0.32	0.02
C014	Mudstone ALM	Clay Loam	41.9	31.2	28.2	24.6	16.7	0.083	1.125	0.42	0.00
C015	Limestone roof	Sandy Loam	42.1	35.3	31.1	20.5	5.4	0.018	1.305	0.42	0.11
C017	Limestone roof	Sandy Loam	42.8	27.3	21.5	16.6	12.0	0.048	1.368	0.43	0.09
C018	Orebody	Clay	41.7	32.3	28.0	24.2	14.6	0.037	1.160	0.42	0.00
C019	Mudstone Floor WLA	Clay Loam	42.1	32.7	26.2	21.6	17.9	0.019	1.533	0.42	0.17
C101	Treated residue	Silt Loam	0.45	0.37	0.33	0.29	0.26	0.027	1.414	0.45	0.24

5 Interpretation

5.1 Acid base accounting

5.1.1 Maximum potential acidity

Maximum potential acidity (MPA) includes total actual acidity (TAA) + potential acidity (PA).

5.1.1.1 Total actual acidity

Actual acidity can be divided into **soluble acidity** and **retained acidity**.

- Soluble acidity is defined as acidity measured using a 1:5 (soil:water) extract.
- Retained acidity is defined as the acidity that is not recorded in such an extraction however, there is no clear-cut distinction between soluble acidity and retained acidity because part of the retained forms of acidity can be released during successive extractions with water.

Soluble acidity can be subdivided into **active soluble acidity** and **buffered acidity**.

- Active soluble acidity accounts for the activity of hydrogen ions (H^+) (pH).
- Buffered soluble acidity accounts for other soluble acidic cations (mainly Fe^{2+}, $AlSO_4^+$ and Al^{3+}) that can produce hydrogen ions when they hydrolyse[1].

Retained acidity can be sub-divided into **(a) exchangeable acidity, (b) acidity carried by protonated variably charged particles, such as clays, and (c) acidity carried by basic sulfate minerals.**

These retained forms of acidity are temporarily immobilised by soils and are subject to re-mobilisation if geochemical conditions change, e.g. during liming, or re-flooding with brackish tidal water.

Exchangeable acidity is acidity that is retained through cation exchange reactions[1]. An example of exchangeable acidity is found in the sulfate mineral Jarosite; One mole of jarosite carries three moles of acidity that can be released by hydrolysis: $KFe_3(OH)_6(SO_4)_2 + 3OH^- \text{-->} 3Fe(OH)_3 + 2SO_4^{2-} + K^+$

Acidity that is buffered through protonation of variably charged particles can be released through their de-protonation, e.g.: $[Al(OH)]SO_4 + 2OH^- \text{-->} Al(OH)_3 + SO_4^{2-}$

Table 5-1 lists terms that can be used to define pH.

Table 5-1: pH concentrations and terms used to describe pH

pH	Term
< 2	Very strongly acid
2 to 3	Strongly acid
3 to 4	Moderately acid
4 to 5.5	Mildly acid
5.5 to 7.5	Circum-neutral
7.5 to 8.5	Mildly alkaline
8.5 to 9.5	Moderately alkaline
9.5 to 10.5	Strongly alkaline
> 10.5	Caustic

5.1.1.2 Potential acidity

Total sulfur (**TS**) is measured by combustion of the sample in a furnace at 1,350ºC in the presence of strong oxidants/catalysts. This method measures the total concentration of sulfur, including elemental sulfur, sulfur

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[1] Lin, C. Lancaster, L.A. Sullivan, D. McConchie, D. and Saenger, P. (2002). Actual Acidity in Acid Sulfate Soils: Chemical Processes and Analytical Methods. Acid Sulfate Soils in Australia and China.

present in sulfide and sulfate minerals as well as organic sulfur. The most environmentally conservative approach to calculate maximum potential acidity (MPA) is to assume that all sulfur in a sample is potentially reactive sulfide and therefore capable of generating acid. By convention in acid base accounting studies, it is assumed that the sulfide sulfur is present as pyrite (FeS_2). Therefore, the stoichiometry of pyrite oxidation is used to calculate a theoretical maximum amount of sulfuric acid that could be generated which is expressed in kg H_2SO_4 / tonne. However, this ignores the fact that not all sulfur will contribute to the generation of acidity (e.g. sulfate sulfur in gypsum and barite). As a result, the total sulfur concentration may overestimate the acid generation potential of a sample.

Sulfur can be present within acid producing primary minerals such as pyrite and marcasite (FeS_2), chalcopyrite ($CuFeS_2$) and bornite (Cu_5FeS_4) and non-acid producing primary minerals such as galena (PbS) and sphalerite (ZnS). Sulfur can also be also present as a large number of non-acid producing secondary minerals such as alunite ($KAl_3(SO_4)_2(OH)_6$), gypsum ($CaSO_4 \bullet 2H_2O$) through to minerals such as jarosite ($KFe^{3+}{}_3(OH)_6(SO4)_2$) that can store and release acid and trace, minor and major elements.

To differentiate between total sulfur and sulfide sulfur the **CRS** method was used to measure the sulfide sulfur. The CRS method provides a direct measure of reduced inorganic sulfur over the wide range of values encountered in acid sulfate soils and mineral waste in geological materials. The selectivity of the CRS test in samples containing residual organic sulfur makes it an ideal choice analytically to measure sulfide within primary sulfide minerals. While this method excludes sulfur present as sulfate, or organic sulfur it does not differentiate between acid producing (e.g. pyrite) and non-acid producing (e.g. sphalerite) minerals.

Acid generation is caused by the exposure of sulfide minerals, most commonly pyrite (FeS_2), to atmospheric oxygen and water. Sulfur assay results are used to calculate the maximum acid that could be generated by the sample by either directly determining the pyritic sulfur content or assuming that all sulfur not present as sulfate occurs as pyrite. Pyrite reacts under oxidising conditions to generate acid according to the following overall reaction: $4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 8SO_4^{2-} + 16\ H^+$. According to this reaction, the MPA of a sample containing 1% sulfur as **pyrite** would be 30.6 kg H_2SO_4/t.

The chemical components of the acid generation process consist of the above sulfide oxidation reaction and acid neutralization, which is provided by inherent carbonates and, to a lesser extent, silicate materials. The amount and rate of acid generation is determined by the interaction and overall balance of the acid generation and neutralisation components.

5.1.1.3 Sulfide mineral morphology and reactivity

The assumptions used to calculate MPA are generally:

- All sulfide are pyrite.
- All sulfide will react to produce acid.
- The rate of oxidation and reaction is always the same.

5.1.1.4 Total acid neutralising capacity (ANC_T)

The primary minerals in geological materials that are readily able to neutralise acidity are calcium and magnesium carbonates, although RGS has verified that some manganese carbonate minerals such as kutnohorite and rhodochrosite can also provide ANC. Secondary neutralising minerals accounted for in the measurement of ANC include basic silicates such as calcic feldspars, olivine, amphiboles, and biotite. However, due to their slower dissolution rates, their contribution to the overall ANC is generally considered to be small under ambient conditions. Felsic silicates such as sodic and potassic feldspars, muscovite, most clay minerals, and quartz do not contribute significantly to the ANC. In addition, carbonate minerals that contain iron and/or manganese do not report to the ANC measurement.

The total ANC (ANC_T) can be measured using a number of analytical methods (Mills, Downing and Robertson, 2014).

- BC Research Inc. Initial Test Procedure
- BC Research Inc. Confirmation Test Procedure
- Coastech Research Modified Biological Oxidation Test Procedure
- Lapakko Neutralization Potential Test Procedure
- Modified Acid Base Accounting Procedure for Neutralizing Potential (Lawrence)
- Net Carbonate Value (NCV) for Acid Base Accounting (Bucknam)
- Peroxide Siderite Correction for Sobek Method (Skousen et al.)
- Sobek Neutralization Potential Method (Procedure)
- Static Net Acid Generation (NAG) Procedure

Each of these methods may yield different results. Care must be taken in the interpretation of ANC_T data.

RGS provide its samples to ALS Environmental (ALS). The ALS method refers to the AMIRA Guideline (2002) that uses a HCl digest at 80 to 90°C and a back titration with NaOH. The AMIRA method references: Sobek, A.A., Schuller, W.A., Freeman, J.R., and Smith, R.M., 1978. Field and Laboratory Methods Applicable to Overburdens and Minesoils. p.p. 47-50. U.S. Environmental Protection Agency, Cincinati, Ohio, 45268. EPA-600/2-78-054. ANC_T is affected substantially by particle size distribution (PSD). The finer the PSD of a sample the more reactive the sample will be due to the higher surface area. the static ANC_T method measures the total ANC, but under environmental conditions the ANC (in a boulder of limestone for example) is weathered slowly over decades, centuries or millennia.

5.1.1.5 Reactive acid neutralising capacity

The reactive (available) ANC is determined using the acid buffering characteristic curve (ABCC) (AMIRA, 2002) method that was derived from the British Columbia Research Incorporated Initial Neutralisation Potential method (Duncan and Bruynesteyn, 1979). The measurements of reactive (available) acid neutralising capacity involves slow titration of a sample with the addition of hydrochloric or sulfuric acid over set time intervals while continuously measuring the pH. The method is used to estimate the ANC of the material and the buffering capacity available at a pre-determined pH value. When acid is added to finely ground particles or aggregates the material will react with the acid neutralising components and reduce the pH of the solution. The amount of acid required to reach each pH interval is dependent on the amount of neutralisation present. ‘Buffering’ occurs where a significant amount of acid is added before the pH drops, thereby producing a ‘step-like’ curve in a plot of pH versus volume of acid added.

The relative reactivity of acid consuming minerals at pH 5 is provided in **Table 5-2**.

Table 5-2: Relative Mineral Reactivity

Mineral Group	Typical Minerals	Relative Reactivity at pH 5
Dissolving	Calcite, aragonite, dolomite, magnesite, brucite	1.0
Fast weathering	Anorthite, nepheline, olivine, jadeite, leucite, spodumene, diopside, wollastonite	0.6
Intermediate weathering	Epidote, zoisite, enstatite, hypersthene, augite, hedenbergite, hornblende, glaucophane, tremolite, actinolite, anthophyllite, serpentine, chrysotile, talc, chlorite, biotite	0.4
Slow weathering	Albite, oligoclase, labradorite, montmorillonite, vermiculite, gibbsite, kaolinite	0.02
Very slow weathering	K-feldspars, muscovite	0.01
Inert	Quartz, rutile, zircon	0.004

(Source http://technology.infomine.com/enviromine/ard/acid-base%20accounting/ABAdiscussion.htm)

5.1.1.6 Net acid producing potential (NAPP) and neutralisation potential ratio (NPR)

Geochemical classification is achieved using the net acid producing potential (NAPP) of a sample, which is calculated from acid base accounting (ABA) procedures (COA, 2016). The NAPP value is derived as the difference between the MPA and ANC of a sample.

The neutralising potential ratio (NPR) is also used as a means of assessing the risk of acid generation from mine waste materials. The purpose of the NRP is to provide an indication of the relative margin of safety within a material. As a general rule, an NPR of 2 can signify that a material will remain circum-neutral in pH and an NPR of 3 or more can signify that a material will retain mildly alkaline drainage (AMIRA, 2002; INAP, 2009).

5.1.2 Metalliferous drainage potential

The potential of a geological material to leach trace, minor or major elements (salts, metal(loids)) is a function of the fractionation and speciation of the elements and the way the mine waste materials will be managed.

5.1.3 Speciation

Speciation refers to specific metal species such as, organometallic compounds, metals bonded to different anions (e.g. chlorides, sulfates, sulfides, carbonates, oxides, etc.) or metals with different redox states that determine elemental toxicity such as Cr^{3+} (limited toxicity) and Cr^{6+} (highly toxic) (Templeton et al., 2000; Quevauviller, 2002).

5.1.4 Fractionation

Fractionation refers to and describes the physical or chemical properties or methods that are used to remove metals from a soil (Templeton et al., 2000). In this thesis the term operationally defined fraction (ODF) refers to the metals removed from a soil using a specific selective extractant. For instance the use of water or 0.01M $CaCl_2$ is often used to describe the “bioavailable” soil fraction. In effect these should be described as the water-soluble ODF or the 0.01M $CaCl_2$ ODF, and can only be referred to as a “bioavailable” fraction when a specific biotic endpoint (e.g. the earthworm species Eisenia. fetida) has total body tissue metal concentrations that correlate with either of the aforementioned extractants.

5.1.4.1 2 - acid aqua regia fraction

The 2-acid aqua regia fraction is commonly referred to as the “total” element concentration. The static methods used in this assessment will measure the “total” and “water soluble” fractions of these elements. The geochemical abundance index (GAI) quantifies a “total” assay result for a particular element in terms of the average crustal abundance for that element. The index, based on a log (2) scale, is expressed in seven integer increments (0 to 6), which correspond to enrichment factors from 0 to over 96 times average crustal abundance, as shown in **Table 5-3**.

Table 5-3: Geochemical Abundance Index (GAI) values and Enrichment Factor

GAI	Enrichment factor	GAI	Enrichment factor
0	Less than 3-fold enrichment	4	24 – 48 fold enrichment
1	3 – 6 fold enrichment	5	48 – 96 fold enrichment
2	6 – 12 fold enrichment	6	Greater than 96 fold enrichment
3	12 – 24 fold enrichment		

As a general rule, a GAI greater than or equal to three indicates element enrichment to a level that may warrant further investigation (INAP, 2009). This is the case with some environmentally important ‘trace’ elements, such as As, Cd, Cu and Zn, rather than with major rock-forming elements, such as Ca, Mg, K and Na. Elements identified as enriched may not necessarily be a concern for revegetation, drainage water quality or public health, but their significance should still be evaluated. Similarly, because an element is not enriched does not mean it will never be a concern, because under some conditions (e.g., low pH) the solubility of common environmentally important elements such as Al, Cu, Cd, Fe and Zn increases significantly.

5.1.4.2 Water soluble fraction

A 1:5 (solid:solute) or more concentrated deionised water leach test at 1:3 or 1:2 ratio can be used to measure the pH, EC, and the concentration of major ions and trace metals/metalloids in water extracts. It should be recognised that direct comparison of geochemical data from water extracts with guideline values can be misleading.

RGS prefers to evaluate the solubility of metals/metalloids and major ions in leachate from mining wastes and rejects using kinetic leach column testing that generally provides an indication of the rate of weathering and associated concentration/release rate of elements in the leachate over time under controlled laboratory conditions.

5.1.5 Saline drainage potential

Three measures of electrical conductivity (EC) are:

- $EC_{1:5}$ —the electrical conductivity of a 1:5 soil water suspension, used routinely in analyses
- ECse—the electrical conductivity of the soil saturation extract, used for predicting plant response (commonly predicted from 1:5 and soil properties, or can be measured directly)
- ECs—the electrical conductivity of soil at measured or predicted maximum field water content (approximating field capacity), used to assess salt movement through the soil (usually predicted from 1:5 and soil properties).

$EC_{1:5}$ provides a measure of the content of salts in a 1:5 soil water suspension, the most commonly used method of analysis. EC, chloride (Cl) and pH are usually measured together to provide additional information for interpretation. Saline drainage is of concern to regulators in Queensland and other states and territories. Saline drainage can come from the release of major cations and anions from geological units due to weathering of the host rock, or from the accumulation of elements over time e.g., accumulation of NaCl in soil from leaching by rain. Saline drainage can also be attributed to sulfide oxidation process that release sulfate and or the weathering of sulfate minerals such as gypsum, alunite, celestine. Sulfate and other major ions such as NaCl can be present under both acid and neutral pH conditions.

5.2 Topsoil (Quaternary Alluvium)

Topsoil for this assessment is based on viable mine scale soil stripping approaches (not soil morphology) and is defined as soil from 0 to ~ 0.5 m bgl. The topsoil is likely to include the O and or A and the Upper B horizon.

5.2.1 Actual and potential acidity

Actual acidity includes water soluble acidity (H^+), exchangeable acidity (e.g. water soluble and exchangeable Al, Cu, Mn and Zn) and retained acidity (e.g. Jarosite).

Potential acidity is acidity that is stored in sulfide minerals (e.g. pyrite): when the pyrite is exposed to oxygen actual acidity is mobilised.

TS contour plots in **Section 10.5.1** document the spatial distribution by elevation within the proposed pit shell.

- TS content > 0.2% has the potential to contribute to sulfate in drainage regardless of the ANC
- TS content > 0.5% is likely to contribute to sulfate in drainage regardless of the ANC
- TS content > 1.0 % will almost certainly contribute to sulfate in drainage regardless of the ANC

The CRS contour plots in **Section 10.5.2** provide a spatial indication of potential AMD risk. The Orebody (TLBB to TLBE) contains ANC that is initially high but diminishes with depth, whereas the ANC in WLA is low.

- In the absence of any ANC, CRS content > 0.2% has the potential to contribute to minor acid and sulfate
- In the absence of any ANC, CRS content > 0.5% is likely to contribute to moderate acid and sulfate
- In the absence of any ANC, CRS content > 1.0 % will almost certainly contribute to significant acid and sulfate

The water soluble actual acidity ($pH_{1:5}$) is circum neutral to mildly alkaline at 6.6 to 9.5 (**Figure 4-1**), and these conditions are attributed to the prevalence of calcite in the soil and regolith strata. Topsoil samples have < 0.4% total sulfur (TS) (**Figure 4-5**), essentially no sulfide sulfur (<0.02% CRS) (**Figure 4-7**), and low to moderate ANC (1 to 93 kg H_2SO_4/t) (**Figure 4-9**).

The sulfur is present as sulfate minerals such as gypsum and barite and acid conditions are highly unlikely due to the moderate ANC. The net acid producing potential (NAPP) results derived using TS ($NAPP_{TS}$) verify that: 56% of topsoil samples have NAPP values between -0.9 and -7.1 and, 44% are between -13 and -91 (**Figure 4-9**). Geochemically, the samples classify as NAF-LC (56%), NAF (38%), or acid consuming (6%) (**Table 4-1**) and the soil units will therefore remain circum neutral to mildly alkaline at 6.6 to 9.5.

5.2.2 Salinity

88% of topsoil samples have negligible to mild $EC_{1:5}$ at 17 to 616 µS/cm and two samples had moderate $EC_{1:5}$ at 1,160 to 1,510 µS/cm but the median EC of 132 µS/cm is very low verifying that the potential for the topsoil units to leach salt is very low (**Figure 4-3**). The ESP was measured at <0.2 to 27%, however the median ESP of 5.5% is in the low range of ESP results indicating that the potential for the topsoil to be dispersive should also be very low (**Table 4-6**). The EC and ESP results classify topsoil as Class 2A or 2B (**Figure 4-27)**. The EC and ESP results verify that these soils should have limited structural problems related to dispersion, and while some of the topsoil samples could be considered to be sodic (based on the ESP results) most of the samples have a very low ESP due to the prevalence of calcium in the system.

5.2.3 Metal(loids)

Concentrations of total (2-acid aqua regia digest) and water soluble metal(loids) in topsoils represent baseline background conditions and can be used to define performance criteria for rehabilitation purposes. For example, materials placed on the rehabilitated surface should be consistent with the measured concentrations of total (2-acid digest) and water soluble metal(loids). This will ensure that the major, minor and trace elements leached from the rehabilitated land are consistent with pre-mine conditions. The 52 metal(loids) measured using the 2-acid aqua regia digest are consistently in the lower range of results for the deposit (**Figure 4-18**). Similarly, the water soluble fraction in the upper profile of the deposit are also in the range of results (**Figure 4-19**).

5.2.4 Physical properties

The topsoils classify (subjectively) as Emerson Class 2, 3, 4, or 5 (**Table 4-5**). 56% of the samples are Class 2 defining them as having some potential to be dispersive, but the balance of the samples are non-dispersive due to the low ESP and higher proportion of calcium in the soil matrix. The Emerson Class results correlate with the results from the chemically defined classification (**Figure 4-3**) verifying these soils should have limited structural problems.

Topsoils have a moderate clay content (31%) that is similar to the Allaru Mudstone (ALM) (23-53%) (**Table 4-9** and **Table 4-10**). The cation exchange capacity (CEC) is 6 to 22.7 meq/100g with a median CEC of 6.8 meq/100g (**Table 4-6**) which is in the low range of CEC results for clay and explained by the even proportions of silt and sand sized fractions.

The column settlement rates for the topsoil are slower than the other material types but still much faster than most soil types that can retain high suspended sediment concentrations in solution for day (or even weeks) (**Figure 4-33** and **Table 4-17**). All other material types produce a clear solution after 48 hours, demonstrating that dispersion issues are not present. However, turbidity in topsoil solutions may be caused by dissolved nitrates, phosphates, and organic matter, which are have higher concentrations in this unit compared to subsoil and underlying lithologies (**Table 4-6**). The settlement results align with the subjective assessment using the Emerson Classification and the measured EC and ESP results and the Rengassamy method (**Figure 4-3**).

Topsoils are moderately plastic (**Figure 1-8** and **Figure 4-30**), have moderate moisture retention (**Figure 4-34**) and moderate shrink/swell (shrink swell index (Iss) 2%, (**Table 4-15**) based on physical analysis.

5.2.5 Soil fertility

Nutrients are adequate to support native vegetation and represent baseline background conditions that can be used as performance criteria for other material types if they are used for rehabilitation.

5.2.6 Rehabilitation considerations

The topsoil samples have no chemical limitations and are suitable to be used for rehabilitation purposes. The soils in this region are known to be susceptible to erosion and this hazard has been addressed through the landform designs aspects in **Section 6**.

5.3 Subsoil (Quaternary Alluvium)

Subsoil for this assessment is based on viable mine scale soil stripping approaches (not soil morphology) and is defined as soil from ~ 0.5 to 2 m bgl. The subsoil is likely to include the B and C horizon.

5.3.1 Actual and potential acidity `

The water soluble actual acidity ($pH_{1:5}$) is circum neutral to mildly alkaline at 7.6 to 9.6 (**Figure 4-1**) and because the subsoil layer contains no sulfide sulfur (<0.01% CRS) and low to high ANC at 3 to 437 kg H_2SO_4/t (**Figure 4-12**), there is no potential for this unit to produce acid drainage. As the $pH_{1:5} > 5.5$, the potential for exchangeable acidity (e.g., soluble Al, Mn) or retained acidity (e.g., jarosite) to be present in this unit is negligible.

47% of the subsoil samples were < 0.2% TS and 53% of the samples were 0.2% to 0.4%. (**Figure 4-5**). The XRD results verify that gypsum is present in the deposit and it is a probable source of the sulfur, that is present as sulfate (**Figure 4-20**).

The net acid producing potential (NAPP) results derived using TS ($NAPP_{TS}$) verify that: 29% of subsoil samples have $NAPP_{TS}$ values of 2.6 to -8 kg H_2SO_4/t , 59% are -16 to -48 kg H_2SO_4/t and are NAF, and 12% are AC with -79 to -437 kg H_2SO_4/t. Geochemically, the samples classify as PAF-LC (6%), NAF-LC (23%), NAF (59%), or AC (12%).

5.3.2 Salinity

Salinity in and of itself can pose an environmental risk if the water enters freshwater streams or it has the potential to impact groundwater systems if the relative contributions in terms of volume of flow rates and their concentrations are above those in the receiving environment. These conditions are unlikely to occur at this site (refer to **Section 6**). However, this assessment has verified that a wide range of results can occur within the same stratigraphic unit. In terms of rehabilitation, it will be prudent to obtain the most appropriate geological strata for rehabilitation, including selecting alluvium and soils with low potential be sodic and dispersive.

Electrical conductivity in the subsoil has a very wide range of 18 to 2,830 µS/cm, with a low median concentration of 407 µS/cm (**Figure 4-3**). The reason for the wide range in results may be due to the sampling or logging methods and or variations in the topsoil and subsoil horizon depth that seem to be verified by the fact that there may be two groups of results with one group having EC values of < 1,000 µS/cm and the upper range of samples being in the 2,000 to 3,000 µS/cm range. The salinity in the subsoil is attributed to sodium chloride and sulfate (**Table 10-3**).

Soil texture ranges from clay to loam. There is a correlation between CEC and ESP, suggesting that clay particles are an important factor. Subsoil samples can exhibit relatively high CEC (9.9 to 27.1 meq/100g) and ESP (13 to 37%), or conversely, relatively low CEC (4.2 to 9.4 meq/100g) and ESP (typically < 0.2%). These two groups of results align with EC trends noted earlier. Plasticity and moisture retention properties are influenced by PSD and are slightly lower in subsoils compared to topsoils and decrease further for loamy subsoils (**Figure 4-28**, **Figure 4-30**, and **Figure 4-29**). Subsoils may be Emerson Class 2 or 4c, and the majority (88%) are Emerson Class 2 (**Table 4-5**). They can be salinity class 2A, 2B or 3A (**Figure 4-27**). Subsoils settle after 24 hours, verifying they flocculate better than topsoils. Overall, the subsoil samples have no limitations and are suitable to be used for rehabilitation purposes.

5.3.3 Metal(loids)

Total (2-acid digest) elements are slightly higher in the subsoil compared to topsoil, with the exception of Ag, Mn, Ce, and Co (**Figure 1-4** and **Figure 1-5**). The 0.45µm filtered soluble metal(loids) in the 16hr and 1:3 ratio shake flask extraction (SFE) results are low or below the limit of reporting and are comparable to topsoil, excluding Ba which is 0.048 mg/L in topsoil and 0.181 mg/L in subsoil (**Table 10-5**).

5.4 Alluvium (Wondoola Beds)

5.4.1 Actual and potential acidity

$pH_{1:5}$ is mildly alkaline to alkaline at 8.2 to 9.9 (**Figure 4-1**) in the Wondoola Beds (WDB). Silt /sand samples have negligible TS (<0.2%), low to high ANC at 3.6 to 864 kg H_2SO_4/t and classify as NAF-LC (19%), NAF (54%), or acid consuming (27%). Overall, all alluvium (WDB) samples have negative $NAPP_{TS}$ values and will not produce acid drainage. The potential sulfate to be leached from these units is also low given the low TS concentrations.

5.4.2 Salinity

The unconsolidated alluvial sediments have low to high $EC_{1:5}$ of 59 to 3,380 µS/cm, with a moderate median concentration of 602 µS/cm (**Figure 4-3**).

The variability in the salinity of this unit is attributed to the:

- Geomorphology and different physical properties of the alluvial fans that used to meander across the project area e.g. deep sandy, gravelly lenses in some areas or shallow lenses in other areas with higher silt and clay fractions.
- Accumulation or leaching of salts from the alluvial lenses that very in depth from surface and the depth of the actual profile (**Section 1.4.1**).

The high range in measured EC values in the alluvial sediment verifies that the chemical and physical properties of the surface units is highly variable. These findings are consistent with the soil suitability assessment and groundwater monitoring program.

The subjective assessment using the Emerson Class method is that 47% are Class 2, 33% are Class 3 or and 20 % are Class 4 or 4C (**Table 4-7**).The measured EC and ESP data classify these samples as Class 2B or 3A with 64% of samples potentially dispersive (**Figure 4-27**).

Kinetic leachate column concentrations (KLC 1) demonstrate a rapid release of salts (e.g., Ca, Mg, Na, Cl, SO_4, F) within one leaching cycle (**Figure 4-24**).

5.4.3 Metal(loids)

Concentrations of total (2-acid digest) elements appear to increase gradually with depth and are higher than topsoils and subsoils (**Figure 4-18**). Soluble metals and metalloids concentrations, however, remain low and present negligible environmental risk (**Figure 4-19**). There is a notable contrast between concentrations in filtered (<0.45 µm) and unfiltered fractions for all material types, verifying that most elements are mobilised as suspended solid particulates rather than in the dissolved phase (**Table 10-5** and

Table 10-7).

5.4.4 Physical properties

Soil texture ranges from clay to sandy loam, and silt /sand samples have an even proportion of clay, silt, and sand compared to other material types (**Table 4-9** and **Table 4-10**).

CEC is variable (8 to 58 meq/100g), and ESP also ranges widely (<0.2 to 38%), but silt /sand samples are more likely to have salinity and sodicity issues compared to topsoil and subsoil.

Silt /sand samples settle after 7 – 24 hours, verifying the correlation between settlement rates, saline chemical properties and particle size (**Figure 4-33**). Samples exhibit low to moderate plasticity (PI 15 – 27%) and variable moisture retention characteristics (**Figure 4-30** and **Figure 4-34**). Overall, silt /sand is less suitable as a growth medium due to the potential for salinity and sodicity, but nevertheless this material type presents negligible risk in terms of acid generation.

Sand-mudstone transition materials display similar geochemical and physical characteristics to silt /sand samples and for the purposes of management can be regarded as the same unit.

5.5 Regolith (ALM and TLBA)

The characteristics of the weathered to extremely weathered Mudstone (ALM) and limestone roof (TLBA) are as follows.

5.5.1 Actual and potential acidity

Allaru Mudstone (ALM) $pH_{1:5}$ mildly alkaline at alkaline at 8 to 9.7 (**Figure 4-1**). While the majority of samples have < 0.2% TS, 26% of the ALM samples have 0.2 to 0.8% TS present as gypsum (**Figure 4-20**). There is also chromium reducible sulfur present at concentrations of 0.01% to 0.56% verifying that there is reactive sulfur that can oxidise to produce acid (**Figure 4-7**). The ANC in the samples is low to very high at 8 to 954 kg H_2SO_4/t within these units (e.g., calcite) and there is excess ANC to neutralise any acid production (**Figure 4-12**). Geochemically, the ALM samples classify as NAF-LC (5%), NAF (49%), or AC (46%). Limestone roof (TLBA) $pH_{1:5}$ is mildly alkaline at 8.1 to 9.2 (**Figure 4-1**). TS is highly variable, ranging from 0.01 to 2.2% (**Figure 4-5**). For the limestone roof samples (50%) that have >0.2% TS, approximately half is sulfide sulfur and is reactive (**Figure 4-7**). However, limestone roof samples are acid consuming and have excess ANC (484 to 785 kg H_2SO_4/t) to neutralise any acid produced (**Figure 4-17**). XRD results (84% calcite) also verify that the limestone roof is mineralogically distinctive from Mudstone ALM, silt /sand, and orebody which have 9 – 27% calcite (**Figure 4-20**). 100% of the limestone roof samples are AC. The TS plots verify that TS > 0.5% at a depth of 109 m RL (**Figure 10-57**) to 99 m RL. This corresponds to units TLBB to WLA, which are below the ALM and TLBA.

5.5.2 Salinity

The ALM samples have low to moderate EC of 168 to 3,310 μS/cm, with a median EC of 1,770 μS/cm (**Figure 4-3**). Limestone roof (TLBA) have low to moderate EC of 178 to 3,840 μS/cm, with a median EC of 1,000 μS/cm) (**Figure 4-3**). The SFE results verify that the salts in the ALM are dominated by calcium sulfate with lesser sodium chloride, whereas the TLBA (limestone) unit has much less water soluble sodium chloride within it (**Figure 4-19).** The KLC results provide similar results to the SFE results (**Figure 4-25**) for the ALM and TLBA units. The ALM unit classifies subjectively as Emerson Class 2 (**Table 4-5**) or numerically as Class 2B or 3A (**Figure 4-27**), verifying that these samples may be subject to mild dispersion or slaking. The ALM has a high CEC (28.9 meq/100g) and elevated ESP (36%) (**Table 4-7**). Limestone roof has a higher proportion of sand (46 – 57 %) compared to Mudstone ALM (7 – 48%) and has a soil texture classification of a sandy loam (**Table 4-9** and **Table 4-10**). CEC and ESP were not measured on these samples, but the limestone units unlikely to be sodic due the high total (2- acid digest) concentration of calcium carbonate (**Table 10-1**).

5.5.3 Metal(loids)

In the ALM, concentrations of total (2-acid digest) elements continue to increase with depth, with the exception of Ba and Mg which are lower in the ALM than in silt /sand samples (**Table 10-1** and **Table 10-2**). The water soluble (16 hr 1:3) 0.45 μm filtered fraction is a neutral ($pH_{1:3}$ 7.1 to 7.9) but saline leachate ($EC_{1:3}$ 293 to 4,110 μS/cm) with low or below the limit of reporting metal and metalloid concentrations (**Table 10-3**). Kinetic leachate concentrations (KLC 2 and KLC 3) demonstrate a moderate to rapid initial flush followed by steady but slow salt release, with low concentrations of trace elements (**Figure 4-24** to **Figure 4-26**).

In limestone roof (TLBA), total (2-acid digest) concentrations in this unit are varied and elevated compared to topsoils (e.g, Ag, As, Ca, Cd, Cr, Cu, Hg, Mo, Ni, P, Rh, Sb, Se, Sr, S, Te, U, V and Zn) (**Figure 4-18**). Some elements are lower than topsoils (e.g., Al, Ba, Cs, Ga, Pb, Rb, and Th). The water soluble (16 hr 1:3) 0.45 μm filtered leachate is rich in Ca (3,010 to 7,760 mg/L) but is circumneutral and moderately saline (398 to 2,920 μS/cm) (**Table 10-3**). Soluble trace metal and metalloid concentrations are low or below the limit of reporting (**Table 10-5** and

Table 10-7). Kinetic leachate concentrations (KLC 4) are similar to Mudstone ALM and demonstrate a moderate to rapid initial flush followed by steady but slow salt release, with low concentrations of trace elements (**Figure 4-24** to **Figure 4-26**)..

5.5.4 Physical properties

Particles <2 mm settle quickly and produce a clear solution within 7 hours (**Figure 4-33**).

Soil textures for these materials range from silty clay to sandy clay loam and are characterised by high proportions of clay (23 – 53%) (**Table 4-9**).

Mudstone ALM samples have low permeability when compacted (7.0 x 10^{-10} to 1.5 x 10^{-9} m/s at ksat 95%) (**Table 4-13**) and high plasticity (PI 14 – 46%) (**Table 4-12**) compared to topsoils and subsoils and if crushed may be suitable in the construction of impermeable barriers. Further testing would be required to ascertain the durability of these rocks (e.g., point load testing, sodium soundness). Overall, Mudstone ALM samples have some limitations regarding salinity and sodicity but is suitable as rocky soil mulch. The crushed material has potential applications due to its high plasticity.

Limestone roof samples have low permeability when compacted (1.4 x 10^{-9} to 8.5 x 10^{-9} m/s at ksat 95%), and moderate permeability when loosely compacted e.g., as backfill (1.2 x 10^{-8} to 1.3 x 10^{-8} m/s at ksat 90%) (**Table 4-13**). Samples demonstrate low plasticity (PI 11%) (**Table 4-12** and **Figure 4-30**) and classify as Emerson Class 4c (**Table 4-5**), verifying that these materials have good structure as a soil material and are not dispersive. Overall, the limestone roof samples have no limitations, and are a beneficial resource as an acid consuming material.

5.6 Ore (TLBB-TLBE) and black shale (WLA)

The characteristics of the weathered Toolebuc formation associated with the orebody (TLBB to TLBE), and the partially weathered to fresh mudstone floor (WLA) are as follows.

It is assumed that the entire TLB_B to TLB-E formations will be processed and returned to the pit as NAF residue. The WLA formation will be exposed during this process. If the WLA formation contains sulfide minerals it will react and become AF within days to weeks of exposure. However, the CRS plots verify the distribution of sulfide minerals in the lower part of the deposit is limited to two areas at 103 m RL (**Figure 10-73**).

5.6.1 Actual and potential acidity

Pre-assessment database results had 0.03 to 4.69% TS from 34 drill holes. The analyses for the samples in this assessment verify the following. The TLBB to TLBE $pH_{1:5}$ is mildly alkaline at 7.9 to 9.3 (**Figure 4-1**). TS is 0.01% to 2.67% for TLBB, 0.02% to 7.31% for TLBD, and 0.11% to 3.23% for TLBE. 83% of the samples analysed have <0.2% CRS, verifying that most S is not sulfide sulfur (**Figure 4-15**). ANC for orebody samples is low to high (7.3 to 900 kg H_2SO_4/t).(**Figure 4-17**) The samples are geochemically classified (based on TS) as Acid Consuming (76%), NAF (12%), NAF-LC (2%), PAF-LC (3%), PAF (5%), or PAF-HC (2%). The proportion of acid consuming materials decreases with depth (100% AC in TLBB to 16% AC in TLBE).

The WLA black shale $pH_{1:5}$ is mildly alkaline at 7.8 to 9.4 (**Figure 4-1**). TS is 0.03 to 2.32% and 85% of samples have >0.2% TS, which is verified as predominantly sulfide sulfur (**Figure 4-15**). Assay data for this basement unit is limited but suggests a higher range for TS, from 2.65 to 4.66% TS. The ANC for the WLA floor samples is 0.7 to 80 kg H_2SO_4/t (**Figure 4-17**). The geochemical classification for Mudstone floor WLA samples (based on TS) is NAF (17%), NAF-LC (12%), PAF-LC (10%), PAF (29%), or PAF-HC (32%). The KLC results for the WLA formation verify that the PAF shale will oxidise rapidly and produce acid drainage in < 1 month.

The CRS contour plots in **Section 10.5.2** provide a spatial indication of potential AMD risk. The Orebody (TLBB to TLBE) contains ANC that is initially high but diminishes with depth, whereas the ANC in WLA is low.

- In the absence of any ANC, CRS content > 0.2% has the potential to contribute to minor acid and sulfate.
- In the absence of any ANC, CRS content > 0.5% is likely to contribute to moderate acid and sulfate.
- In the absence of any ANC, CRS content > 1.0 % will almost certainly contribute to significant acid and sulfate.

The CRS contour plots show that significant sulfide sulfur first becomes present (CRS > 0.5%) in the SW and central regions (**Figure 10-73**) at 103 m RL, which corresponds to the Toolebuc Arrola shale (TLBD) unit. This increases to encompass the entire pit shell with CRS > 1% in the mudstone floor (WLA) at 99 m RL.

Although the mudstone floor (WLA) is expected to oxidise and produce acid quickly, the readily available and abundant acid consuming materials in the overburden ensures that this hazard can be managed through strategic mining and mine waste placement.

5.6.2 Salinity

Orebody (TLBB-TLBE) samples have mild to moderate salinity (441 to 2,100 µS/cm) and have a median of 565 µS/cm. Mudstone floor (WLA) samples have mild to moderate salinity (594 to 1,600 µS/cm) and have a median of 904 µS/cm (**Figure 4-3**). Rock samples were excluded from soil quality analyses.

5.6.3 Metal(loids)

Orebody (TLBB-TLBE) total (2-acid digest) concentrations are similar to limestone roof samples, but are particularly elevated compared to topsoils for Bi, Ce, Cs, Cu, P, Rb, Sc, Se, Th, V, and Zn (**Table 10-1** and **Table 10-2**). The water soluble (16 hr 1:3) 0.45 µm filtered fraction is a neutral ($pH_{1:3}$ 7.8) but saline leachate ($EC_{1:3}$ 3,010 µS/cm) (**Table 10-3**) with low or below the limit of reporting metal and metalloid concentrations with the exception of Mn, Mo, Ni, Se, Sr, and Zn (**Table 10-5** and
Table 10-7).

Kinetic leachate concentrations (KLC 5) demonstrate a slow initial flush and salt release, with variable concentrations of trace elements. The mobility of K, Li, Rb, Se, Sr, and U appears higher in orebody samples than other materials (**Figure 4-24** to **Figure 4-26**).

Mudstone floor (WLA) total (2-acid digest) concentrations are elevated compared to topsoil samples for Ag, As, Bi, Cd, Ca, Cs, Cu, Fe, Hg, K, Pb, Mg, Mo, Na, Ni, P, Rb, S, Se, Sb, Sr, Tl, U, Y, and Zn but are lower than orebody concentrations (**Table 10-1** and **Table 10-2**).. The water soluble (16 hr 1:3) 0.45 µm filtered fraction is a neutral ($pH_{1:3}$ 7.0 to 7.9) but saline leachate ($EC_{1:3}$ 3,820 to 5,620 µS/cm) (**Table 10-3**) with low or below the limit of reporting metal and metalloid concentrations with the exception of Ni, Se, Sr, and Zn (**Table 10-5** and
Table 10-7)..

Kinetic leachate concentrations (KLC 6) are typical for PAF materials, demonstrating a decline in pH over time (from pH 6.8 to pH 3.8) and an increase in the concentration of acid-mobilised elements such as F, Cd, Li, Ni, Rb, Sr, and Zn with successive leach events (**Figure 4-24** to **Figure 4-26**)..

5.6.4 Physical properties

Physical analyses were not performed on the orebody (TLBB-TLBE) and mudstone floor (WLA) units as the available borehole sample mass was limited (**Section 2.2.1**).

Overall, any Toolebuc orebody materials (TLBB-TLBE) disposed of as waste due to low grade should be treated as deleterious due to the potential for neutral metalliferous drainage.

Although unlikely to be mined, any mudstone floor (WLA) basement waste should be treated as deleterious and encapsulated due to potential acidic metalliferous drainage issues.

5.7 Residue and high purity alumina

5.7.1 Vanadium and HPA Flowsheet

The concept level flowsheet summarised below in this report has informed the concept level process flowsheet (Figure 1) and summarises the current understanding, with the treatment of ROM ore through to production of a bagged V_2O_5 product and a high purity alumina product. Several simplifications have been made to reflect current understanding.

The flowsheet comprises of the following unit operations:

- Crushing
    - The crushing circuit will be designed to reduce the top size of the ore to below 5 mm.
    - A rolls crusher or sizer would be appropriate for this ore which is soft.
    - A scrubber will pre-condition the ore to disperse the clays from the calcite and other gangue.
    - The intention is to not promote fines generation that might impact calcite rejection but to ensure liberation of vanadium.

- Flotation
    - A reverse flotation circuit has been devised where the Calcite is floated off leaving the valuable Vanadium bearing minerals in the tail. This is critical in rejecting Calcium.
    - Multiple stages of concentrate cleaning have shown that additional vanadium can be recovered.
    - The flotation tail will require thickening / filtration to minimise water going into leaching.
- Sulphuric acid Leach
    - Contacting the ore with H_2SO_4 in stirred tanks will extract the Vanadium as a sulphate. This leach also extracts aluminium and iron as sulphates.
    - Operating in counter current fashion so that the most leached ore contacts the highest acid concentration.
    - Operating at sufficient free acid concentration to secure fast kinetics and reduce residence time at atmospheric conditions to minimise energy.
    - Operating at 20-25wt% solids to manage viscosity.
    - Finishing with a CCD wash for Vanadium and acid recovery.
- Solvent Extraction
    - The leachate will be partially neutralised to be compatible with the solvent extraction organic. This can be achieved through the neutralisation with ore to minimise the costs of pH adjustment. This has been assessed and will significantly reduce acid costs.
    - Contacted with organic in multiple stages of extraction with an O:A ratio to be determined. Mextral 984 H (which is an aldoxime and oxime) is successful at extracting vanadium with low amounts of Fe / V.
  - The Vanadium rich organic phase will then be stripped in multiple stages with Ammonia at an O:A ratio to be determined to remove Vanadium into the stripped liquor. An Ammonia solution has also been very successful at stripping Vanadium from the organic, to produce a clean V loaded strip solution.
- Ammonium Metavanadate (AMV) precipitation
    - The stripped liquor is then pH adjusted and Ammonium sulphate added to promote precipitation of NH_4VO_3. while managing impurities. Precipitation of the AMV is achieved in this process and yield and purity will be controlled through manipulation of pH and temperature, seeding.
    - The work done to date has been rudimentary but effective. Further work needs to go into understanding the optimum NH_4VO_3 conditions while minimising the precipitation of impurities (or washing them out)
- Calcination to V_2O_5
    - The filtered AMV is then dried (100 degrees celsius) and submitted to a calciner which drives the temperature to 450 degrees C. The AMV decomposes to V_2O_5 and NH_3 is then captured and recycled back to the start of the AMV precipitation.
    - Calcined V_2O_5 is then packaged into 1T bulk bags for transport.
- High Purity Alumina (HPA)
    - This process is shown as a side stream of raffinate from the Solvent Extraction process.
    - As described above, the leach conditions promote the extraction of Aluminium into a sulphate solution. This provides a rich source of Al for purification and concentration.
    - Vecco have partnered with Lava Blue to develop a suitable stream to feed their patented HPA process.
    - Waste from this process must be managed (treated and disposed) within the proposed lease boundary.

The back end of the process involves management of residue.

- Residue Filtration
    - This is conducted to recover as much of the vanadium as possible after the CCD recovery of Vanadium.
    - A test work programme has been drafted to understand the requirements for recovering V and acid and managing solid / liquid separation.
- Residue Neutralisation and Filtration

  - The leached residue must be neutralised prior to disposal. This is achieved through contact with the Ca rich concentrate (ground) from the flotation circuit (and/or TLB_A) in a series of stirred tanks.
  - Final pH adjustment will be achieved though the addition of lime (calcined).
  - The neutralised residue is filtered in large plate and frame filters.
- Residue Disposal
  - Filtered, neutralised residue is to be co-disposed into the pit with other waste. The residue and mine waste will be mixed prior to disposal (mixing via a scrubber).
  - The co-disposed residue will be trucked to the pit where it will be placed inside internal embankments which will contain the residue as it dries and compacts – potentially with additional mechanical assistance (dozing/ripping).
  - As it meets compaction objectives, fresh residue can then be placed on top of compacted residue.
  - A small ex-pit facility will be used to manage any unplanned events affecting suitability for co-disposal.

5.7.2 Rare Earth Flowsheet

- Beneficiation
  - The mine material may be subjected to a water based beneficiation process to concentrate the rare earths present in the apatite. At this time there is no clear pathway as test work is underway, but likely to involve screens and cyclones. The waste from this process can be disposed into the mining pit, subject to being suitable and compatible with the neutralised residue from the vanadium flowsheet. Water, if acidic will need to be treated prior to re-use or disposal
- Leaching
  - Rare earths are extractable at modest leach conditions (pH=1, 90 degrees, 4-8hr duration). As shown in the diagram It is anticipated that an H2SO4 leach will be utilised.
  - The rare earths are now in liquor form as sulphates
  - The product will be thickener and filtered to recover the liquor and densify the residue.
  - The residue will be washed and neutralised for disposal with the Vanadium waste.
- Neutralisation and Precipitation
  - The liquor will be sequentially neutralised with Sodium Carbonate and the impact will be the removal of Ca and Fe, further concentrating the rare earths fraction. These waste stream will be neutralised and also co disposed with the Vanadium waste.
  - The precipitated rare earths concentrate will then be washed, filtered, dried and bagged for transport.

5.7.3 Residue solid and aqueous components

Process water supernatant is an aqueous phase with pH 7.4 and is circumneutral due to the addition of limestone and calcium hydroxide. The salinity, measured as EC is 2,600 µS/cm and is moderately saline. Total alkalinity (as $CaCO_3$) is 41 mg/L and titratable acidity (as $CaCO_3$) is 6 mg/L. Filtered (<0.45 µm) concentrations of major cations, anions, and trace elements in treated supernatant are low or below the limit of reporting and comparable to leachate from Mudstone ALM. The treated supernatant is suitable for re-use as recycled water or may be suitable for environmental release depending on flow conditions.

Calcite neutralised supernatant is an aqueous phase with pH 9.3 to 9.7, is mildly alkaline and moderately saline (2,340 to 2,370 µS/cm). The total alkalinity (as CaCO3) is 92 to 94 mg/L and titratable acidity (as CaCO3) is <1 mg/L. Overall, the pilot plant treated residue have more alkalinity than the small-scale RGS experiments. Soluble concentrations of major cations, anions, and trace elements in pilot plant treated supernatant are low or below the limit of reporting with the exception of Mo, Sr, and V. The solubilities of these elements are investigated in detail in **Section 10.4**. The pilot plant treated supernatant is suitable for re-use as recycled water or may be suitable for environmental release depending on flow conditions.

Calcite neutralised residue are a solid phase material with $pH_{1:5}$ ranging from 9.9 to 10.6 and are moderately alkaline and saline (2,160 to 2,190 µS/cm). The total sulfur is 7.5 to 9.1% TS but CRS content is 0.02 to 0.03%. The samples are geochemically classified as NAF (100%). Titratable actual acidity (TAA) is <0.2 mole H^+/t verifying the successful neutralisation of the acidic untreated residue. ANC ranges from 348 to 407 kg H_2SO_4/t and is comparable to the RGS treated residue. NAPP values range from -406 to -347 kg H_2SO_4/t and NPR values are 428 to 553 and classified as “negligible risk”. Soluble concentrations (16 hour leach at 1:3 w:v) of major cations, anions, and trace elements in pilot plant treated residue are low or below the limit of reporting with the exception of Mo, Sr, and V. Compared to the pilot plant treated supernatant, shake flask extraction leachate concentrations were slightly higher for Sr, but lower for V, and much lower for Mo, which provides an indication of the order of solubility of these elements. Kinetic leaching data for KLC 9 demonstrates that the pH drops slightly from 9.0 to 6.8 under oxidising (free leach) conditions but remains circumneutral. Under saturated conditions (KLC 10), the pH remains constant. KLC concentrations of Ca, As, K, Mo, Sb, and V are higher in treated residue than in soil and rock but are not expected to exceed environmental limits. Overall, the pilot plant treated residue have a slight risk in terms of saline drainage but a low risk of acid of metalliferous drainage. They are unsuitable as a growth medium and would benefit from a soil cover for rehabilitation.

5.7.4 Raw processed HPA solid and aqueous components

RGS was provided with a small (140 g) HPA sample from metallurgical analyses for metallurgical recovery analysis. The raw HPA residue stream includes an aqueous and solid component that is acidic and contains elevated salts and metals. These samples were provided to RGS for metallurgical recovery analyses and are not representative of post processed residue quality.

HPA residue pH 4 supernatant is an aqueous phase sample with pH 3.0 and titratable acidity of 3,030 mg/L (as $CaCO_3$). The measured titratable acidity value infers that the equivalent mass of $Ca(OH)_2$ would be required to bring the pH up to 8 to 9. The supernatant is strongly saline at 7,480 µS/cm and is dominated by sulfate (SO_4^{2-}) at 6,580 mg/L with <<< Mg (481 mg/L). << Ca (406 mg/L), < Na (138 mg/L). Concentrations of major, minor and trace metal(loids) are elevated, especially for some elements that have increased solubility at low pH (e.g., Cd, Cs, Co, Cu, Fe, Mn, Ni, Y, and Zn). The supernatant will need to be neutralised to precipitate major, minor and trace metal(loids). The precipitates are an increased risk due to the potential for AMD and will require management such as encapsulation with other hazardous material.

HPA residue pH 4 had a small sample mass (140 g) and due to its water holding characteristics, could not generate sufficient leachate for a full soluble ME analysis suite. pH was measured as $pH_{1:5}$ 4.5 with total sulfur at 22.4% and CRS is 0.024% and this sample is classified as Acid Forming. This sample is saline with an $EC_{1:5}$ of 2,440 µS/cm. Soluble sulfate is 1,440 mg/L in a 1:3 w:v 16 hour leach. Measurements of major cations and anions verified lower concentrations of Mg, Na, K, and SO_4 compared to the pH 2 sample, but higher concentrations of Ca and Cl. Overall, concentrations of soluble minor and trace metal(loids) were much lower in the HPA residue pH 4 sample due to the precipitation of metal(loids) and some major ions (sulfate); conversely there is a much higher high concentration of Ca (179,000 mg/kg).

5.7.5 Environmental management of HPA residue

To minimise the environmental risk posed by the raw HPA residue the residue will be pH neutralised with the calcite flotation stream or the addition of limestone from the TLBA unit to reach a pH of 8.5 to 9. This waste stream will then be blended with the main vanadium process residue. Additional static and kinetic leach analyses of the neutralised HPA residue is to be done by RGS when additional sample mass is available for metallurgical programs.

6 Mine waste management in the final void

6.1 Mining method

Mining will progress with a starter pit and a small out-of-pit waste dump and continue over approximately 26 years using shallow (< 35 m deep), truck and shovel, strip mining methods and progressive in-pit backfilling to slightly above pre-mine topography (**Figure 1-1** and **Figure 1-2**).

As the open pit is developed the mined pit will be backfilled. The backfilled void will reduce the size of the final residual void at the end of the mine life.

The external waste dump and all backfilled landform slopes will be < 1:10 angles that will reduce the potential for erosion due to surface runoff. The surface of all rehabilitated landforms will comprise a 2 m soil cover with 1.5 m of subsoil and 0.5 of topsoil.

During the commencement of mining, a small external mine waste storage area is required, it will be designed to contain geochemically inert material. Soil covers systems will be built on these areas to reinstate pre-mine vadose conditions that will minimise seepage to the regolith.

6.2 Climate

All the climate data used by RGS for the water balance assessment of the operational pit sump was based on Zonia Downs station with historical data from 1900 – 2022. This data was fed into SCL which then generated 100 realisations of stochastic climate results for rain (**Figure 6-1**) and potential evapotranspiration (**Figure 6-2**).

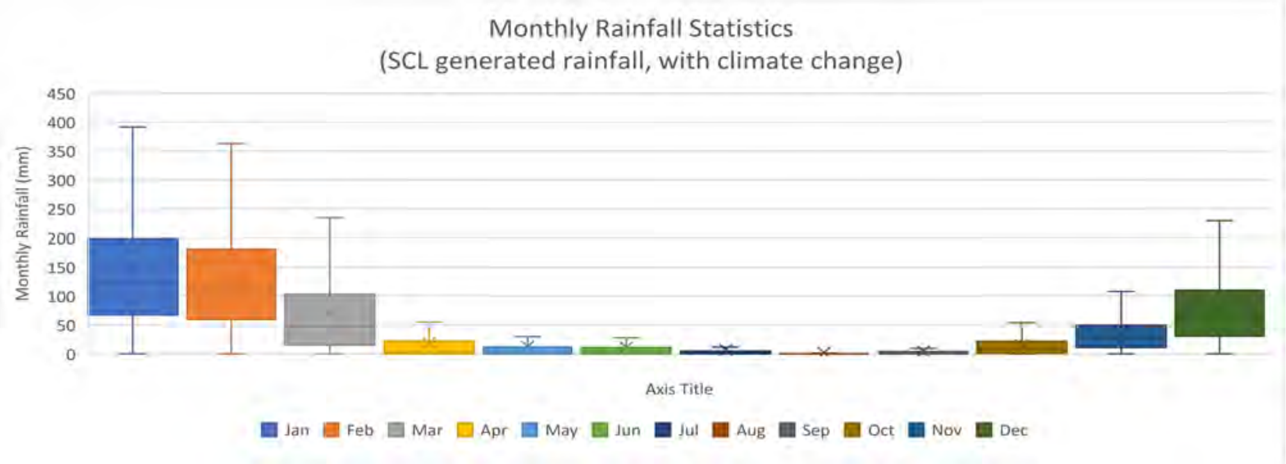

Figure 6-1: Modelled range of rainfall

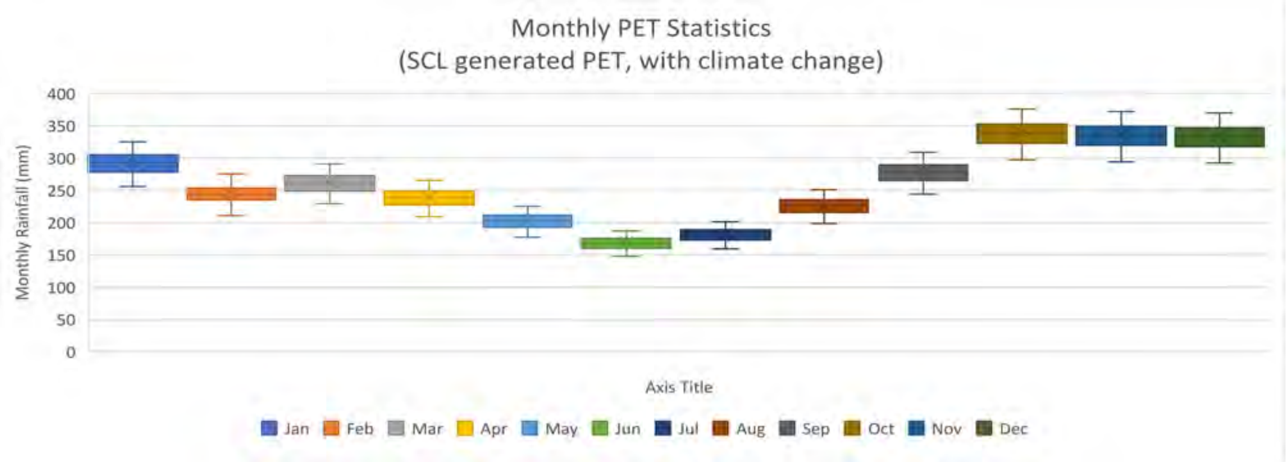

Figure 6-2: Modelled range of PET

6.3 Vadose (unsaturated zone) properties

The soil physical properties of (i) undisturbed pre-mine soil profiles and (ii) cultivated Vertosol soil units is known to differ significantly (Freebairn et al., 1996). Undisturbed Vertosol profiles comprising shrinking – swelling clay (Table 4-15) develop surface cracks that funnel surface runoff from large rainfall events down the cracks. Water then moves out laterally through the “cracked blocks”, and then wet “up” the profile all within the ET extinction zone. Redistribution within the soil blocks between cracks takes many days or weeks due to the low saturated permeability of these soils before equilibrium is achieved (Freebairn et al., 1996). When water percolates past the soil profile movement of water may occur via diffuse lateral flow down through the alluvium. Beyond this strata, preferential flow is likely to occur via structurally controlled processes through the limestone strata until the low permeability weathered shale and fresh shale at the groundwater level is reached.

6.4 Chemical properties

The overburden above the ore is dominated by NAF and AC strata that provide substantial ANC within the deposit. The alkaline pH of the pore water in these units and elemental content **Table 10-1** and **Table 10-2** verify that the range of environmentally mobile elements and their concentrations are low, posing low environmental risk.

Of the 52 metal(loids) analysed using the water soluble $\mathrm{SFE}_{16hr\text{-}1:3}$ method only 8 elements were present consistently (**Figure 4-19**) and the data verify that:

- low concentrations occur in the soil, Quaternary Alluvium (QA) and Wondoola Beds (WDB), Allura Mudstone (ALM), and the Toolebuc-St Elmo Coquina, banded shelly limestone;
- in the sulfide mineralised Toolebuc TLBB-TLBE formations and Wallumbilla Formation sulfate, lithium, manganese, strontium and zinc are elevated;
- the residue is elevated in comparison to the units above in sulfate, arsenic, molybdenum, strontium and vanadium.

The $\mathrm{SFE}_{16hr\text{-}1:3}$ results are validated by the KLC box and whisker results (**Figure 4-21** to **Figure 3-19**) and KLC temporal results (**Figure 4-24** to **Figure 4-26**).

Whereas the overburden strata above the ore are NAF and AC, the floor of the open pit comprising weathered to fresh black shale with low (<0.2% CRS) to high (>1% CRS) sulfide content and low acid neutralising capacity (refer to **Figure 4-5, Figure 4-7** and **Figure 4-10**). The KLC data for this unit verify that when it includes sulfide mineralisation it is susceptible to rapid sulfide oxidation and physical degradation that enable the material to become acid forming (AF) in less than one month (**Figure 4-24**) and potentially within days of exposure to oxygen.

To manage this mine waste risk it is proposed to remove the ore and then place pH neutralised low permeability residue over the shale. Residue from the process plant may need to be contained out-of-pit until there is available room inside the pit to place the residue over the mined shale.

The placement of acid neutralising low permeability residue will stop oxidation of the sulfide minerals in the shale by cutting off oxygen and neutralise actual acidity that may have been produced in the short period of time that the shale is left exposed.

The residue backfill process may be done by filling cells with a thickened residue slurry or by trucking in and end-tipping a dewatered paste over the shale. As mining progresses mixed mine waste from the active mine face will be hauled and end-tipped from the backfilled mine face over the residue cell. The geochemical nature of the AC overburden units will provide additional soluble alkalinity into the open pit to maintain mildly alkaline to alkaline conditions in the backfilled void.

The topsoil (nominally defined as the 0 to 0.5 m bgl layer) and subsoil (nominally defined as the 0.5 to 2.0 m bgl layer) will be stripped ahead of mining and placed into separate topsoil or subsoil stockpiles unless these units can be progressively mined and replaced for rehabilitation work over the life of the mine. Due to the strip mining method, and low depth of the open pit progressive rehabilitation should be feasible from early in the mine life.

6.4.1 Mechanisms of metal(loid) mobilisation and attenuation

The biogeochemical behaviour of Mo, Sr and V and the mechanisms by which these elements are mobilised and attenuated is uncertain in the literature.

6.4.1.1 Molybdenum

Molybdenum forms molybdate oxyanions in natural water; the dominant species are $HMoO^{4-}$ between pH 2 and 5, and $MoO_4^{2–}$ above pH 5 (Brookins 1988). Being anionic, neither Mo species are strongly adsorbed by clay particles, although they are adsorbed by Fe, Al and Mn oxyhydroxides (Kaback and Runnels 1980, Kabata-Pendias 2001); they are also readily coprecipitated by organic matter, $CaCO_3$, and several cations, such as Pb^{2+}, Cu^{2+}, Zn^{2+}, Mn^{2+} and Ca^{2+}. All these reactions are highly dependent on pH and Eh conditions and, therefore, Mo migration during weathering may be poorly predictable (Kabata-Pendias 2001).

Molybdates (MoO_4^{2-}) are the most mobile forms of Mo and any residual MoS_2 or thiomolybdates present in mine waste are likely to be released into seepage and surface runoff in this form, after being oxidised through surface exposure. The relatively low solubility product of calcium molybdate suggests that water containing high Ca concentrations should not contain high concentrations of Mo. The concentration of Mo (VI) is well dispersed in oxygenated water. However, in anoxic water in the presence of sulfide (S^{2-}), O ions are replaced by S ions and the concentration of dissolved Mo(VI) in water gradually decreases and Mo(VI) sequestration in sediment occurs. Mo is used as a palaeoredox indicator by mapping the concentrations of Mo surrounded by oxygen (O) ions in an octahedral configuration (MoO_4^{2-}), compared to concentrations of Mo when surrounded by sulfur (S) ions in a tetrahedral configuration (MoS_4^{2-}). Fox and Doner (2003), observed that Mo accumulated in (and attenuated within) sediments under reducing conditions could become water-soluble again when the samples were oxidised as they dried. There is also a strong relationship between Mo and total organic carbon (TOC) in sediments deposited in euxinic waters (Ardakani et.al., 2020).

6.4.1.2 Strontium

Strontium is a lithophile metallic element. Strontium may substitute for calcium in a variety of rock-forming minerals including K-feldspar, gypsum, plagioclase and, especially, calcite and dolomite, which are the main sources of Sr in stream water where natural concentrations vary over four orders of magnitude in Europe, from 0.001 to 13.6 mg/L, with a median value of 0.11 mg/L. In sedimentary processes, the distribution of Sr is affected both by strong adsorption on clay minerals, extensive substitution of Sr^{2+} for Ca^{2+} in carbonate minerals such as strontianite ($SrCO_3$) and Sr^{2+} for Ba^{2+} in sulphate minerals such as celestite ($SrSO_4$), as well as the amount of detrital feldspar. Enrichment of Sr up to concentrations of 1000 mg/kg is, therefore, common in limestone and evaporates. The minerals and are present in sedimentary rocks.

Strontium is easily mobilised during weathering, especially in oxidising acid environments, and is incorporated in clay minerals and strongly fixed by organic matter. Strontium as the aqueous cation Sr2+ is mobile under most environmental conditions, despite the relatively low solubility of the carbonate and sulphate at neutral to high pHs (Brookins 1988). At pH values below 4.5, the Sr^{2+} ion is dominant. Under more basic conditions (pH 5 to 7.5), $SrSO_4$ forms, and under alkaline conditions (pH>8), $SrCO_3$ is predominant.

6.4.1.3 Vanadium

Vanadium is one of the lightest members of the first row transition elements, consisting of Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu and Zn. Vanadium is a highly mobile element. It displays both cationic character under acid conditions, as vanadyl VO^{2+} and VO_2^{2+} ions, and anionic character under less acid to alkaline conditions, as vanadate HVO_4^{2-} or H_2VO^{4-} ions (Brookins 1988). The solubility of V is strongly controlled by its oxidation state. Its solubility is highest in oxic environments, where vanadyl cations predominate. Complexes with fluoride, sulphate and oxalate may also act to increase V solubility under oxidising conditions (Wanty and Goldhaber 1992), although the presence of U and phosphates can result in the formation of highly insoluble V^{5+} complexes. Under more reducing conditions, the relatively immobile V^{3+} state dominates. The redox regime is important, V remaining mobile under oxidising conditions but being subject to precipitation just above the sulphate/sulphide redox threshold within a pH range of 5.0–8.0 (Brookins 1988).

6.5 Operating open pit sump assessment

6.5.1 Basis of the assessment

As the operating open pit is developed and then moves through the deposit (**Figure 1-1**) this void will collect and store water in the open pit sump during rainfall events. The open pit will be backfilled over the mine life. The backfilled mined pit method will ensure there is no open mine void at the end of the mine life.

During the wet season there is surface runoff from the backfilled pit wall, the in-situ pit walls that are exposed during mining, direct rain fall, and small amount of groundwater inflow. Groundwater flow is so small that evaporation removes the water, precipitating the salts within the basement unit.

- The overburden is dominated by NAF and AC strata with no sulfide mineralisation so the potential for the backfilled material to generate acid drainage is highly unlikely.
- During mining at the interface of the PAF shale, NAF residue will be placed to cut off sulfide oxidation and provide water soluble alkalinity to neutralise any soluble or exchangeable acid in this contact zone.

6.5.2 Purpose

The purpose of the open pit assessment is to quantify the volume and the quality of the water that will accumulate in the operating pit sump at Year 1, Year 10 and Year 25.

6.5.3 Objectives

Utilise the water soluble shake flask extraction and kinetic leach column results as source terms in numerical models.

Use PHREEQC and the source terms to assess the probable range of outcomes on surface, vadose and ground water receptors.

Use GoldSim to quantify climate outcomes in terms of change and variability and water balance considerations, specifically the range in the volume and quality of water that will collect in the mine pit over the wet season.

Document the hazards, risks, and opportunities with the operation, cessation of processing, rehabilitation and relinquishment of the mine as it relates to the backfilled void water quality.

6.5.4 Approach – annual wet season water quality in the operational open pit

6.5.4.1 Operating pit sump water balance

The volume of water likely to accumulate in the operating open pit sump over the wet season (December to March) could be in the range of 69 to 111 ML with an average of 95 ML (**Figure 6-3**).

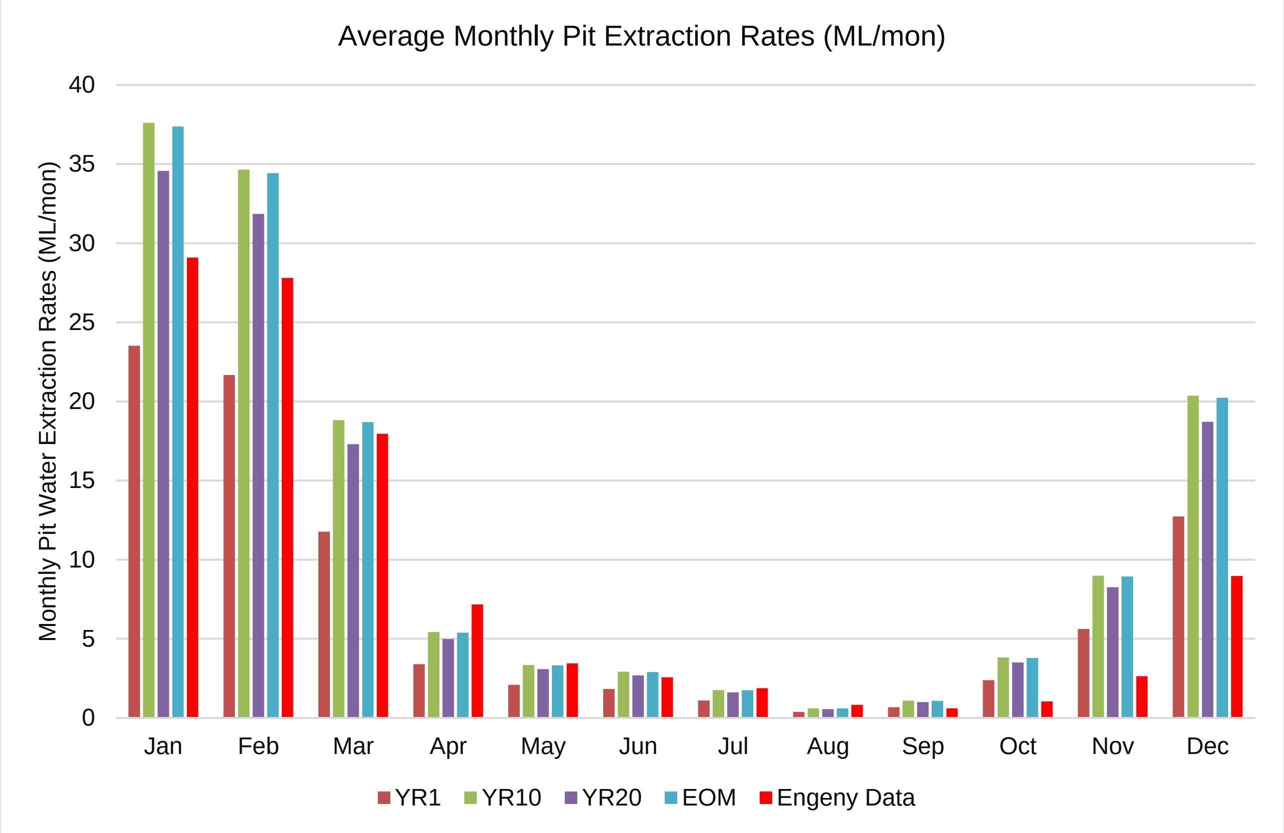

Figure 6-3: Modelled range of operating pit sump volumes

6.5.4.2 Source terms

- Precipitation – assumed low solute concentration data are used for rain.
- Water soluble SFE results are static results that provide quality for a single event; the 1:3 ratio makes the results comparable to a first flush event from surface runoff or pore water quality.
- The KLC concentrations are provided for a first flush event through to "steady state" conditions at 12 months when the sample has re-attained structural integrity and a cohesive nature and the concentration leached from the KLC samples remains mostly unchanged with each subsequent leach event.
- Groundwater is measured from the site (1 x round of samples collected 1st October 2022).
  - The groundwater quality data from October 2022 represents end of dry season conditions.
  - The water quality will change when there is groundwater recharge from rainfall events.
  - The available groundwater data is used directly in the modelling process. The groundwater quality has:
    - moderate salinity (1,900 µS/cm) to high salinity (12,400 µS/cm)
    - salinity is attributed to sodium chloride and calcium sulfate
    - high carbonate alkalinity 290 to 593 mg/L
    - 0.45µm filtered As at 0.005 to 0.032 mg/L
    - 0.45µm filtered Mo at 0.087 to 0.772 mg/L
    - 0.45µm filtered V at 0.087 to 0.772 mg/L
    - 0.45µm filtered Zn at BDL to 0.291 mg/L.

- Water balance – Engeny provided RGS with a daily water balance for the operating open pit. The water balance was run for 25-years and included 50 climate iterations.
- RGS compared the Engeny operational pit sump water balance with a broader stochastic climate modelling method that includes IPCC and QLD Government climate variability and climate change analyses.
- The 10th, 50th and 95th percentile wet season volumes were evaluated to provide a probable range for the water volume and quality that would need to be pumped from the open pit each wet season.
- The annual volume to be pumped from the operating pit was then partitioned into reasonable proportions for rainfall, pit wall runoff from the active mine face, runoff from the backfilled angle of repose slope, alkaline residue water and acid contact water from exposed shale.

6.5.4.3 Modelling code

The following code and assumptions are used in PHREEQC.

- Surface complexation constants for the database distributed with the program and used in this assessment (minteq.dat and minteq.v4.dat) are taken from MINTEQA2 (Allison and others, 1990; U.S. Environmental Protection Agency, 1998).
- SFE and KLC concentrations are used in PHREEQC.
- SFE and KLC results provide definitive major, minor and trace elements that will be present in the chemical system.
- SFE and KLC results provide the probable range of results for each unit in the geological profile.
- Pit wall runoff from
  - backfilled material is the equivalent water quality to {Gi}, with a higher volume of water as it is surface runoff not seepage;
  - in-situ ground is the equivalent water quality to {Gii}, with a higher volume of water as it is surface runoff not seepage
- The KLC data for the AF shale is used to represent shale that has not been covered with residue (assumed to be 50% of the floor of the open pit).
- The KLC data for the NAF residue is used to represent shale that has been covered with residue (assumed to be 50% of the floor of the open pit).
- The concentration of each KLC sample for each lithological unit in the geological profile is mixed in PHREEQC and charge balanced.
- Mineral precipitation and sorption mechanisms are included to enable elements such as Mo, Sr and V to be attenuated in the solid phase of the chemical system.
- pH ranges from the KLC results are used. It is assumed that the NAF residue are placed over freshly exposed unoxidized shale that retains circum-neutral pH.
- Positive Eh values are applied for the oxidised above the water table.
- Groundwater proportions are estimated values for solute mass (not volumes).

6.5.4.4 Model scenarios

Seven scenarios were evaluated in PHREEQC to determine what the range in the quality of the sump water could be like during a dry wet season (Scenario 7) or a wet season (Scenario 1).

1: Average wet season pit sump – All inputs	WLA is partially exposed
2: Wet season pit sump - No Residue	WLA is fully exposed
3: Wet season pit sump - No WLA	WLA is covered
4: Dry season pit sump - All inputs	WLA is partially exposed
5: Dry season pit sump - No Residue	WLA is fully exposed

6: Dry season pit sump - No WLA	WLA is covered
7: Low rainfall pit sump - All inputs	WLA is partially exposed

An example of how the proportion of inputs to the pit sump were determined is in **Table 6-1.** Similar approaches were made for the other 6 scenarios.

Table 6-1: Example of the way water quality inputs are mixed in PHREEQC to calculate pit water quality

Wet season - all		
In-situ pit wall		
	Average thickness of each stratigraphic unit (m)	**% mixed in solution**
Topsoil	0.5	0.000
Subsoil	1.4	0.001
WDB	7.3	0.004
ALM	9.5	0.005
TLBA	4.1	**0.002**
	22.7	0.013
TLBB-TLBD	7.0	**0.013**
WLA	4.5	**0.025**
	Average depth of the mine profile (excluding) WLA 29.7 m	
Backfilled pit wall		
Topsoil	0.5	0.000
Subsoil	1.4	0.001
WDB	7.3	0.005
ALM	9.5	0.006
	18.6	0.013
NAF Residue	10.0	**0.025**
Groundwater		**0.013**
Direct rainfall		**0.900**
Rain quality		
pH	5.47	
Alkalinity	5	
Na	2.46	
K	0.37	
Ca	1.2	
Mg	0.5	
Cl	4.43	

6.5.5 Results – annual wet season water quality

The water quality for the major ions, and metal(loids) of relevance in this deposit, have determined solute concentrations in the pit sump should be in a low range that is comparable or better than groundwater and should not exclude the water in the operational pit sump being returned into the process water circuit.

It is even feasible that the pit water may comply with release criteria for surface water so the excess water in the pit sump can be removed from the water balance.

There is some uncertainty around the range of concentrations in groundwater parameters as only one round of analyses is available. Elements such as F, Li, and Sr are not in the groundwater suite. The concentration of Cr, Pb, Hg, Se were below detection limits in the groundwater.

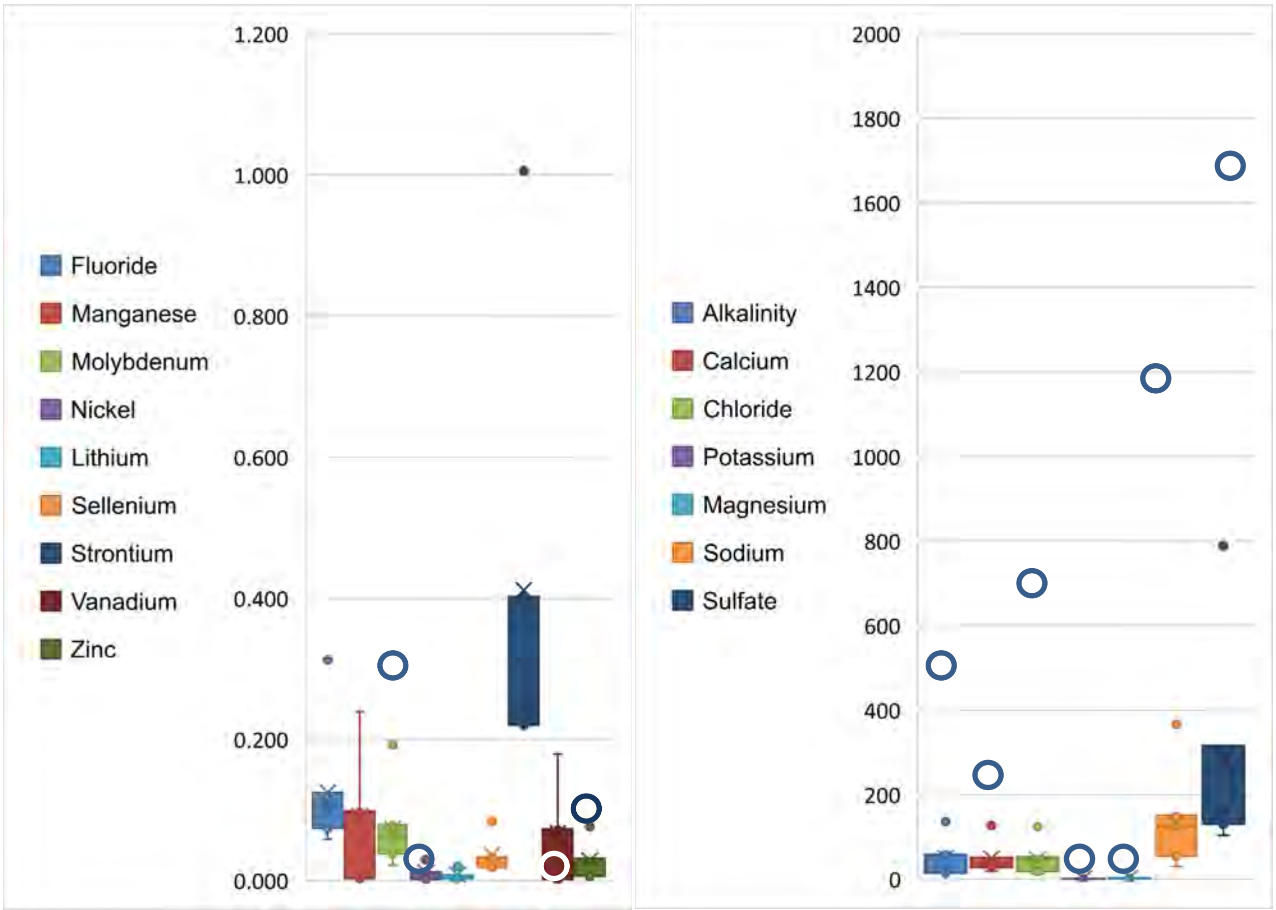

Figure 6-4: Operational pit sump water quality outputs from PHREEQC modelling

Open circles denote groundwater concentrations
All concentrations are in mg/L

6.5.6 Implications for potential adverse effects on the receiving environment

Groundwater inflow to the operating pit is considered to be extremely low and no ponding water from groundwater inflow is likely. However the solutes in the groundwater seeps will precipitate in the mined pit and become soluble inputs to the wet season water balance.

The water that may accumulate in the open pit from wet season rainfall events will be pumped out to maintain effective mining conditions. It is envisaged that a sump will be developed and maintained so all wet season flows can be removed from the operating pit as quickly as possible.

The quality of the wet season flow should not preclude it being used in the process water circuit making any adverse effects from this water source highly unlikely.

6.6 Backfilled void assessment

6.6.1 Basis of the assessment

Approximately 10 m of NAF residue is proposed to be placed over the top of the black shale and covered with approximately 50% of the TLBA (limestone) and all the Wondoola Beds, Allaru Mudstone, Quaternary Alluvium including the pre-mine soil profile (approximately 20 m of overburden).

As the operating open pit is progressively backfilled over the life of the mine, rain will initially percolate through the backfilled loose unconsolidated soil, alluvium, and overburden strata under first flush conditions e.g.

- k_{sat} of 20 to 30 cm /yr at 90% Proctor in the soil and Allaru Mudstone
- k_{sat} of 38 to 117 cm /yr at 90% Proctor in the TLBA (limestone unit)

The conceptual model is that the first flush through the backfilled overburden will mix with the porewater in the residue and the precipitated groundwater solutes within the backfilled void.

The movement of water through the backfilled strata is then envisaged to decrease by up to an order magnitude as the end tipped units settle and consolidate e.g.

- k_{sat} of 2 to 11 cm /yr at 90% Proctor in the soil and Allaru Mudstone
- k_{sat} of 4 to 41 cm /yr at 90% Proctor in the TLBA (limestone unit).

The small volumes of water moving through the backfilled material in the open pit contribute to groundwater recovery in the mined pit that are modelled to take many decades before the pre-mine groundwater level is reached and the pre-mine groundwater flow paths are reinstated (JBT, 2023).

Other considerations in this numerical assessment include the following.

- Mining increases the particle size distribution of intact geological units through mechanical and physical (anthropogenic) weathering.
- The increased surface area enables soluble and sparingly soluble weathering products to be leached from the solid phase into the aqueous phase. The mechanical mixing and enhanced oxidation will also result in accelerated weathering and the mobilisation of exchangeable and carbonate minerals.
- Surface runoff from the rehabilitated land will be comprised of suspended and bedload sediment from the replaced topsoil profile.
- No surface water quality issues from the rehabilitated land in the receiving environment are anticipated: excluding potential issues associated with erosion and the movement of suspended sediment and bedload sediment in surface runoff, and the effect of the erosion on the landform itself.
- As little as up to 1% of the net annual rainfall percolates through the backfilled material to the backfilled NAF tailings.
- The groundwater recharge from rainfall occurs during highly irregular, high intensity and duration rainfall events and are unlikely to occur at all during the dry season or during periods of drought.
- The overburden is dominated by NAF and AC strata with no sulfide mineralisation so the potential for the backfilled material to generate acid drainage is highly unlikely.
- The backfilled strata has low concentrations of major ions (salts) and metal(loids) (Section 4.2 and 4.3).
- The low flow rate and low annual volume of water moving through the backfilled material results in a very low aqueous to solid ratio.
- The extremely low aqueous to solid ratio in the in-situ or backfilled mine pit can lead to significantly higher water soluble concentrations in the porewater than occur under the 1:3 aqueous to solid ratio in the SFE method or the 1:2.5 aqueous to solid ratio used in the KLC method.
- Accounting for assumed preferential or diffuse flow through in-situ or mined and backfilled material is required so all aqueous and solid mixing mechanisms are assumed to be evenly distributed, as they are under SFE and KLC laboratory methods.
- Major ion concentrations in groundwater are due to long term leaching through the regolith, coupled with low transmissivity of groundwater through the deposit i.e. soluble ions accumulate over time, and mobilised elements are redistributed and attenuated through complex bio-geochemical processes.
- Metal(loid) concentrations are attenuated through cation exchange, precipitation, and co-precipitation in the oxic alkaline overburden or via anoxic/reducing mechanisms in the groundwater systems, that may also be driven by organic complexation due to high organic carbon and hydrocarbon sources within the shale units.
- During mining at the interface of the PAF shale, NAF residue will be placed to cut off sulfide oxidation and provide water soluble alkalinity to neutralise any soluble or exchangeable acid in this contact zone.

- Conceptually it is envisaged that when the extremely small amount of water percolating through the backfilled soil and regolith strata above the NAF tailings reaches the NAF tailings lateral flow of water will direct pore water across the tailings rather than moving porewater vertically through the NAF tailings to the groundwater table.

6.6.2 Purpose

The purpose of the open pit assessment is to quantify the quality of the water that will accumulate in porewater of the base of backfilled mined void above the pre-mine groundwater table. The porewater in this zone remains physically isolated from the pre-mine groundwater until the pre-mine groundwater level is reinstated decades to centuries after mining ceases.

6.6.3 Objectives

Utilise the water soluble shake flask extraction and kinetic leach column results as source terms in numerical models.

Use the measured permeability data and groundwater modelling to define probable percolation and recharge rates and mechanisms.

Use PHREEQC and the source terms to assess the potential range in water quality that may accumulate within the dewatered zone of the mined pit for many decades before the pre-mining groundwater level is reached.

Document the hazards, risks and opportunities with the operation, cessation of processing, rehabilitation, and relinquishment of the mine as it relates to the backfilled void water quality.

6.6.4 Approach – backfilled void water quality post closure

The vadose processes of the upper soil cover system on the upper profile of the constructed mine landform rehabilitated profile will be more akin to cultivated soil units and in time (2 to 3 seasons) it is suggested that pedogenic reformation of the soil will reinstate the shrinking – swelling properties of the soil profile.

6.6.4.1 Source terms

- Precipitation – assumed low solute concentration data are used for rain.
- Water soluble SFE results are static and provide quality for a first flush, single event; the 1:3 solid to water ratio simulates pore water quality.
- The KLC concentrations are provided for a first flush through to “steady state” conditions at 12 months when the samples has re-attained structural integrity and a cohesive nature and the concentration leached from the KLC samples remains mostly unchanged with each subsequent leach event.
- Groundwater quality is from one measured and the available groundwater solute mass is used directly in the modelling process.

6.6.4.2 Modelling code

The following code and assumptions are used in PHREEQC.

- KLC concentrations are used in PHREEQC.
- KLC results provide definitive major, minor and trace elements that will be present in the chemical system.
- KLC results provide the probable range of results for each unit in the geological profile.
- Each KLC unit is weight averaged to reflect the total solute input to the system e.g. the soil layer of 1 m depth represents 5% of the inputs in a 20 m deep geological profile.
- The second leach event for each KLC sample is used as a probable upper range first flush input. An alternative run utilises the cumulative mass of the leachate in each KLC samples to provide a potential upper range.

- The concentration of each KLC sample for each lithological unit in the geological profile is mixed in PHREEQC, and charge balanced to account for attenuation (precipitation and sorption mechanisms).
- Mineral precipitation and sorption mechanisms are included to enable elements such as Mo, Sr and V to be attenuated in the solid phase of the chemical system.
- pH ranges from the KLC results are used. It is assumed that the NAF residue are placed over freshly exposed unoxidized shale that retains circum-neutral pH.
- Positive Eh values are applied for the oxidised above the water table.
- Negative anoxic and reducing Eh values are applied for the saturated zone below the water table.
- Groundwater is mixed with the annual volume of water passing through the backfilled geological profile.
- The results in **Figure 6-5** also include modelled concentrations at Year 1 to Year 25.

6.6.4.3 Scenarios analysed and temporal results

A range of management outcomes was evaluated using PHREEQC to document the range in water quality results that could occur as the backfilled mined pit accumulates water. The rate that water will percolate through the backfilled material or drain laterally into the backfilled pit as seepage of groundwater is assumed to be very low. This is due to low average annual recharge rate to groundwater from rain (1 or 2%) in this region and the projected groundwater flows into the operating pit and then into the backfilled pit determined in the Groundwater system (JBT, 2023).

The **scenarios** evaluated using PHREEQC (**Table 6-2**) include the following, noting that: the % values below represent the solute contribution from each unit that accumulates in the base of the pit: the groundwater contribution allows for the input of salts that accumulate in the pit over the life if mine (it is not a purely volumetric input).

The **results** in **Figure 6-5** includes charge balanced inputs and then the results for **Year 1 (All_G)** and then results for **Year 2 (Gi+G)** to **Year 6 (Gvi+G)** and then results for **Year 19 (G19+G)** and **Year 50 (G50+G)**.

Scenario 1 assumes there are essentially no inputs from NAF or AF shale and decreasing contributions from limestone in Scenario 1a to 1c.

Scenario 2 is the most probable outcome whereby PAF shale is excluded from the mine plan or is covered immediately after ore is removed to stop sulfide oxidation and acid production.

Scenario 3 is a worse case (highly unlikely) outcome whereby all shale in the base of the pit is PAF (which is not the case) and the shale then becomes AF and is not managed to neutralise acid.

Table 6-2: Relative proportions of source terms added to PHREEQC

	Scenario 1a	Scenario 1b	Scenario 1c	Scenario 2	Scenario 3
	% of the total volume of water that accumulates in the base of the backfilled pit				
Topsoil	1	1	1	1	1
Subsoil	3	3	4	3	3
Combined	4	5	5	4	4
Wondoola Beds	17	17	18	16	16
Allaru Mudstone	22	23	24	21	21
Combined	38	40	42	36	36
TLBA	9	5	0	4	4
TLBB-TLBE	0	0	0	0	0
WLA (NAF)				10	
WLA (PAF)					10
Residue	23	24	25	22	22
Groundwater	25	26	28	24	24

6.6.5 Results – backfilled void water quality

The results of the backfilled mine pit scenarios have determined that a narrow band of outcomes are probable for pH and salinity and the key elements (Mo, Sr, and V) that will be most mobile at the highest concentrations within the backfilled pit; for example;

- pH at 7.5 to 8.8
- EC at 1,250 to 5,000 µS/cm
- Mo at 0.443 mg/L to 0.675 mg/L
- Sr at < 1.736 to 2.272 mg/L
- V at 0.621 to 0.715 mg/L - Vanadium is present at higher concentrations when residue are added to the backfilled pit.

The measured groundwater quality that can be considered as the receiving environment has comparative concentrations from one groundwater monitoring event of:

- pH at 7.9 to 8.3
- EC at 1,900 to 12,400 µS/cm with an average of 5,888 µS/cm
- Mo at < 0.087 mg/L to 0.722 mg/L
- Sr not included in the groundwater monitoring
- V at 0.01 to 0.03 mg/L

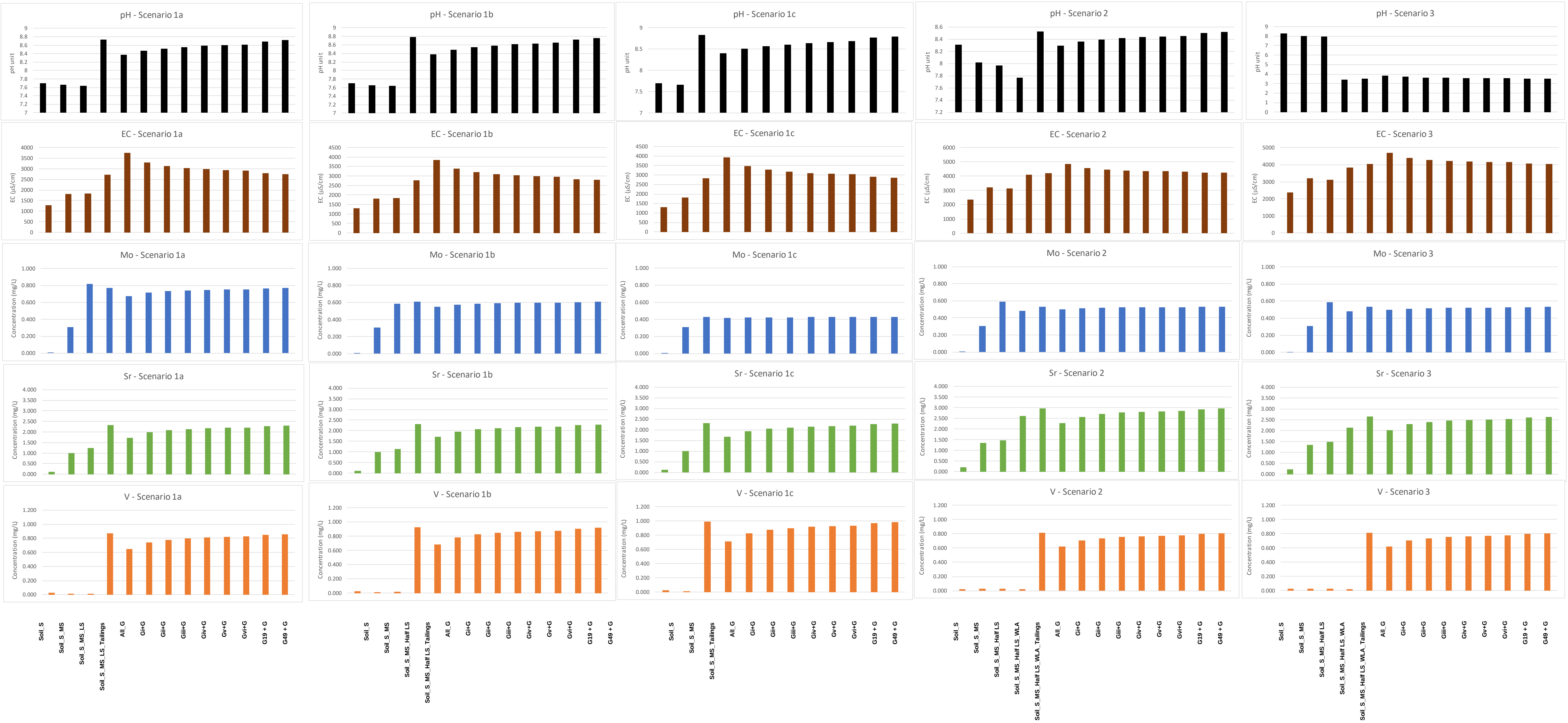

Figure 6-5: Backfilled pit scenarios

6.6.6 Implications for potential adverse aquatic ecotoxicity effects

There is limited freshwater aquatic ecosystem chronic and acute ecotoxicity data in the Australian Water Quality Guideline (2018) for Mo and V and nothing for Sr. The limited ecotoxicity data verify that the potential for adverse effects on the receiving environment are also highly uncertain.

- A freshwater low reliability trigger value of 6 µg/L was calculated for vanadium. This should only be used as an indicative interim working level (AWG, 2018). The range of values known to induce chronic or acute ecotoxicity are unique for each of the species used and the concentrations range of 1 or even 2 orders of magnitude.
- A freshwater low reliability trigger value of 34 µg/L was calculated for molybdenum. This should only be used as an indicative interim working level (AWG, 2018). The range of values known to induce chronic or acute ecotoxicity are unique for each of the species used and the concentrations range of 1 or even 2 orders of magnitude.
- Strontium has no freshwater data (AWG, 2018).

The freshwater ecosystem chronic and acute ecotoxicity data in the water quality guidelines have not been updated since the ANZECC and ARMCANZ, 2000 guidelines and are based on a small number of standard species for freshwater aquatic ecosystems: **not** groundwater.

The intent of the section is to document the high degree of uncertainty that there is for these particular elements and reiterate that the lack of scientific research and data infers that the scientific community that developed the ANZECC and ARMCANZ 2000 Guideline and the revised AWG (2018) regulatory framework consider these elements to be low risk considerations.

The reference point for the determination of potential adverse environmental effects to the groundwater system from water within the backfilled void would be the groundwater quality from the local monitoring bore results that are provided in the groundwater assessment as unfiltered (total) and 0.45 µm filtered (soluble) fractions. However at this point there is only one groundwater monitoring event to provide comparative results.

The measured groundwater data, the measured static and kinetic leach column data, and the PHREEQC modelled predications for water quality all indicate a low degree of risk to the receiving groundwater system beyond the backfilled void.

The risk to the receiving environment is further reduced by the groundwater modelling report that has determined it will take many decades (potentially centuries) for the pre-mine groundwater level to be reinstated, and it is only at that point that water in the backfilled void would interact with the surrounding coquina aquifer, where the dilution of any elevated solutes could be expected.

Furthermore the Saxby River to the south of the Project area is;

- ephemeral and the available data indicates that the regional groundwater level is a significant depth below the base of alluvium in the Project area and that any groundwater in the Saxby River alluvium is hydraulically disconnected from the regional water table.
- conceptualised as being disconnected from the regional groundwater system in the Project area and is neither a gaining, or losing, stream in the Project area.
- not a source of groundwater extraction for landowners who preferentially draw on groundwater from the much deeper Gilbert River Formation.

7 Conclusions

This technical report has provided data to characterise all the mined stratigraphic units (soil, regolith and rock), as well as residue and HPA process residue from the proposed VCMP.

7.1 Climate

At Cloncurry near this project minimum, mean and maximum rainfall is highly variable 117, 500 and 996 mm/yr) with a mean of 5.5 days per years when there is ≥ 25 mm of rain per day. This will result in short duration intense rainfall events and long protracted periods of low or no rainfall. These conditions will need to be considered for rehabilitation planning.

7.2 Geology

The typical depth of the strata and lithological units that will be mined from this deposit is about 30 m bgl (**Table 7-1**).

Table 7-1: Geological units in the deposit

	RGS geochem samples			ATCW drill logs			
Unit Thickness (m)	**DEB21_05**	**DEB21_12**	**DEB21_17**	**DEB21_03R**	**DEB22_18R**	**DEB22_50**	**Average**
Topsoil	0.5	0.5	0.5	0.7	0.4	0.2	0.5
Subsoil	0.5	0.5	1.5	2.2	2.6	1.3	1.4
Assumed potential evaporation extinction depth							
Silt/Sand	9.0	10.0	7.0	8.1	2.5	7.0	7.3
Mudstone ALM	9.0	6.0	19.0	6.0	10.1	6.6	9.5
Limestone (TLBA)	2.0	6.0	6.0	3.3	3.0		4.1
Toolebuc Fm (TLBB-TLBD)	9.5	7.5	5.5	5.1	4.7		6.5
REE (TLBE)*	0.5	0.5	0.5	0.4	0.5		0.5
Mudstone WLA							
Total	35.0	35.0	44.0	30.5	29.5	15.1	30.1

7.3 Surface runoff and groundwater recharge

Surface runoff occurs as overland flow. Net annual recharge from rainfall to groundwater in this climate region may be as low 1 to 2% per annum in the unmined structurally controlled pedolith and regolith units at the site. Most of the rainfall falling on the surface of the soil profile is lost as evaporation or transpiration.

Movement of water through the regolith occurs in pulses during the irregular, but high intensity rainfall events. The movement of water through unmined strata is probably dominated by preferential flow, but in the backfilled strata in an external dump or backfilled pit the movement of water through the mixed overburden profile is more likely to occur through diffuse, lateral flow at very low rates.

7.4 Topsoil and subsoil

The 0 to 0.5 m topsoil layer and underlying 1.5 of the subsoil layer are to be stripped and replaced as cover material over the constructed mine landforms.

Within the project area the topsoil and subsoil are documented to be Grey Vertosol and Dermosol, Arenosol, and Alluvium (AARC, 2023). The chemical and physical properties of these soil types vary, but all soil units support self-sustaining vegetation communities. The Grey Vertosol and Dermosol may provide better outcomes for rehabilitation of the constructed mine landforms than the Arenosol and Alluvium. The topsoil and subsoil samples analysed by RGS are non-dispersive but the soils in the project area are known to be prone to erosion. To overcome the potential for erosion of the constructed mine landforms very low slope angles are proposed to be used on the external slopes of the small out-of-pit dump and the backfilled areas of the open pit.. Field trails developed early in the mine life would provide additional evidence on which soil unit provides the best outcomes for rehabilitation. Ongoing soil mapping within the proposed open pit will verify the areas that are covered by each soil type. The soil mapping combined with the proposed mining schedule will then verify the volumes of each soil type that will be recovered (and progressively used for rehabilitation over the mine life).

7.5 Overburden

All overburden will be mined and backfilled into the open pit.

Initially overburden will be placed into a small out-of-pit dump. It is estimated that 25 to 50% of the limestone unit will be used in processing and that the balance of this unit will be used for mitigating AMD potential in the open pit; mostly by covering PAF-HC shale if/when it is identified.

Below the topsoil and subsoil layers in the pedolith there is Quaternary Alluvium (QA) and Wondoola Beds (WDB), Allaru Mudstone (ALM) and a limestone dominated Toolebuc Formation horizon (TLBA). All overburden units are NAF or AC. These units are within the regolith and above the groundwater table. They are extremely to partially weathered, and the QA, WDB and TLBA units enable rapid percolation of water through the profile due to the fractured, porous nature of the units. When all these units are mined, the physical and mechanical weathering will degrade the intact structure and the material will become dominated by gravel, sand, silt and clay fractions. The change in the physical properties of these units will affect the movement of water through the backfilled material.

7.6 Orebody

All ore (TLBB to TLBE) is proposed to be processed.

In the orebody samples (**Section 5.6**) 83% of the samples have < 0.2% CRS, but there are a high proportion of samples with elevated TS with 0.01% to 2.67% for TLBB, 0.02% to 7.31% for TLBD, and 0.11% to 3.23% for TLBE. The TS is associated with sulfate bearing minerals such as gypsum. The ANC for orebody samples is low to high (7.3 to 900 kg H_2SO_4/t).(**Figure 4-17**) The samples are geochemically classified (based on TS) as AC (76%), NAF (12%), NAF-LC (2%), PAF-LC (3%), PAF (5%), or PAF-HC (2%). The proportion of acid consuming materials decreases with depth (100% AC in TLBB to 16% AC in TLBE).

7.7 Basement unit

The basement material is black shale, and it predominantly PAF-LC, PAF, and PAF-HC. The PAF and PAF-HC shale will produce AMD is short periods after is exposed. All basement shale will be covered with NAF residue or AC limestone progressively during mining.

The black shale (WLA) transitions from partially weathered shale to fresh (unweathered, non-oxidised rock). Assay data for this basement unit within the deposit (not the proposed pit shell) has TS measured at 2.65 to 4.66% (**Figure 1-4**). TS analyses from the sample within the pit shell are 0.03 to 2.32% and 85% of samples have > 0.2% TS. In this unit the TS is predominantly sulfide sulfur (**Figure 4-15**). The ANC in this unit is low to moderate at 0.7 to 80 kg H_2SO_4/t (**Figure 4-17**). The geochemical classification for this unit samples (based on TS) is NAF (17%), NAF-LC (12%), PAF-LC (10%), PAF (29%), or PAF-HC (32%). The KLC results for the WLA formation verify that the PAF shale will oxidise rapidly and produce acid drainage in < 1 month (**Section 4.3**).

From an operational perspective the PAF-HC shale may be covered as soon as possible after ore is removed with 0.5 m of AC limestone from the TLBA unit or covered in with the NAF residue. In both cases the addition of NAF residue or AC limestone will cut off oxidation processes and neutralise any actual acidity

7.8 Final void

The proposed approach to backfilling the mined pit over the life of mine will ensure there is no open final void that could develop into a pit lake.

7.9 Proposed mine waste and residue management strategy

The proposed mine waste and management strategy for the residue stream is to float off the calcite, recover vanadium and then neutralise the sulfuric acid leached residue with the entrained calcite float from the ore, and supplement this with $Ca(OH)_2$ and limestone overburden to ensure the residue will not produce acid in the future.

During mining approximately 10 m of pH neutralised NAF residue is to be placed over the exposed PAF shale progressively over the mine life in cells so the shale is not allowed to oxidise and produce acid. If the PAF shale does oxidise and produce acidity it would be neutralised by the NAF residue or acid consuming (AC) limestone from the TLBA unit. Maintaining mildly alkaline pH (pH 8 to 9) in the backfilled mine voids will result in low concentrations (or concentrations below detection) of elements such as Al, Cd, Co, Cu, Fe, Mn, Ni, and Zn). The elements such as Mo, Sr and V present at low mg/L concentration will maintain environmental mobility as they are less prone to precipitation, but other attenuation mechanisms with organic components, and clay minerals under anoxic or reducing conditions or co-precipitation with other metalloids, is likely to reduce soluble concentrations of these elements over time.

The quality of the water for the backfilled scenarios is not significantly different to the measured groundwater quality so adverse impacts to groundwater quality are considered unlikely. Adverse effects to groundwater in the receiving environment are further decreased because the accumulation of porewater within the backfilled void will occur over many decades or even centuries (JBT, 2023) because of the very low:

- recharge rate from rainfall through the backfilled pit that is projected to be < 1% of the annual rainfall, and,
- groundwater flow to the operational pit that is anticipated to be < 1 L/s - however the water will be lost to evaporation leaving the precipitated solutes on the pit floor to be mixed with the wet season rain.

Adverse effects to the receiving environment from porewater in the voids of the backfilled material is further mitigated by the fact that the:

- Saxby River to the south of the Project area is;
  - ephemeral and the available data indicates that the regional groundwater level is a significant depth below the base of alluvium in the Project area and that any groundwater in the Saxby River alluvium is hydraulically disconnected from the regional water table;
  - conceptualised as being disconnected from the regional groundwater system in the Project area and is neither a gaining, or losing stream in the Project area; and,
- the water in the Toolebuc Formation where any future backfilled void water table will develop decades or centuries into the future is not a source of groundwater extraction for landowners who preferentially draw on groundwater from the much deeper Gilbert River Formation.

7.10 AMD potential

7.10.1 Acid drainage

Acid drainage from the units above the orebody is improbable. Acid drainage is possible, even probable, if PAF-HC shale in the basement unit is exposed and is not managed by covering it with NAF residue or AC limestone. The overwhelming abundance of NAF residue and AC limestone will be more than sufficient to neutralise any acid that is produced in this deposit at the source, negating issues beyond the immediate area of disturbance. The geochemical source terms from the static water soluble shake flask extractions and the kinetic leach column analyses combined with the water quality evaluations using PHREEQC verify the neutral or mildly alkaline drainage is the most probable outcome.

7.10.2 Saline drainage

Saline drainage within the backfilled voids is likely but should not exceed measured groundwater conditions. Measured groundwater data from one sample event verify that the groundwater is moderately to highly saline. Additional sample events will determine if the measured salinity varies with rainfall events and recharge. Sulfuric acid is used in the processing of the ore, and this will add sulfate to the hydro-geochemical system in the backfilled pit, however the abundance of calcium in the residue and in the overlying backfilled strata in the pits will favour the reformation of gypsum immobilising sulfate.

Salinity in the open pits has been evaluated using PHREEQC and the geochemical source terms from the static SFE and KLC work program. The salinity in the operating pits is unlikely to be higher than the groundwater due to the predominant input of rain to the pits during the wet season. The salinity in the open pit will of course vary with the rainfall intensity, frequency, and duration.

7.10.3 Metalliferous drainage

Metalliferous drainage within the backfilled voids is likely, but should be limited to elements such as molybdenum, strontium, and vanadium whose concentrations should not exceed measured groundwater conditions.

Metalliferous drainage occurs when mined waste is dominated by sulfide minerals, oxide minerals (e.g. scorodite that can release arsenic, or chalcocite that may release copper) or carbonate minerals (e.g. malachite that may release copper).

In this deposit vanadium is being extracted from oxide minerals in the regolith above the groundwater table. Accessory elements occur at low concentrations that can be precipitated / attenuated by carbonate alkalinity, which is provided by calcite.

Of the elements analysed, molybdenum, strontium, and vanadium and likely to be the elements present at higher soluble concentrations. The PHREEQC modelling of the operational pit water quality has determined that the water quality is in the range of concentrations present in the groundwater, so adverse impacts to the receiving environment are considered to be highly unlikely or improbable.

8 Recommendations

It is recommended that additional work is undertaken on process reside streams as they are produced from pilot scale metallurgical programs. This should include undertaking static and kinetic leach column analyses and physical analyses include k_{sat} and soil water characteristics.

Continue to build up the geochemical database within the pit shell through ongoing drilling, sampling and analysis using, $pH_{1:5}$, $EC_{1:5}$, TS, CRS and ANC.

Obtain bulk samples of topsoil and subsoil layers (in each of the main soil units within the pit shell) and the underlying strata including the Allaru Mudstone (ALM) Wondoolla Beds (WDB) and the Toolebuc TLB Limestone unit (TLBA) from bulk ore sampling programs and analyse these samples for a full suite of soil fertility, geochemical and physical properties.

Use the bulk samples to measure erosion rates so that erosion modelling can be done to verify probable performance criteria for the proposed rehabilitation at the site.

Use the bulk samples from the bulk ore sampling process to:

- quantify how the particle size distribution, porosity and permeability between in-situ conditions and backfilled conditions changes over time;
- install soil moisture, soil suction sensors that can verify how water moves through the backfilled profile; and,
- document rates of settlement and consolidation in each of the overburden and ore units.

Develop a landform design performance monitoring plan that will enable the project to establish field trials in Year 1 on the ex-pit waste rock dump.

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10 Attachments

10.1 Attachment A: Additional tables and figures

10.1.1 Attachment Ai: Project location

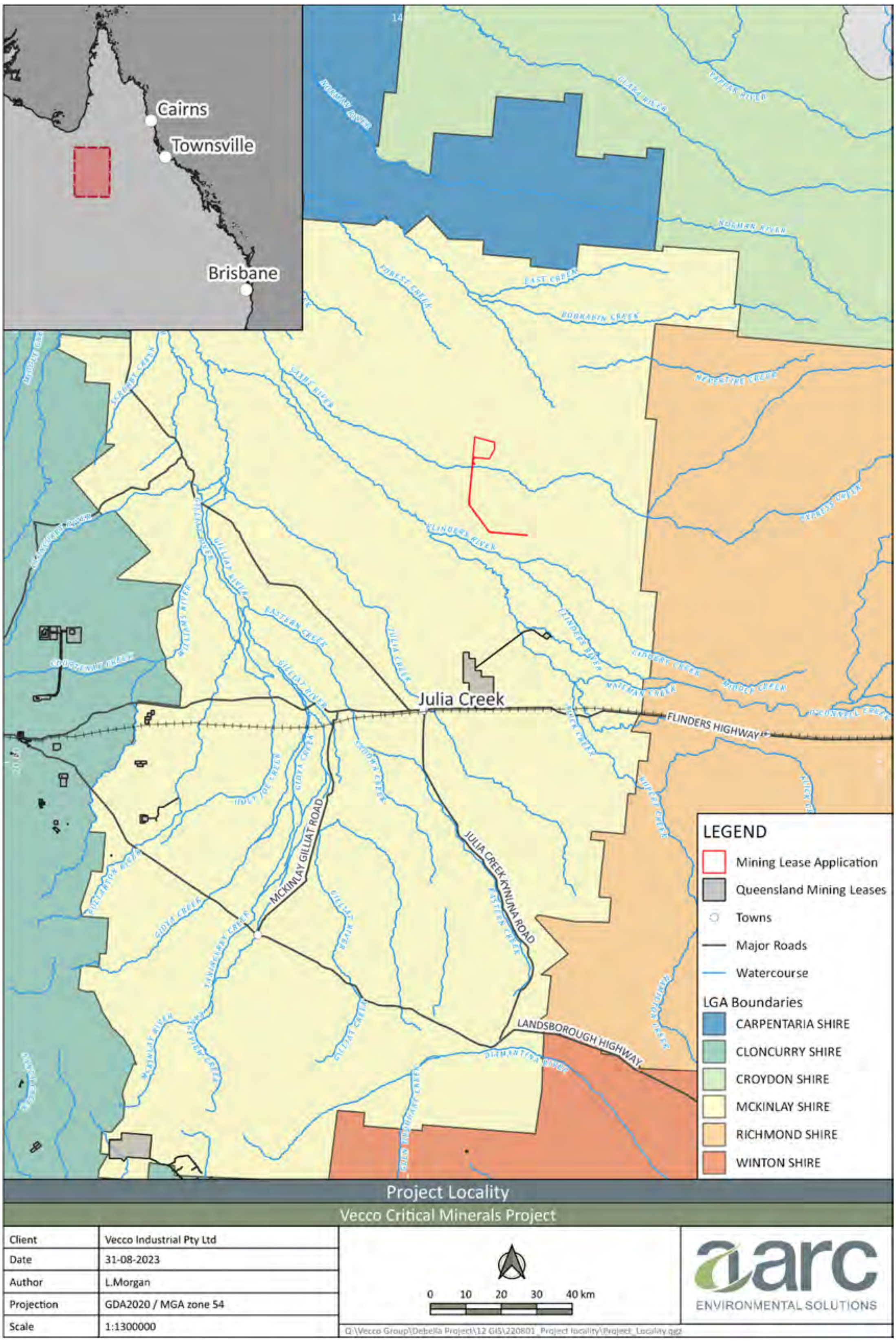


Figure 10-1: Project location

10.1.2 Attachment Aii: 2 acid digest and water soluble shake flask extraction results

Table 10-1: Total metal (2-acid digest) results for soil, rock, and residue (Al - Mg)

Batch number	Sample number	Lithology	Aluminium	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cadmium	Calcium	Caesium	Cerium	Chromium	Cobalt	Copper	Gallium	Germanium	Hafnium	Indium	Iron	Potassium	Lanthanum	Lead	Lithium	Magnesium
		Concentrations in mg/kg																							
1	C003	Topsoil	16,200	0.09	1.6	140	0.54	0.08	0.04	3,600	0.96	30	18	7.9	9.8	4.67	0.06	0.15	0.02	6,160	400	12.1	7.9	5.8	2,000
2	C001	Topsoil	12,700	0.12	1.8	120	0.51	0.08	0.06	5,900	0.74	26.9	19	5.7	9.3	4.06	0.05	0.16	0.019	13,900	400	10.3	7.1	5.6	1,300
2	C002	Topsoil	14,700	0.10	1.6	180	0.59	0.09	0.08	8,200	0.84	30.9	17	6.5	9.5	4.39	0.05	0.15	0.022	14,000	400	13.4	8.3	5.7	2,000
1	C004	Subsoil	19,700	0.10	1.9	150	0.56	0.09	0.05	6,600	1	29.6	21	7.5	10	5.26	0.07	0.22	0.022	6,060	500	13.3	7.4	6.7	2,300
2	C003	Subsoil	11,800	0.11	1.8	160	0.54	0.07	0.06	17,000	0.77	32.2	16	6.7	7.8	3.65	0.05	0.14	0.019	12,700	400	14.4	7.2	4.7	1,800
2	C004	Subsoil	12,300	0.09	2.1	900	0.61	0.08	0.06	9,300	0.81	37.7	15	6.2	7.7	3.36	<0.05	0.13	0.016	12,300	500	13.7	6.9	4.7	2,500
1	C005	Subsoil /sand	13,600	0.10	3.1	260	0.51	0.08	0.06	17,300	0.83	27.2	14	6.6	8.7	3.84	0.07	0.13	0.018	4,460	500	12.0	6.3	5.3	2,600
1	C006	Silt /sand	5,700	0.12	2.8	100	0.25	0.04	0.08	2,900	0.41	12.6	8	3.4	6.3	1.66	0.05	0.1	0.008	2,820	400	6.5	3.5	2.2	1,000
1	C007	Silt /sand	17,400	0.10	7.4	260	0.72	0.13	0.09	48,200	1.15	30.3	15	12.6	14.3	5.98	0.08	0.14	0.038	11,000	1,100	13.2	9.0	10.2	5,000
1	C008	Silt /sand	21,600	0.12	7.5	240	0.81	0.18	0.11	25,700	1.36	31.6	19	13.6	21.2	7.96	0.07	0.18	0.046	17,200	1,700	13.6	9.9	18.3	6,200
2	C005	Sand	7,900	0.09	1.9	80	0.38	0.05	0.08	6,000	0.62	18.3	11	3.5	6.3	2.43	<0.05	0.13	0.011	10,100	500	7.9	4.4	3.6	1,400
2	C006	Sand	7,700	0.11	3.0	120	0.37	0.07	0.09	9,400	0.59	18.4	11	4.3	7.7	2.36	<0.05	0.12	0.011	11,300	600	8.1	4.8	4.0	1,600
1	C009	Sand-mudstone transition	15,400	0.12	7.0	300	0.62	0.13	0.12	38,300	1.08	24.8	13	9.2	14.6	5.09	0.07	0.14	0.031	10,000	1,100	11.0	8.3	10.8	4,000
2	C007	Sand-mudstone transition	10,700	0.15	5.8	100	0.62	0.13	0.24	9,200	0.96	23.1	11	7.4	17.4	3.73	0.05	0.14	0.027	18,000	1,000	9.8	7.4	7.8	2,500
2	C008	Sand-mudstone transition	13,900	0.13	7.1	190	0.74	0.14	0.21	18,900	1.12	27.0	14	9.6	18.8	4.63	0.06	0.17	0.029	22,600	1,200	10.9	9.0	9.4	3,600
2	C009	Sand-mudstone transition	11,700	0.14	6.7	110	0.58	0.13	0.30	27,600	0.94	21.0	12	7.6	17.5	4.42	0.05	0.18	0.029	21,500	1,100	8.6	7.0	13.0	3,300
1	C010	Mudstone ALM	11,300	2.30	21.1	70	0.51	0.14	2.87	194,500	1.14	17.5	22	7.6	67.2	4.34	0.07	0.16	0.030	6,080	1,400	8.9	7.1	8.3	2,900
1	C011	Mudstone ALM	20,300	0.16	10.2	60	0.89	0.28	0.18	23,000	1.62	36.4	17	13.2	39.3	7.65	0.1	0.15	0.062	20,500	2,100	15.2	12.7	21.7	5,000
1	C012	Mudstone ALM	20,300	0.12	9.2	70	0.85	0.26	0.08	16,500	1.61	36.7	17	15.3	35	7.76	0.08	0.19	0.059	20,400	1,900	14.6	13.4	24.6	5,500
1	C013	Mudstone ALM	21,100	0.15	9.4	100	0.88	0.25	0.46	18,800	1.6	34.9	18	15	33.5	7.88	0.08	0.18	0.053	21,400	2,000	14.5	11.8	24.5	5,800
1	C014	Mudstone ALM	15,500	1.00	17	90	0.74	0.23	2.73	116,000	1.54	26.6	19	11.2	60.5	6.06	0.08	0.16	0.049	14,700	1,700	11.8	11.2	16.4	4,300
2	C010	Mudstone ALM	15,500	0.65	12.9	60	0.76	0.22	1.5	92,800	1.33	26.1	18	11	50.4	5.91	0.06	0.18	0.044	28,200	1600	10.7	11.2	18.3	3,800
2	C011	Mudstone ALM	15,500	0.29	9.5	80	0.76	0.19	0.75	42,400	1.34	25.4	15	10.5	31	5.81	0.06	0.22	0.040	28,600	1600	10.5	10.2	17.3	3,700
2	C012	Mudstone ALM	17,100	0.31	10.7	70	0.86	0.24	0.88	43,000	1.34	31.2	16	12.2	40.2	6.52	0.07	0.21	0.049	34,200	1600	12.0	17.2	20.3	4,500
1	C015	Limestone roof	6,600	8.56	27.8	60	0.40	0.11	10.3	>500,000	0.61	12.8	33	5.6	93	2.58	0.08	0.16	0.016	3,520	900	11.4	5.9	4.6	1,800
1	C016	Limestone roof	6,200	4.28	24.7	40	0.33	0.11	8.01	>500,000	0.72	11.5	17	6.2	72.2	2.55	0.08	0.11	0.020	8,420	800	7.2	4.7	6.0	2,100
1	C017	Limestone roof	4,800	9.42	50.9	40	0.37	0.14	13.9	>500,000	0.55	11.3	31	8.6	98	2.26	0.11	0.13	0.020	10,200	800	9.5	4.7	4.4	1,600
1	C018	Orebody	19,000	5.96	31.7	250	1.01	0.38	13.9	68,200	1.77	52.5	53	11.2	122	7.2	0.18	0.25	0.054	20,900	2,600	38.1	14.2	14.6	3,600
1	C019	Mudstone floor WLA	16,700	0.59	8.5	80	0.83	0.41	1.4	18,900	2.32	38.9	28	10.3	62.7	7.12	0.08	0.25	0.061	27,800	2,500	18.3	15.4	18.8	3,900
1	C020	Mudstone floor WLA	17,700	0.38	8.1	110	0.85	0.39	0.72	10,300	2.31	37.6	27	10.5	56.2	7.38	0.08	0.25	0.060	28,600	2,800	16.9	15.6	20.0	4,200
1	C001	Untreated once washed residue	1,900	7.06	4.3	40	0.06	0.18	6.47	160,500	0.42	15.0	15	0.5	19.4	0.45	0.09	0.16	<0.005	1,600	400	13.5	14.6	0.9	200
1	C002	Untreated twice washed residue	1,100	6.80	2.7	40	<0.05	0.19	2.00	168,000	0.44	15.1	9	0.2	14.4	0.24	0.09	0.16	<0.005	800	300	13.5	13.0	0.5	100
2	1005	Pilot plant treated residue	1,320	10.7	7.3	49	<0.5	<0.5	8.70	248,000	<0.5	21.2	15	1.0	42.9	1.00	0.90	<1	<0.5	2,560	360	20.1	7.5	<0.5	600
2	1006	Pilot plant treated residue	1,190	12.2	8.3	52	<0.5	<0.5	9.10	257,000	<0.5	22.8	18	0.9	50.1	1.10	0.80	<1	<0.5	2,210	320	21.0	8.1	<0.5	600

2	1007	Pilot plant treated residue	2,070	8.90	10.3	38	<0.5	<0.5	8.20	274,000	<0.5	21.8	15	1.9	53.0	1.30	0.90	<1	<0.5	4,970	440	18.7	12.6	<0.5	900
2	1004	HPA residue pH 2	4,290	1.50	80.6	2	<0.5	<0.5	6.00	215,000	<0.5	2.1	60	2.8	55.0	1.80	<0.5	<1	<0.5	24,800	810	2.5	7.8	1.0	1,000
2	1008	HPA residue pH 4	800	<0.05	0.4	<10	0.05	<0.01	0.99	179,000	<0.05	0.87	21	0.1	5.6	0.34	<0.05	<0.02	<0.005	500	50	1.1	0.6	0.1	50

*Results below Limit of Reporting (LoR) not shown.

Table 10-2: Total metal (2-acid digest) results for soil, rock, and residue (Mn - Zr)

Batch number	Sample number	Lithology	Manganese	Mercury	Molybdenum	Nickel	Phosphorous	Rhenium	Rubidium	Scandium	Selenium	Silver	Sodium	Strontium	Sulfur	Tellurium	Thallium	Thorium	Tin	Titanium	Uranium	Vanadium	Yttrium	Zinc	Zirconium
		Concentrations in mg/kg																							
1	C003	Topsoil	313	0.01	0.39	9.0	30	<0.001	10.2	4.0	0.2	0.06	700	53.0	100	0.01	0.13	3.9	0.6	90	0.29	43	8.53	16	4.7
2	C001	Topsoil	206	0.01	0.83	7.8	50	0.001	6.8	3.7	0.1	0.04	300	39.4	100	0.01	0.12	3.5	0.6	100	0.36	50	7.93	14	5.3
2	C002	Topsoil	288	0.01	1.06	7.8	70	<0.001	8.0	4.1	0.1	0.03	900	66.3	1,000	0.02	0.12	3.8	0.6	90	0.44	47	9.63	18	4.8
1	C004	Subsoil	299	0.01	0.56	10.3	40	<0.001	10.5	4.4	<0.2	0.04	800	62.0	200	0.01	0.14	4.2	0.8	160	0.74	53	9.44	17	7.5
2	C003	Subsoil	319	0.01	0.97	7.6	40	<0.001	6.5	3.2	0.1	0.02	600	69.2	100	0.01	0.12	3.4	0.5	80	0.85	47	10.20	12	4.8
2	C004	Subsoil	266	<0.01	1.62	8.0	40	<0.001	7.5	3.0	0.1	0.01	1,900	144.5	2,500	0.01	0.09	3.6	0.5	60	1.82	46	10.90	16	4.3
1	C005	Subsoil /sand	290	<0.01	0.67	8.7	80	<0.001	8	3.4	<0.2	0.07	1,600	77.9	500	0.02	0.1	3.3	0.5	70	1.09	49	9.05	19	4.1
1	C006	Silt /sand	203	<0.01	0.72	5.2	200	<0.001	4	1.5	<0.2	0.01	300	29.2	100	0.01	0.12	2.1	0.3	50	0.79	32	5.04	12	3.5
1	C007	Silt /sand	899	<0.01	1.18	16.6	470	0.001	8.3	5.6	0.4	0.02	4,400	111.5	300	0.03	0.09	3.4	0.6	50	0.94	60	11.15	52	3.8
1	C008	Silt /sand	847	0.01	1.87	21.1	630	0.002	11	7.7	0.3	0.01	5,200	102.5	500	0.04	0.09	4.1	0.8	60	1.53	63	11.30	75	4.7
2	C005	Sand	132	<0.01	0.55	5.5	200	<0.001	4.8	2.2	0.1	0.08	300	51.0	50	0.01	0.12	2.5	0.4	60	0.85	34	5.60	15	4.0
2	C006	Sand	211	<0.01	1.22	6.9	170	<0.001	5.5	2.1	0.1	0.02	1,200	63.2	500	0.01	0.10	2.5	0.4	50	1.37	39	6.49	17	4.0
1	C009	Sand-mudstone transition	627	0.01	2.52	13.4	400	0.001	8.5	4.9	0.4	0.03	2,700	123.0	1,400	0.03	0.27	3.0	0.6	50	1.42	56	9.36	41	4.1
2	C007	Sand-mudstone transition	261	0.01	3.14	14.3	390	<0.001	7.7	4.2	0.1	0.03	800	94.8	100	0.03	0.59	2.9	0.5	25	1.57	60	9.19	50	4.2
2	C008	Sand-mudstone transition	576	<0.01	4.76	15.6	540	<0.001	9.4	4.8	0.1	0.03	2,200	116.5	200	0.03	0.39	3.5	0.6	50	2.64	73	10.30	46	5.2
2	C009	Sand-mudstone transition	358	0.01	2.89	13.7	490	0.001	8.0	4.7	0.3	0.06	2,500	169.0	1,700	0.03	0.22	3.0	0.5	50	1.89	51	8.29	49	4.9
1	C010	Mudstone ALM	521	0.04	25.9	57.2	980	0.003	8.8	4.9	1.7	0.05	800	388.0	200	0.05	0.84	2.3	0.5	50	6.86	209	10.90	211	5.4
1	C011	Mudstone ALM	514	0.07	1.19	23.5	760	0.012	13.8	9.3	0.7	0.04	4,200	138.5	900	0.04	0.15	5	0.9	50	0.82	61	13.75	90	4.3
1	C012	Mudstone ALM	633	0.08	0.82	24.2	790	0.003	13.4	9.2	0.4	0.01	4,500	154.5	800	0.04	0.11	4.9	0.9	50	0.74	56	13.60	89	4.5
1	C013	Mudstone ALM	599	0.05	3.95	24.2	710	0.003	13.4	9	0.4	0.01	4,000	162.0	1,200	0.04	0.44	4.8	0.9	60	1.72	64	12.80	87	4.9
1	C014	Mudstone ALM	570	0.04	30.00	37.7	930	0.145	11.9	7.5	3.8	0.34	2,000	309.0	5,700	0.05	1.26	3.7	0.7	50	8.00	114	13.05	161	5.1
2	C010	Mudstone ALM	440	0.06	14.10	35.5	770	0.002	12.2	7.5	0.9	0.14	2,000	247.0	4,000	0.04	1.00	3.5	0.7	50	4.06	94	12.70	138	5.9
2	C011	Mudstone ALM	439	0.05	7.62	21.1	630	0.001	11.4	7.3	0.5	0.33	2,000	270.0	2,900	0.03	0.73	3.4	0.7	60	2.66	64	10.95	82	6.2
2	C012	Mudstone ALM	438	0.05	9.90	24.7	830	0.001	11.8	8.3	0.8	0.12	3,000	242.0	7,400	0.05	0.76	4.0	0.7	50	3.53	68	13.55	97	6.1
1	C015	Limestone roof	360	0.06	74.10	88.4	2,340	0.004	5.4	3.4	2.3	0.13	600	589.0	200	0.09	1.00	1.1	0.3	60	24.6	613	25.30	368	9.5
1	C016	Limestone roof	335	0.06	91.60	66.6	1,100	0.344	5.5	3.6	9.5	0.66	1,300	545.0	6,300	0.06	1.94	1.3	0.3	25	21.5	314	12.65	311	4.3
1	C017	Limestone roof	269	0.09	201.00	146.0	1,300	0.518	4.7	3.1	22.3	1.05	1,100	564.0	14,700	0.11	4.20	1.1	0.3	25	54.8	681	20.3	565	6.6
1	C018	Orebody	395	0.09	93.40	161.5	3,440	0.175	21.8	8.1	28	0.62	2,000	377.0	14,900	0.12	1.88	6.1	0.9	60	33.2	799	82.2	629	12.5
1	C019	Mudstone floor WLA	360	0.06	10.85	43.6	870	0.056	24.5	7.7	4.7	0.22	2,400	188.5	18,400	0.03	0.38	6.8	1.1	50	4.46	99	21.2	218	7.1
1	C020	Mudstone floor WLA	297	0.05	6.78	37.2	690	0.035	24.6	7.8	3.4	0.16	3,900	168.5	18,000	0.04	0.16	6.8	1.1	50	3.07	76	16.9	166	6.7

1	C001	Untreated once washed residue	23	0.07	22.50	18.4	110	<0.001	3.0	1.0	1.9	0.22	200	333.0	50,000	0.06	0.43	0.8	0.3	70	3.00	190	24.8	51	9.0
1	C002	Untreated twice washed residue	6	0.08	16.40	4.1	50	<0.001	2.8	0.5	2.0	0.21	100	339.0	50,000	0.06	0.35	0.4	0.3	70	1.00	97	19.6	19	8.6
2	1005	Pilot plant treated residue	77	<0.1	26.50	23.1	1,130	0.023	1.4	1.3	5.0	<0.5	190	501.0	91,600	<0.5	0.50	1.2	<0.5	70	16	271	42.8	114	7.1
2	1006	Pilot plant treated residue	65	<0.1	26.90	27.0	980	0.021	1.8	1.4	7.0	<0.5	180	444.0	89,000	<0.5	0.60	1.2	<0.5	86	14	308	44.9	137	7.6
2	1007	Pilot plant treated residue	149	<0.1	24.50	35.4	1,010	0.026	2.0	1.9	8.0	<0.5	260	417.0	97,500	<0.5	0.80	1.2	<0.5	73	14	260	31.1	161	8.2
2	1004	HPA residue pH 2	102	<0.1	228.00	67.4	4,030	0.006	2.4	2.6	5.0	<0.5	550	87.0	179,000	<0.5	1.90	0.9	<0.5	117	11	2140	8.7	242	7.5
2	1008	HPA residue pH 4	<5	<0.01	1.96	3.6	30	<0.001	0.3	3.6	0.5	<0.02	100	98.6	>100,000	0.01	0.08	1.8	<0.2	25	1.12	24	6.04	11	<0.5

*Results below Limit of Reporting (LoR) not shown.

Table 10-3: Water soluble SFE 16-hr&1:3 ratio 0.45 µm filtered results for major element concentrations for solid soil, rock, residue and HPA residue

Batch Number	Sample number	Lithology	$pH_{1:3}$ Value	$EC_{1:3}$ @ 25°C	Hydroxide Alkalinity as CaCO3	Carbonate Alkalinity as CaCO3	Bicarbonate Alkalinity as CaCO3	Total Alkalinity as CaCO3	Acidity as CaCO3	Calcium	Magnesium	Sodium	Potassium	Chloride	Sulfate as SO4	Fluoride
			pH unit	µS/cm	Concentrations in mg/L											
1	C003	Topsoil	7.35	302	<1	<1	45	45	3	280	86	87	17	50	25	0.3
2	C001	Topsoil	7.96	363	<1	<1	101	101	<1	15	2	63	<1	10	68	0.9
2	C002	Topsoil	7.89	1,690	<1	<1	74	74	2	154	24	178	2	44	723	0.6
1	C004	Subsoil	7.47	630	<1	<1	52	52	2	912	197	144	41	80	118	0.5
2	C003	Subsoil	7.84	467	<1	<1	93	93	<1	4	<1	93	<1	43	54	1.9
2	C004	Subsoil	7.52	3,870	<1	<1	35	35	4	431	51	478	2	143	2060	0.7
1	C005	Subsoil /sand	7.25	1,760	<1	<1	37	37	3	2,590	208	407	28	294	409	0.8
1	C006	Silt /sand	8.00	195	<1	<1	57	57	2	464	108	93	36	11	20	0.6
1	C007	Silt /sand	7.05	2,600	<1	<1	40	40	3	5,440	252	756	22	756	125	0.6
1	C008	Silt /sand	7.30	3,050	<1	<1	44	44	2	3,120	329	858	46	812	269	1.0
2	C005	Sand	8.44	177	<1	<1	76	76	<1	2	<1	37	<1	7	4	1.0
2	C006	Sand	8.34	1,180	<1	<1	63	63	<1	13	2	230	<1	62	391	1.0
1	C009	Sand-mudstone transition	6.97	3,690	<1	<1	24	24	4	1,040	97	502	19	391	1,450	0.7
2	C007	Sand-mudstone transition	8.88	322	<1	17	80	97	<1	1	<1	70	<1	12	36	1.3
2	C008	Sand-mudstone transition	8.98	795	<1	23	98	121	<1	2	<1	165	<1	70	140	2.0
2	C009	Sand-mudstone transition	7.56	3,730	<1	<1	36	36	3	326	36	556	4	116	1,910	0.6
1	C010	Mudstone ALM	7.90	293	<1	<1	47	47	1	8,770	167	82	44	5	76	1.2
1	C011	Mudstone ALM	7.61	1,950	<1	<1	85	85	2	2,530	428	733	117	442	632	0.5
1	C012	Mudstone ALM	7.25	2,880	<1	<1	41	41	13	2,250	455	826	114	523	672	0.8
1	C013	Mudstone ALM	7.05	4,110	<1	<1	28	28	3	196	38	675	7	537	1,360	0.8
1	C014	Mudstone ALM	7.28	3,300	<1	<1	36	36	4	1,880	112	327	19	122	1,770	0.4
2	C010	Mudstone ALM	7.56	3,670	<1	<1	34	34	3	494	45	450	5	82	2,100	0.7
2	C011	Mudstone ALM	7.59	3,630	<1	<1	34	34	3	472	45	430	6	67	2,010	0.6
2	C012	Mudstone ALM	7.58	4,410	<1	<1	34	34	3	457	50	654	5	115	2,450	0.8
1	C015	Limestone roof	7.17	398	<1	<1	25	25	2	7,760	40	54	10	4	144	1.0
1	C016	Limestone roof	7.28	2,220	<1	<1	39	39	3	3,320	73	260	19	126	936	0.3
1	C017	Limestone roof	6.51	2,920	<1	<1	54	54	5	3,010	63	229	26	137	1,650	0.3

1	C018	Orebody	7.82	3,010	<1	<1	94	94	5	7,970	284	344	158	70	1,520	0.3
1	C019	Mudstone floor WLA	7.94	3,820	<1	<1	142	142	5	2,280	411	457	217	27	2,080	0.2
1	C020	Mudstone floor WLA	7.02	5,620	<1	<1	54	54	10	537	107	816	39	315	2,870	0.2
1	C001	Untreated OW residue	1.69	13,100	<1	<1	<1	<1	5,000	490	48	48	41	2	6,320	17.7
1	C002	Untreated TW residue	2.53	3,620	<1	<1	<1	<1	669	503	8	16	8	4	1,990	5.0
2	1005	Pilot plant treated residue	9.67	2,340	30	41	<1	71	<1	544	<1	10	1	2	1,420	0.8
2	1006	Pilot plant treated residue	9.81	2,330	38	42	<1	80	<1	546	<1	12	<1	2	1,390	1.2
2	1007	Pilot plant treated residue	10.10	2,340	49	45	<1	94	<1	576	<1	15	3	2	1,370	1
2	1004	HPA residue pH 2	2.93	8,620	<1	<1	<1	<1	8,710	440	346	125	102	10	10,100	0.4
2	1008	HPA residue pH 4*	---	---	---	---	---	---	---	474	2	15	3	97	1,440	---

***Analytes limited by low sample mass**

Table 10-4: 0.45 µm filtered results for major element concentrations for aqueous supernatant and process water

Batch Number	Sample number	Lithology	pH Value	EC @ 25°C	Hydroxide Alkalinity as CaCO3	Carbonate Alkalinity as CaCO3	Bicarbonate Alkalinity as CaCO3	Total Alkalinity as CaCO3	Acidity as CaCO3	Calcium	Magnesium	Sodium	Potassium	Chloride	Sulfate as SO4	Fluoride
			pH unit	**µS/cm**	**Concentrations in mg/L**											
1	C101_SN	Untreated supernatant	0.9	<1	<1	<1	<1	5	61,800	3,430	200	161	148	<50	32,800	---
1	SW01	Treated supernatant	7.4	2,600	<1	<1	41	41	6	579	29	51	12	4	1,620	5.5
1	RW01	Process water	1.5	<1	<1	<1	<1	39,800	112,000	702	180	370	92	<50	36,500	1.4

*Results below Limit of Reporting (LoR) not shown.

Table 10-5: Water soluble SFE 16-hr&1:3 ratio results for unfiltered and 0.45 µm filtered trace element concentrations (Al – Li) for soil, rock, residue and HPA residue

Batch Number	Sample number	Lithology	Fraction	Aluminium	Arsenic	Barium	Beryllium	Bismuth	Boron	Cadmium	Caesium	Cerium	Chromium	Cobalt	Copper	Dysprosium	Erbium	Europium	Gadolinium	Gallium	Holmium	Iron	Lanthanum	Lead	Lithium
		Concentrations in mg/L																							
1	C003	Topsoil	Unfiltered	343	0.035	9.56	0.026	<0.010	<0.10	0.0024	0.042	0.796	0.261	0.191	0.306	0.097	0.046	0.036	0.135	0.115	0.018	220	0.512	0.269	0.158
1	C003	Topsoil	Filtered	0.01	0.001	0.048	<0.001	<0.001	0.06	<0.0001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.001
2	C001	Topsoil	Filtered	0.03	0.002	0.147	<0.001	<0.001	<0.05	<0.0001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.001
2	C002	Topsoil	Filtered	0.01	0.001	0.153	<0.001	<0.001	0.13	<0.0001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.001
1	C004	Subsoil	Unfiltered	689	0.082	31.1	0.056	<0.010	<0.10	0.0061	0.082	3.93	0.576	0.996	0.721	0.319	0.148	0.117	0.454	0.295	0.057	479	1.85	1.07	0.282
1	C004	Subsoil	Filtered	0.02	0.001	0.181	<0.001	<0.001	0.08	<0.0001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.001
2	C003	Subsoil	Filtered	0.03	0.003	0.027	<0.001	<0.001	0.1	<0.0001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.001
2	C004	Subsoil	Filtered	0.06	0.002	0.043	<0.001	<0.001	0.24	<0.0001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.005
1	C005	Subsoil /sand	Unfiltered	458	0.144	27.6	0.049	<0.010	0.2	0.0062	0.052	3.05	0.385	0.518	0.556	0.253	0.109	0.1	0.369	0.215	0.043	264	1.39	0.606	0.285
1	C005	Subsoil /sand	Filtered	0.02	0.005	0.084	<0.001	<0.001	0.14	<0.0001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.004
1	C006	Silt /sand	Unfiltered	236	0.086	5.63	0.027	<0.010	<0.10	0.0069	0.024	1.46	0.183	0.22	0.251	0.175	0.081	0.064	0.245	0.124	0.032	161	0.912	0.292	0.151
1	C006	Silt /sand	Filtered	0.02	0.015	0.006	<0.001	<0.001	<0.05	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.001
1	C007	Silt /sand	Unfiltered	399	0.147	20.5	0.034	<0.010	0.18	0.0097	0.066	2.12	0.282	0.53	0.31	0.255	0.109	0.098	0.357	0.18	0.045	300	1.07	0.299	0.548

1	C007	Silt /sand	Filtered	0.02	0.007	0.035	<0.001	<0.001	0.08	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.009
1	C008	Silt /sand	Unfiltered	579	0.137	22.6	0.03	<0.010	0.15	0.0194	0.102	2.9	0.412	0.674	0.538	0.322	0.132	0.128	0.475	0.26	0.054	515	1.26	0.485	0.997
1	C008	Silt /sand	Filtered	0.01	0.002	0.062	<0.001	<0.001	0.1	<0.0001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.018
2	C005	Sand	Filtered	0.02	0.012	0.004	<0.001	<0.001	0.08	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.001
2	C006	Sand	Filtered	0.14	0.01	0.028	<0.001	<0.001	0.11	<0.0001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.11	<0.001	<0.001	0.004
1	C009	Sand-mudstone transition	Unfiltered	151	0.048	4.93	<0.010	<0.010	<0.10	0.0021	0.028	0.477	0.134	0.156	0.167	0.046	0.019	0.017	0.065	0.064	<0.010	146	0.202	0.116	0.232
1	C009	Sand-mudstone transition	Filtered	0.03	0.001	0.044	<0.001	<0.001	0.11	<0.0001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.015
2	C007	Sand-mudstone transition	Filtered	0.03	0.019	0.008	<0.001	<0.001	0.09	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.003
2	C008	Sand-mudstone transition	Filtered	0.02	0.021	0.005	<0.001	<0.001	0.14	0.0001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.005
2	C009	Sand-mudstone transition	Filtered	<0.01	0.001	0.052	<0.001	<0.001	0.2	<0.0001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.025
1	C010	Mudstone ALM	Unfiltered	279	0.404	5.61	0.025	<0.010	<0.10	0.1780	0.092	1.97	0.433	0.434	4.6	0.31	0.151	0.094	0.399	0.156	0.057	242	0.959	0.616	0.488
1	C010	Mudstone ALM	Filtered	0.04	0.013	0.007	<0.001	<0.001	<0.05	<0.0001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.004
1	C011	Mudstone ALM	Unfiltered	797	0.246	5.63	0.051	<0.021	<0.21	0.0377	0.223	4.61	0.666	1.07	2.78	0.514	0.21	0.19	0.751	0.396	0.086	796	1.74	1.46	1.640
1	C011	Mudstone ALM	Filtered	0.03	0.002	0.008	<0.001	<0.001	0.16	<0.0001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.030
1	C012	Mudstone ALM	Unfiltered	842	0.195	5.92	0.046	<0.021	<0.21	0.0135	0.241	4.84	0.669	0.983	1.79	0.521	0.208	0.198	0.762	0.432	0.087	816	1.88	1.25	1.880
1	C012	Mudstone ALM	Filtered	0.01	0.001	0.037	<0.001	<0.001	0.16	<0.0001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.031
1	C013	Mudstone ALM	Unfiltered	16.5	0.004	0.069	<0.001	<0.001	0.13	0.0002	0.003	0.03	0.015	0.01	0.019	0.003	0.001	<0.001	0.004	0.007	<0.001	16.2	0.012	0.008	0.065
1	C013	Mudstone ALM	Filtered	0.01	<0.001	0.02	<0.001	<0.001	0.14	0.0001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.032
1	C014	Mudstone ALM	Unfiltered	125	0.261	0.859	0.011	<0.005	0.26	0.0769	0.024	0.477	0.173	0.253	1.34	0.059	0.027	0.019	0.079	0.047	0.01	267	0.17	0.253	0.368
1	C014	Mudstone ALM	Filtered	<0.01	<0.001	0.04	<0.001	<0.001	0.12	0.0016	<0.001	<0.001	<0.001	0.002	0.016	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.029
2	C010	Mudstone ALM	Filtered	0.05	<0.001	0.03	<0.001	<0.001	0.14	0.0002	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.026
2	C011	Mudstone ALM	Filtered	<0.01	<0.001	0.045	<0.001	<0.001	0.13	0.0001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.025
2	C012	Mudstone ALM	Filtered	<0.01	<0.001	0.029	<0.001	<0.001	0.17	0.0001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.028
1	C015	Limestone roof	Unfiltered	65.6	0.413	2.13	0.016	<0.005	0.08	0.5870	0.013	0.674	0.328	0.111	4.45	0.189	0.116	0.046	0.204	0.024	0.04	36.2	0.524	0.187	0.086
1	C015	Limestone roof	Filtered	0.02	0.005	0.013	<0.001	<0.001	<0.05	0.0001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.004
1	C016	Limestone roof	Unfiltered	103	0.628	0.843	0.009	<0.005	0.25	0.2970	0.022	0.423	0.258	0.309	2.36	0.072	0.038	0.02	0.088	0.042	0.013	245	0.2	0.225	0.253
1	C016	Limestone roof	Filtered	<0.01	0.002	0.025	<0.001	<0.001	0.12	0.0032	<0.001	<0.001	<0.001	0.002	0.038	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.026
1	C017	Limestone roof	Unfiltered	104	0.691	0.744	<0.010	<0.010	0.34	0.2800	0.026	0.27	0.397	0.282	1.83	0.056	0.032	0.014	0.063	0.046	0.012	208	0.169	0.125	0.185
1	C017	Limestone roof	Filtered	0.39	0.003	0.047	<0.001	<0.001	0.16	0.0032	<0.001	<0.001	0.078	0.017	0.016	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.28	<0.001	0.002	0.034
1	C018	Orebody	Unfiltered	752	2.310	14.5	0.072	0.032	0.76	2.1500	0.519	8.6	1.67	1.46	13.5	2.24	1.3	0.528	2.49	0.735	0.455	2520	5.88	2.65	1.54
1	C018	Orebody	Filtered	<0.01	0.001	0.034	<0.001	<0.001	0.2	0.0033	<0.001	<0.001	<0.001	0.008	0.006	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	0.002	0.098
1	C019	Mudstone floor WLA	Unfiltered	1110	1.270	8.04	0.067	0.079	1.52	0.2940	0.745	7.34	1.98	1.92	10.6	1.07	0.568	0.306	1.32	0.812	0.205	4380	3.31	4.06	2.27
1	C019	Mudstone floor WLA	Filtered	<0.01	0.001	0.047	<0.001	<0.001	0.29	0.0008	<0.001	<0.001	0.003	0.01	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.149
1	C020	Mudstone floor WLA	Unfiltered	120	0.110	0.42	0.006	<0.005	0.61	0.0123	0.036	0.465	0.192	0.418	0.982	0.06	0.032	0.018	0.076	0.057	0.011	479	0.167	0.296	0.674
1	C020	Mudstone floor WLA	Filtered	0.02	<0.001	0.08	<0.001	<0.001	0.43	0.0056	<0.001	0.008	<0.001	0.215	0.014	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.05	0.006	0.001	0.267
1	C001	Untreated OW residue	Filtered	320	0.690	0.077	0.017	<0.001	0.2	1.9000	0.007	0.28	3.23	0.168	2.24	0.211	0.193	0.025	0.156	0.077	0.054	349	0.288	0.049	0.246
1	C002	Untreated TW residue	Filtered	61.9	0.030	0.576	0.002	<0.001	0.73	0.4680	<0.001	0.157	0.52	0.025	0.149	0.091	0.069	0.012	0.076	0.004	0.022	19.5	0.163	0.028	0.038
2	1005	Pilot plant treated residue	Filtered	<0.01	0.010	0.113	<0.001	<0.001	0.9	0.0001	<0.001	<0.001	0.003	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.003
2	1006	Pilot plant treated residue	Filtered	0.09	0.008	0.116	<0.001	<0.001	1.06	0.0003	<0.001	<0.001	0.003	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.004
2	1007	Pilot plant treated residue	Filtered	<0.01	0.005	0.154	<0.001	<0.001	1.03	0.0002	<0.001	<0.001	0.005	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.002

2	1004	HPA residue pH 2	Filtered	1100	0.100	0.911	0.085	<0.020	5.7	1.9900	0.026	0.051	7.76	1.21	21.8	0.052	0.048	<0.020	0.034	0.200	<0.020	554	0.078	<0.020	0.627
2	1008	HPA residue pH 4	Filtered	20.2	0.001	0.248	0.002	<0.001	0.09	0.0861	<0.001	0.009	0.118	0.006	0.398	0.021	0.027	<0.001	0.01	0.001	0.005	1.76	0.015	0.001	0.008

*Results below Limit of Reporting (LoR) not shown.

Table 10-6: 0.45 µm filtered trace element concentrations (Al – Li) for aqueous supernatant and process water

Batch Number	Sample number	Lithology	Fraction	Aluminium	Arsenic	Barium	Beryllium	Bismuth	Boron	Cadmium	Caesium	Cerium	Chromium	Cobalt	Copper	Dysprosium	Erbium	Europium	Gadolinium	Gallium	Holmium	Iron	Lanthanum	Lead	Lithium
		Concentrations in mg/L																							
1	C101_SN	Untreated supernatant	Filtered	1,240	4.600	4.400	0.068	0.013	0.80	11.300	0.086	2.210	16.40	0.815	18.00	1.600	1.350	0.200	1.170	0.390	0.400	1,550	2.140	1.180	0.960
1	SW01	Treated supernatant	Filtered	<0.01	0.013	0.031	<0.001	<0.001	<0.05	0.002	<0.001	<0.001	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	0.064
1	RW01	Process water	Filtered	884	6.000	<0.1	<0.1	<0.1	1.6	2.6	<0.1	0.49	9.28	1.01	14.6	0.34	0.28	<0.1	0.27	0.36	<0.1	1,970	0.56	0.31	0.610

*Results below Limit of Reporting (LoR) not shown.

Table 10-7: Water soluble SFE 16-hr&1:3 ratio results for unfiltered and 0.45 µm filtered trace element concentrations (Lu – Zn) for soil, rock, residue and HPA residue

Batch Number	Sample number	Lithology	Fraction	Lutetium	Manganese	Molybdenum	Neodymium	Nickel	Praseodymium	Rubidium	Samarium	Selenium	Silver	Strontium	Terbium	Thallium	Thorium	Thulium	Titanium	Uranium	Vanadium	Ytterbium	Yttrium	Zinc
			Concentrations in mg/L																					
1	C003	Topsoil	Unfiltered	<0.010	6.99	<0.010	0.633	0.224	0.157	0.355	0.141	<0.10	<0.010	3.65	0.018	<0.010	0.106	<0.010	1.15	0.014	1.19	0.035	0.422	0.46
1	C003	Topsoil	Filtered	<0.001	0.002	0.008	<0.001	<0.001	<0.001	0.001	<0.001	<0.01	<0.001	0.02	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	<0.01	0.001	<0.001	<0.005
2	C001	Topsoil	Filtered	<0.001	0.002	0.016	<0.001	<0.001	<0.001	0.002	<0.001	<0.01	<0.001	0.204	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	<0.01	0.001	<0.001	<0.005
2	C002	Topsoil	Filtered	<0.001	0.008	0.031	<0.001	0.001	<0.001	0.009	<0.001	<0.01	<0.001	1.64	<0.001	<0.001	<0.001	<0.001	<0.01	0.002	<0.01	0.001	<0.001	0.006
1	C004	Subsoil	Unfiltered	0.015	34.5	<0.010	2.17	0.712	0.545	0.646	0.478	<0.10	<0.010	8.74	0.061	<0.010	0.307	0.018	0.49	0.086	3.11	0.107	1.24	0.865
1	C004	Subsoil	Filtered	<0.001	0.004	0.014	<0.001	<0.001	<0.001	0.003	<0.001	<0.01	<0.001	0.182	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	<0.01	0.001	<0.001	0.009
2	C003	Subsoil	Filtered	<0.001	0.001	0.058	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	0.062	<0.001	<0.001	<0.001	<0.001	<0.01	0.003	0.02	0.001	0.001	<0.005
2	C004	Subsoil	Filtered	<0.001	0.002	0.084	<0.001	<0.001	<0.001	0.004	<0.001	<0.01	<0.001	4.11	<0.001	<0.001	<0.001	<0.001	<0.01	0.004	0.02	0.001	0.001	<0.005
1	C005	Subsoil /sand	Unfiltered	<0.010	19	<0.010	1.810	0.465	0.438	0.415	0.4	<0.10	0.013	11.50	0.048	<0.010	0.232	0.013	0.54	0.18	3.88	0.074	1.03	0.769
1	C005	Subsoil /sand	Filtered	<0.001	0.002	0.03	<0.001	<0.001	<0.001	0.002	<0.001	<0.01	<0.001	0.616	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	0.05	0.001	<0.001	<0.005
1	C006	Silt /sand	Unfiltered	<0.010	8.76	<0.010	1.140	0.235	0.274	0.266	0.255	<0.10	<0.010	5.89	0.032	<0.010	0.174	<0.010	0.48	0.153	1.98	0.057	0.79	0.855
1	C006	Silt /sand	Filtered	<0.001	0.001	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	0.015	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	0.11	0.001	<0.001	<0.005
1	C007	Silt /sand	Unfiltered	0.011	28.1	<0.010	1.550	0.697	0.359	0.21	0.371	<0.10	<0.010	10.80	0.048	<0.010	0.199	0.013	0.7	0.077	1.74	0.075	0.972	1.48
1	C007	Silt /sand	Filtered	<0.001	0.001	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.01	<0.001	0.228	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	0.04	0.001	<0.001	<0.005
1	C008	Silt /sand	Unfiltered	0.012	39.2	0.016	1.990	1.000	0.458	0.364	0.489	<0.10	<0.010	10.80	0.063	<0.010	0.307	0.016	0.8	0.166	1.43	0.087	1.02	2.43
1	C008	Silt /sand	Filtered	<0.001	0.001	0.024	<0.001	<0.001	<0.001	<0.001	<0.001	0.02	<0.001	0.303	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	<0.01	0.001	<0.001	<0.005
2	C005	Sand	Filtered	<0.001	0.001	0.009	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	0.029	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	0.1	0.001	<0.001	<0.005
2	C006	Sand	Filtered	<0.001	0.004	0.082	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	0.246	<0.001	<0.001	<0.001	<0.001	<0.01	0.004	0.1	0.001	<0.001	<0.005
1	C009	Sand-mudstone transition	Unfiltered	<0.010	8.72	0.07	0.281	0.251	0.064	0.16	0.067	<0.10	<0.010	5.50	<0.010	<0.010	0.061	<0.010	0.54	0.034	0.66	0.013	0.195	0.541
1	C009	Sand-mudstone transition	Filtered	<0.001	0.003	0.114	<0.001	0.002	<0.001	0.001	<0.001	0.01	<0.001	3.23	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	<0.01	0.001	<0.001	0.019

2	C007	Sand-mudstone transition	Filtered	<0.001	0.001	0.198	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	0.026	<0.001	<0.001	<0.001	<0.001	<0.01	0.005	0.18	0.001	<0.001	<0.005
2	C008	Sand-mudstone transition	Filtered	<0.001	0.001	0.299	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	0.041	<0.001	<0.001	<0.001	<0.001	<0.01	0.011	0.25	0.001	<0.001	<0.005
2	C009	Sand-mudstone transition	Filtered	<0.001	0.011	0.184	<0.001	0.001	<0.001	0.002	<0.001	0.01	<0.001	3.09	<0.001	<0.001	<0.001	<0.001	<0.01	0.006	<0.01	0.001	<0.001	<0.005
1	C010	Mudstone ALM	Unfiltered	0.016	28.8	0.114	1.430	2.77	0.329	0.432	0.365	<0.10	<0.010	18.80	0.055	0.092	0.26	0.018	0.65	1.11	5.95	0.11	1.24	7.98
1	C010	Mudstone ALM	Filtered	<0.001	0.001	0.211	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	0.10	<0.001	<0.001	<0.001	<0.001	<0.01	0.002	0.12	0.001	<0.001	<0.005
1	C011	Mudstone ALM	Unfiltered	<0.021	40.5	<0.021	2.920	2.01	0.672	1.09	0.741	<0.21	<0.021	17.10	0.100	<0.021	0.489	0.024	1.02	0.116	1.85	0.131	1.64	5.36
1	C011	Mudstone ALM	Filtered	<0.001	0.001	0.032	<0.001	<0.001	<0.001	<0.001	<0.001	0.05	<0.001	0.305	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	<0.01	0.001	<0.001	<0.005
1	C012	Mudstone ALM	Unfiltered	<0.021	38.3	<0.021	3.080	1.73	0.710	1.09	0.779	<0.21	<0.021	22.80	0.102	<0.021	0.566	0.024	0.88	0.091	1.61	0.134	1.7	4.37
1	C012	Mudstone ALM	Filtered	<0.001	0.002	0.011	<0.001	<0.001	<0.001	0.001	<0.001	0.02	<0.001	0.655	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	<0.01	0.001	<0.001	0.006
1	C013	Mudstone ALM	Unfiltered	<0.001	0.321	0.162	0.016	0.02	0.004	0.019	0.004	0.02	<0.001	2.77	<0.001	<0.001	0.005	<0.001	0.37	0.002	0.04	0.001	0.01	0.07
1	C013	Mudstone ALM	Filtered	<0.001	0.002	0.158	<0.001	<0.001	<0.001	0.002	<0.001	0.02	<0.001	2.58	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	<0.01	0.001	<0.001	0.009
1	C014	Mudstone ALM	Unfiltered	<0.005	8.1	1.32	0.292	1.07	0.063	0.125	0.075	0.28	<0.005	8.83	0.011	0.046	0.082	<0.005	0.1	0.268	1.12	0.020	0.252	2.98
1	C014	Mudstone ALM	Filtered	<0.001	0.238	1.87	<0.001	0.018	<0.001	0.004	<0.001	0.22	<0.001	4.24	<0.001	0.001	<0.001	<0.001	<0.01	0.033	<0.01	0.001	<0.001	0.01
2	C010	Mudstone ALM	Filtered	<0.001	0.005	0.359	<0.001	<0.001	<0.001	0.003	<0.001	0.02	<0.001	5.84	<0.001	<0.001	<0.001	<0.001	<0.01	0.011	<0.01	0.001	<0.001	<0.005
2	C011	Mudstone ALM	Filtered	<0.001	0.001	0.217	<0.001	<0.001	<0.001	0.003	<0.001	0.01	<0.001	5.44	<0.001	<0.001	<0.001	<0.001	<0.01	0.007	<0.01	0.001	<0.001	<0.005
2	C012	Mudstone ALM	Filtered	<0.001	0.001	0.302	<0.001	<0.001	<0.001	0.003	<0.001	0.01	<0.001	4.91	<0.001	<0.001	<0.001	<0.001	<0.01	0.009	<0.01	0.001	<0.001	<0.005
1	C015	Limestone roof	Unfiltered	0.014	9.83	0.056	0.672	1.82	0.145	0.065	0.169	<0.05	<0.005	14.8	0.031	0.038	0.031	0.015	<0.05	1.49	6.58	0.102	1.12	8.38
1	C015	Limestone roof	Filtered	<0.001	0.001	0.229	<0.001	<0.001	<0.001	0.001	<0.001	<0.01	<0.001	0.544	<0.001	<0.001	<0.001	<0.001	<0.01	0.003	0.11	0.001	<0.001	<0.005
1	C016	Limestone roof	Unfiltered	<0.005	6.96	7.20	0.300	3.20	0.066	0.115	0.073	0.64	0.011	8.68	0.012	0.119	0.07	<0.005	0.09	1.02	4.7	0.03	0.353	11
1	C016	Limestone roof	Filtered	<0.001	0.05	5.89	<0.001	0.062	<0.001	0.002	<0.001	0.46	<0.001	2.31	<0.001	0.004	<0.001	<0.001	<0.01	0.126	<0.01	0.001	<0.001	0.019
1	C017	Limestone roof	Unfiltered	<0.010	4.86	9.86	0.225	3.96	0.050	0.155	0.054	0.78	<0.010	9.07	<0.010	0.147	0.034	<0.010	1.99	1.42	7.69	0.028	0.318	12.3
1	C017	Limestone roof	Filtered	<0.001	0.18	4.26	<0.001	0.186	<0.001	0.005	<0.001	0.64	<0.001	3.73	<0.001	0.011	<0.001	<0.001	0.03	0.513	<0.01	0.001	<0.001	0.208
1	C018	Orebody	Unfiltered	0.159	46.4	2.76	8.250	12.50	1.870	2.53	2.070	1.35	0.092	41.70	0.366	0.605	1.04	0.176	1.91	5.34	19.3	1.09	8.93	46.3
1	C018	Orebody	Filtered	<0.001	0.372	0.491	<0.001	0.043	<0.001	0.012	<0.001	0.35	<0.001	6.38	<0.001	0.006	<0.001	<0.001	<0.01	0.092	<0.01	0.001	<0.001	0.057
1	C019	Mudstone floor WLA	Unfiltered	0.070	43.6	0.919	4.990	6.91	1.160	3.61	1.230	0.71	0.048	30.20	0.188	0.234	1.58	0.076	4.47	0.962	6.16	0.476	3.52	30.1
1	C019	Mudstone floor WLA	Filtered	<0.001	0.565	0.095	<0.001	0.058	<0.001	0.033	<0.001	0.15	<0.001	7.30	<0.001	0.003	<0.001	<0.001	<0.01	0.033	<0.01	0.001	<0.001	0.062
1	C020	Mudstone floor WLA	Unfiltered	<0.005	7.31	0.045	0.287	1.23	0.062	0.273	0.070	0.16	<0.005	11.70	0.01	0.006	0.121	<0.005	0.11	0.036	0.44	0.028	0.267	3.16
1	C020	Mudstone floor WLA	Filtered	<0.001	3.40	0.011	0.004	0.619	<0.001	0.028	<0.001	0.14	<0.001	8.24	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	<0.01	0.001	0.007	0.723
1	C001	Untreated once washed residue	Filtered	0.040	7.60	3.03	0.270	5.77	0.060	0.16	0.078	0.06	<0.001	3.64	0.027	0.04	0.13	0.033	0.49	0.97	44.4	0.24	2.39	14.3
1	C002	Untreated twice washed residue	Filtered	0.010	1.40	0.23	0.140	0.65	0.032	0.03	0.040	<0.01	<0.001	2.97	0.013	0.005	0.002	0.01	0.01	0.108	5.53	0.071	0.83	3.2
2	1005	Pilot plant treated residue	Filtered	<0.001	0.001	0.346	<0.001	0.002	<0.001	0.002	<0.001	0.03	<0.001	2.25	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	1.12	0.001	<0.001	0.035
2	1006	Pilot plant treated residue	Filtered	<0.001	0.003	0.335	<0.001	0.004	<0.001	<0.001	<0.001	0.05	<0.001	2.24	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	1.31	0.001	<0.001	0.038
2	1007	Pilot plant treated residue	Filtered	<0.001	0.001	0.505	<0.001	0.002	<0.001	0.002	<0.001	0.03	<0.001	2.36	<0.001	<0.001	<0.001	<0.001	<0.01	0.001	1.34	0.001	<0.001	0.028
2	1004	HPA residue pH 2	Filtered	<0.020	42.40	0.751	0.044	28.00	<0.020	0.375	<0.020	<0.20	<0.020	1.48	<0.020	0.02	0.04	<0.020	<0.20	3.73	9.26	0.061	0.495	107
2	1008	HPA residue pH 4	Filtered	0.005	0.225	0.004	0.010	0.255	0.002	0.018	0.003	<0.01	<0.001	1.50	0.002	0.002	0.001	0.004	<0.01	0.092	<0.01	0.038	0.354	1.56

*Results below Limit of Reporting (LoR) not shown.

Table 10-8: 0.45 µm filtered trace element concentrations (Lu – Zn) for aqueous supernatant and process water

Batch Number	Sample number	Lithology	Fraction	Lutetium	Manganese	Molybdenum	Neodymium	Nickel	Praseodymium	Rubidium	Samarium	Selenium	Silver	Strontium	Terbium	Thallium	Thorium	Thulium	Titanium	Uranium	Vanadium	Ytterbium	Yttrium	Zinc
1	C101_SN	Untreated supernatant	Filtered	0.260	37.10	16.20	2.160	28.50	0.480	0.95	0.630	0.59	0.027	26.40	0.22	0.29	0.93	0.22	5.1	5.1	205	1.59	14.2	68.2
1	SW01	Treated supernatant	Filtered	<0.001	0.074	2.38	<0.001	0.033	<0.001	0.024	<0.001	<0.01	<0.001	3.00	<0.001	0.002	<0.001	<0.001	<0.01	0.027	0.72	0.001	<0.001	<0.005
1	RW01	Process water	Filtered	<0.100	41.40	19.30	0.500	25.10	0.110	0.38	0.130	<1.00	<0.100	4.40	<0.1	0.17	0.18	<0.1	3.9	3.8	184	0.27	2.72	88.2

10.1.3 Attachment Aiii: Particle size distribution

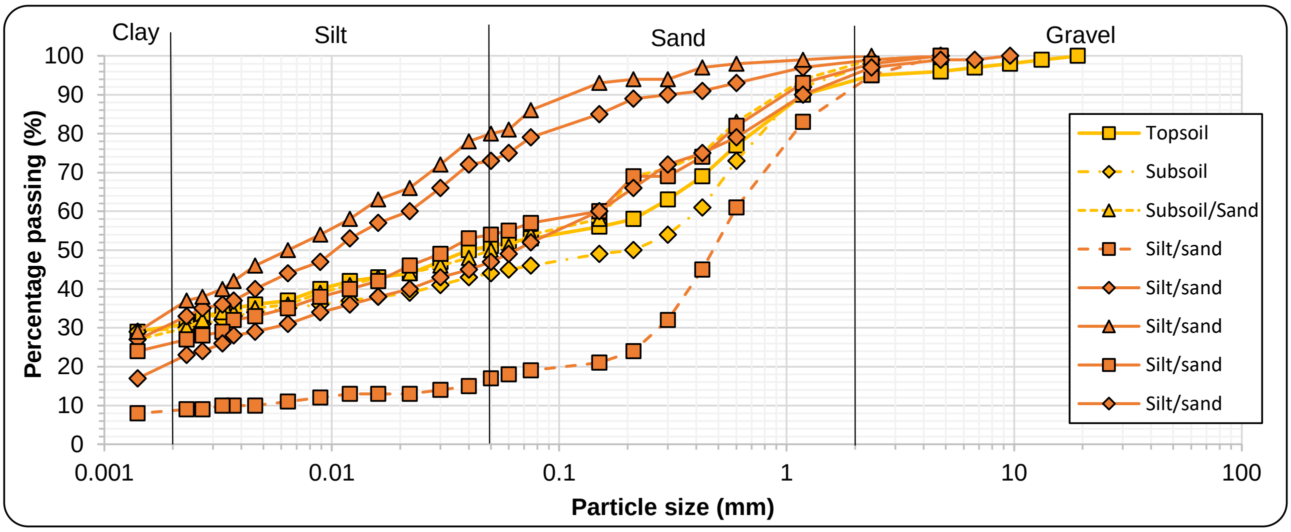


Figure 10-2: Particle size distribution for soil and silt/sand

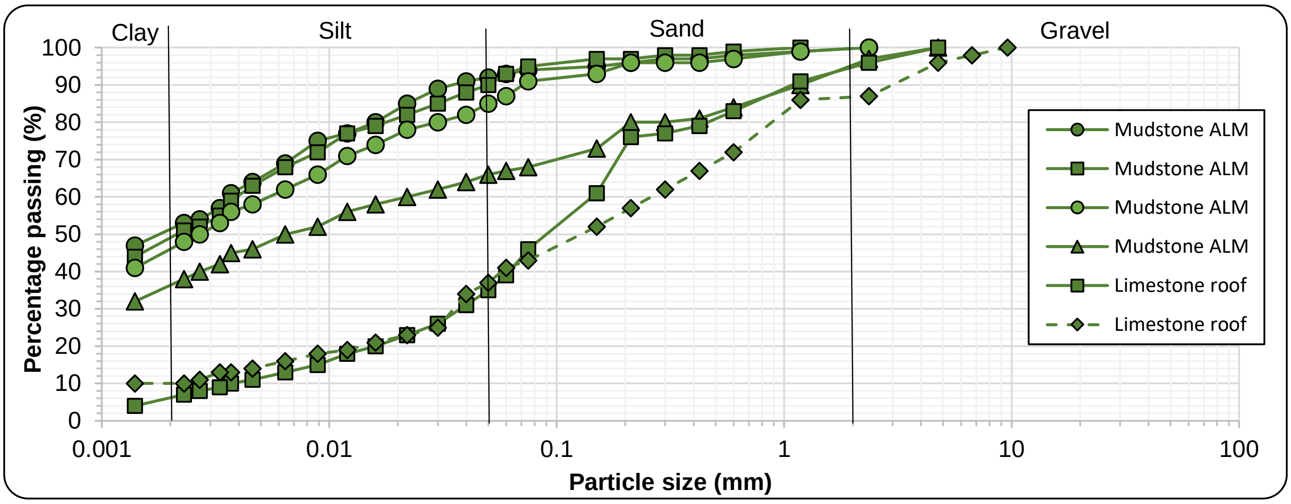


Figure 10-3: Particle size distribution for Mudstone ALM

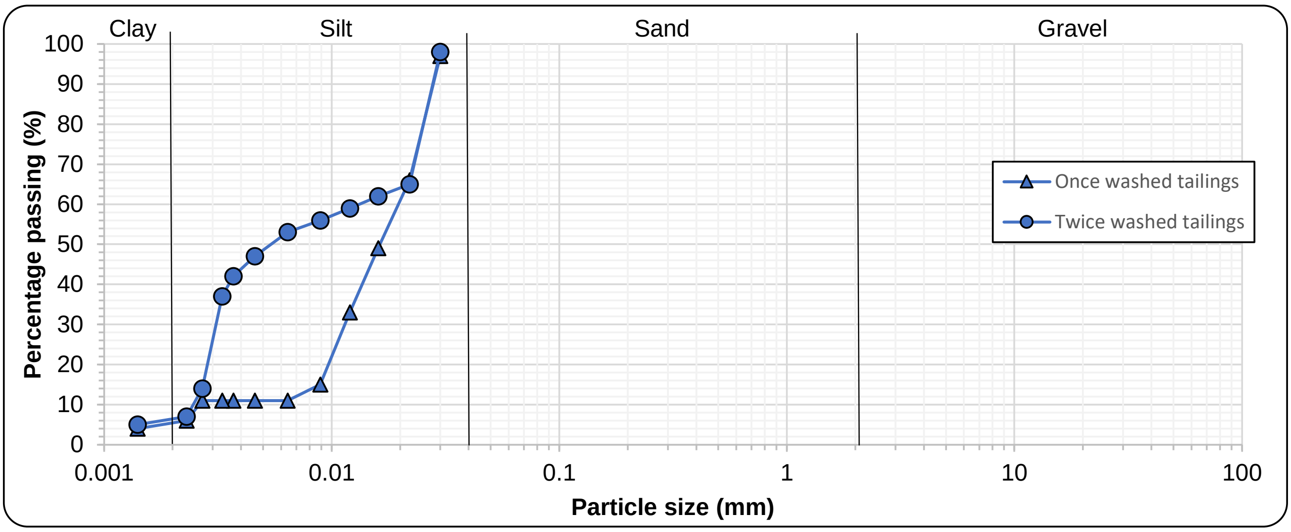
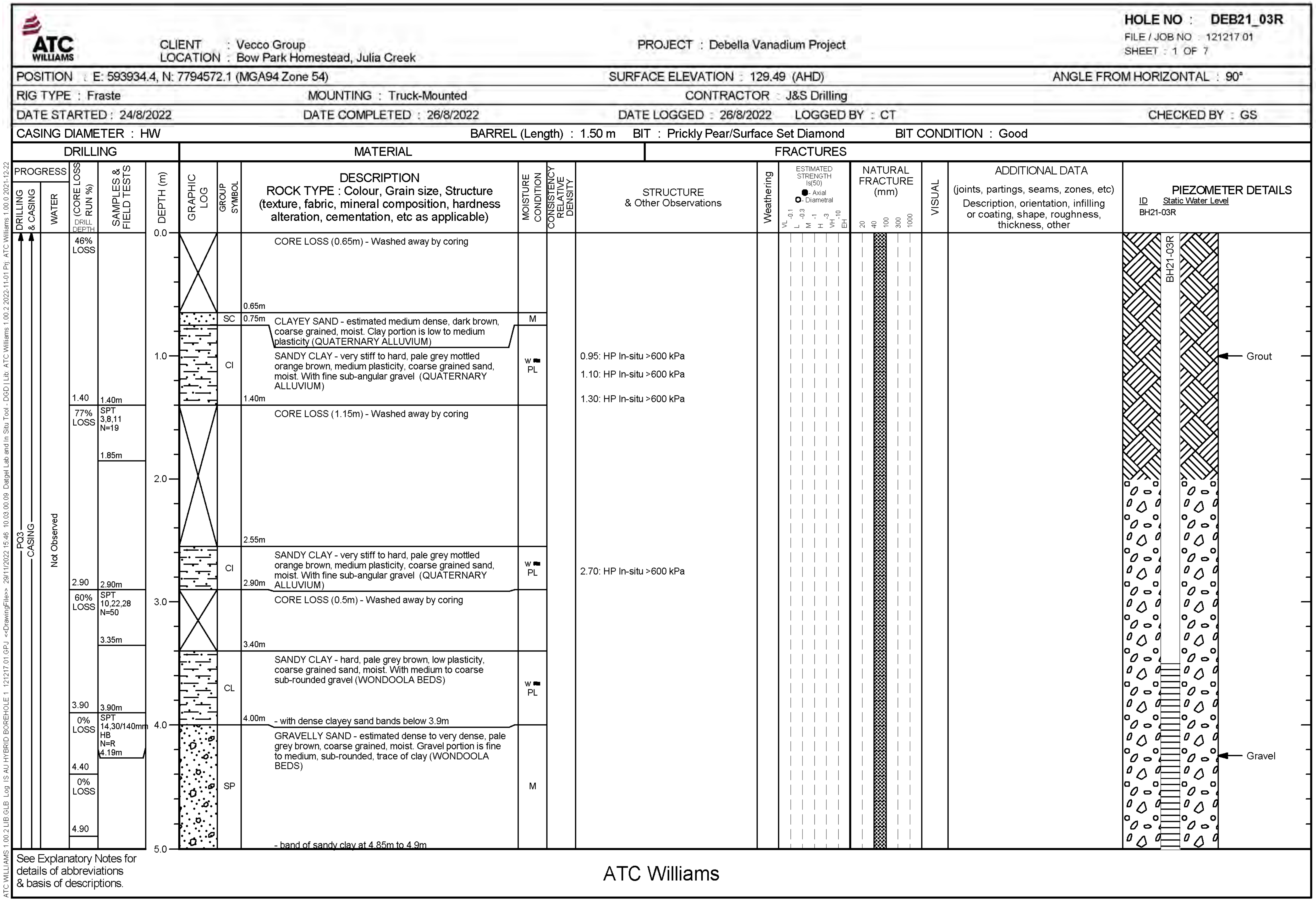


Figure 10-4: Particle size distribution for once and twice washed residue

10.2 Attachment B: Borehole drilling logs



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek
PROJECT : Debella Vanadium Project
HOLE NO : DEB21_03R
FILE / JOB NO : 121217.01
SHEET : 1 OF 7

POSITION : E: 593934.4, N: 7794572.1 (MGA94 Zone 54)
SURFACE ELEVATION : 129.49 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 24/8/2022
DATE COMPLETED : 26/8/2022
DATE LOGGED : 26/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Prickly Pear/Surface Set Diamond
BIT CONDITION : Good

DRILLING PROGRESS DRILLING & CASING	WATER	(CORE LOSS RUN %) DRILL DEPTH	SAMPLES & FIELD TESTS	DEPTH (m)	GROUP SYMBOL	DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)	MOISTURE CONDITION	CONSISTENCY RELATIVE DENSITY	STRUCTURE & Other Observations
PQ3 CASING	Not Observed	46% LOSS 1.40		0.0		CORE LOSS (0.65m) - Washed away by coring 0.65m			
					SC	0.75m CLAYEY SAND - estimated medium dense, dark brown, coarse grained, moist. Clay portion is low to medium plasticity (QUATERNARY ALLUVIUM)	M		
			1.40m	1.0	CI	SANDY CLAY - very stiff to hard, pale grey mottled orange brown, medium plasticity, coarse grained sand, moist. With fine sub-angular gravel (QUATERNARY ALLUVIUM) 1.40m	w ◄ PL		0.95: HP In-situ >600 kPa 1.10: HP In-situ >600 kPa 1.30: HP In-situ >600 kPa
		77% LOSS 2.90	SPT 3,8,11 N=19 1.85m	2.0		CORE LOSS (1.15m) - Washed away by coring 2.55m			
			2.90m		CI	SANDY CLAY - very stiff to hard, pale grey mottled orange brown, medium plasticity, coarse grained sand, moist. With fine sub-angular gravel (QUATERNARY ALLUVIUM) 2.90m	w ◄ PL		2.70: HP In-situ >600 kPa
		60% LOSS 3.90	SPT 10,22,28 N=50 3.35m	3.0		CORE LOSS (0.5m) - Washed away by coring 3.40m			
			3.90m		CL	SANDY CLAY - hard, pale grey brown, low plasticity, coarse grained sand, moist. With medium to coarse sub-rounded gravel (WONDOOLA BEDS) - with dense clayey sand bands below 3.9m 4.00m	w ◄ PL		
		0% LOSS 4.40	SPT 14,30/140mm HB N=R 4.19m	4.0	SP	GRAVELLY SAND - estimated dense to very dense, pale grey brown, coarse grained, moist. Gravel portion is fine to medium, sub-rounded, trace of clay (WONDOOLA BEDS) - band of sandy clay at 4.85m to 4.9m	M		
		0% LOSS 4.90		5.0					

FRACTURES

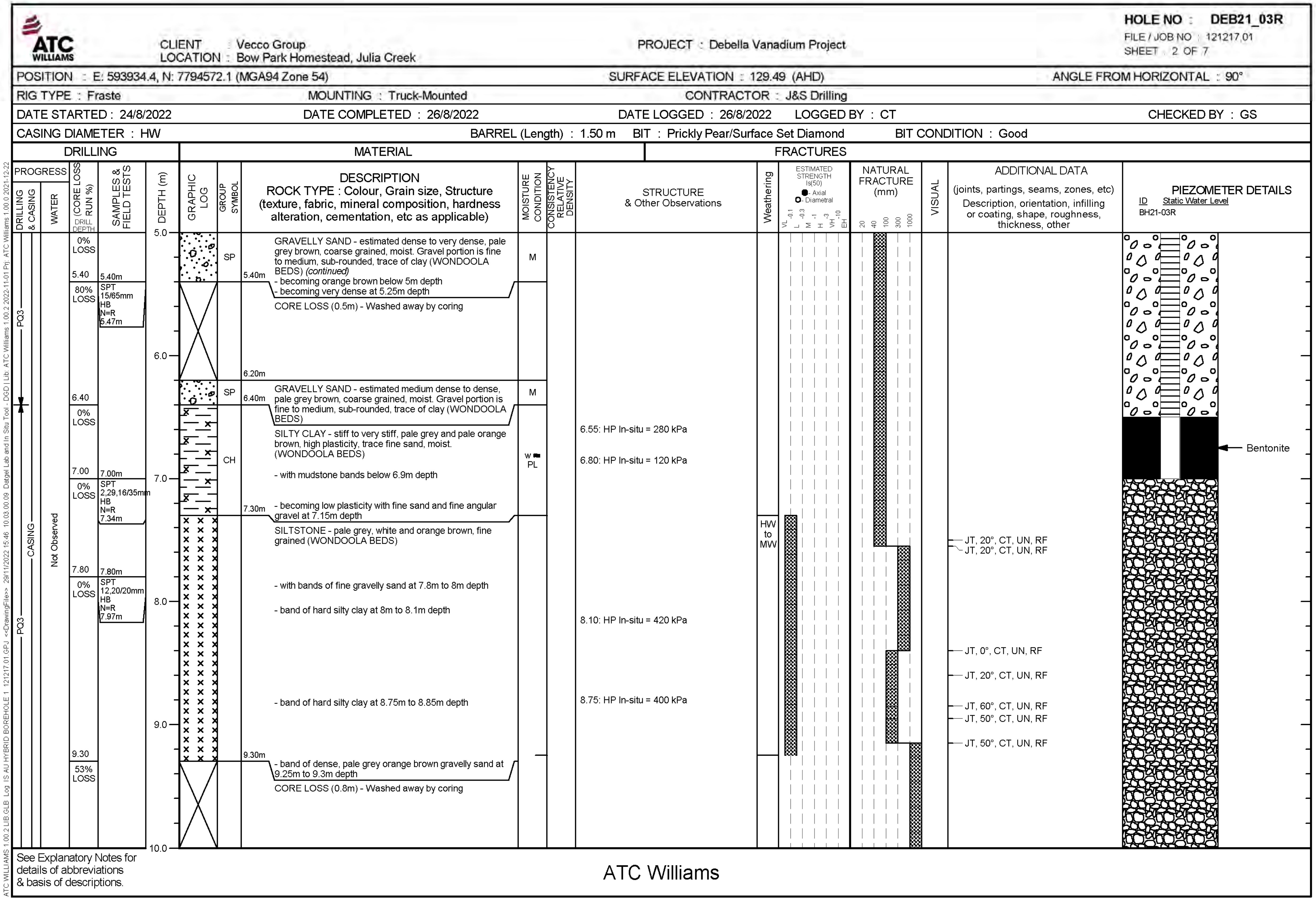
Weathering	ESTIMATED STRENGTH Is(50) ● - Axial ○ - Diametral VL -0.1 L -0.3 M -1 H -3 VH -10 EH	NATURAL FRACTURE (mm) 20 40 100 300 1000	VISUAL	ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other	PIEZOMETER DETAILS ID Static Water Level BH21-03R

See Explanatory Notes for details of abbreviations & basis of descriptions.

ATC Williams

ATC WILLIAMS 1.00.2 LIB.GLB Log IS AU HYBRID BOREHOLE 1 121217.01.GPJ <<DrawingFile>> 29/11/2022 15:46 10.03.00.09 Datgel Lab and In Situ Tool - DGD | Lib: ATC Williams 1.00.2 2022-11-01 Prj: ATC Williams 1.00.0 2021-12-22

Figure 10-5: Borehole log – DEB21_03R (0-5 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek

PROJECT : Debella Vanadium Project

HOLE NO : DEB21_03R
FILE / JOB NO : 121217.01
SHEET : 2 OF 7

POSITION : E: 593934.4, N: 7794572.1 (MGA94 Zone 54)
SURFACE ELEVATION : 129.49 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 24/8/2022
DATE COMPLETED : 26/8/2022
DATE LOGGED : 26/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Prickly Pear/Surface Set Diamond
BIT CONDITION : Good

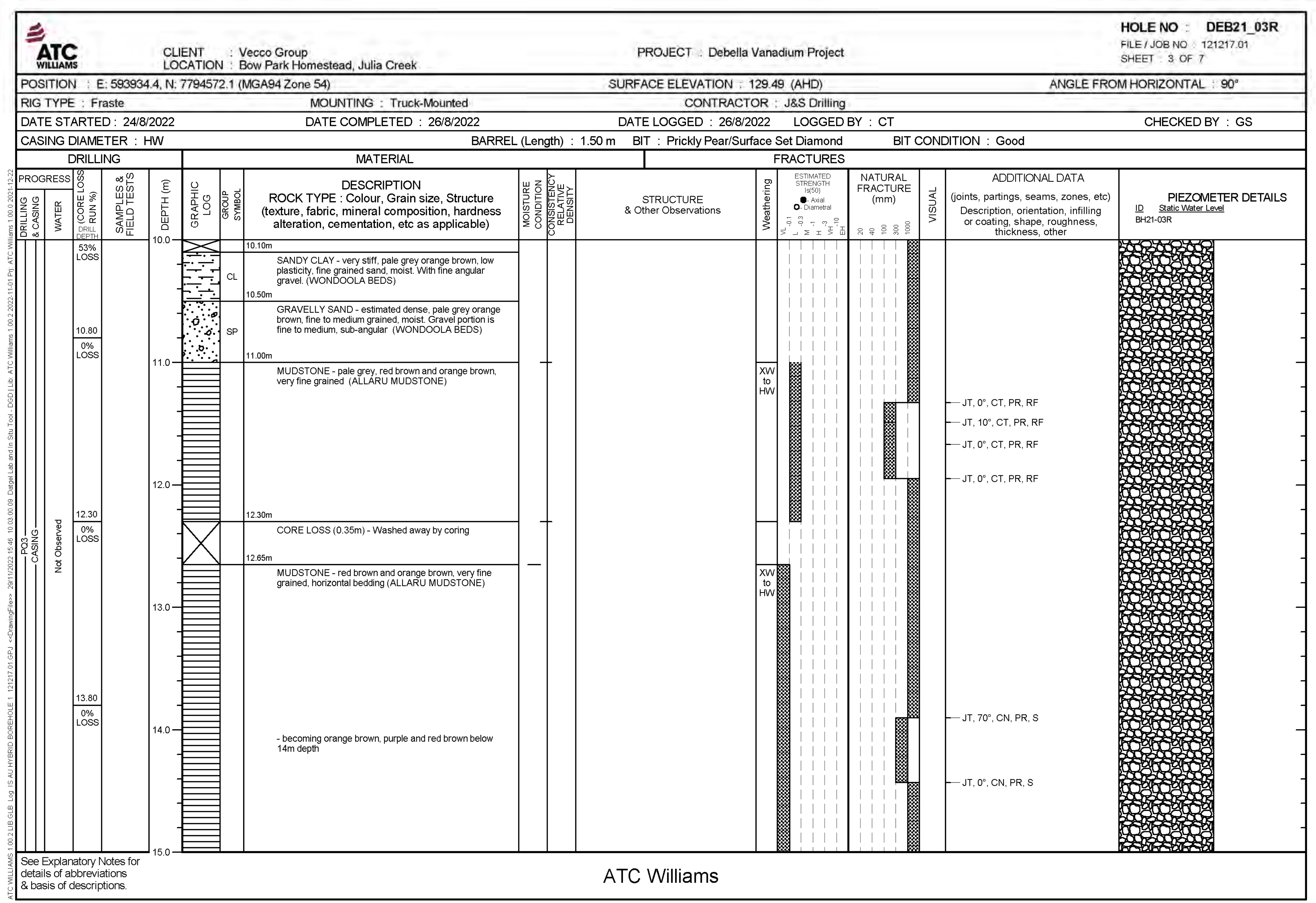
Drill depth / (CORE LOSS RUN %)	SAMPLES & FIELD TESTS	DEPTH (m)	GROUP SYMBOL	DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)	MOISTURE CONDITION	STRUCTURE & Other Observations	Weathering	ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other
0% LOSS 5.40	5.40m	5.0–5.40m	SP	GRAVELLY SAND - estimated dense to very dense, pale grey brown, coarse grained, moist. Gravel portion is fine to medium, sub-rounded, trace of clay (WONDOOLA BEDS) *(continued)* - becoming orange brown below 5m depth - becoming very dense at 5.25m depth	M			
80% LOSS	SPT 15/65mm HB N=R 5.47m	5.40m–6.20m		CORE LOSS (0.5m) - Washed away by coring				
6.40		6.20m–6.40m	SP	GRAVELLY SAND - estimated medium dense to dense, pale grey brown, coarse grained, moist. Gravel portion is fine to medium, sub-rounded, trace of clay (WONDOOLA BEDS)	M			
0% LOSS 7.00 0% LOSS	7.00m SPT 2,29,16/35mm HB N=R 7.34m	6.40m–7.30m	CH	SILTY CLAY - stiff to very stiff, pale grey and pale orange brown, high plasticity, trace fine sand, moist. (WONDOOLA BEDS) - with mudstone bands below 6.9m depth - becoming low plasticity with fine sand and fine angular gravel at 7.15m depth	w ■ PL	6.55: HP In-situ = 280 kPa 6.80: HP In-situ = 120 kPa		
7.80 0% LOSS 9.30	7.80m SPT 12,20/20mm HB N=R 7.97m	7.30m–9.30m		SILTSTONE - pale grey, white and orange brown, fine grained (WONDOOLA BEDS) - with bands of fine gravelly sand at 7.8m to 8m depth - band of hard silty clay at 8m to 8.1m depth - band of hard silty clay at 8.75m to 8.85m depth - band of dense, pale grey orange brown gravelly sand at 9.25m to 9.3m depth		8.10: HP In-situ = 420 kPa 8.75: HP In-situ = 400 kPa	HW to MW	JT, 20°, CT, UN, RF JT, 20°, CT, UN, RF JT, 0°, CT, UN, RF JT, 20°, CT, UN, RF JT, 60°, CT, UN, RF JT, 50°, CT, UN, RF JT, 50°, CT, UN, RF
53% LOSS		9.30m–10.0		CORE LOSS (0.8m) - Washed away by coring				

See Explanatory Notes for
details of abbreviations
& basis of descriptions.

ATC Williams

ATC WILLIAMS 1.00.2 LIB.GLB Log IS AU HYBRID BOREHOLE 1 121217.01.GPJ <<DrawingFile>> 29/11/2022 15:46 10.03.00.09 Datgel Lab and In Situ Tool - DGD | Lib: ATC Williams 1.00.2 2022-11-01 Prj: ATC Williams 1.00.0 2021-12-22

Figure 10-6: Borehole log – DEB21_03R (6-10 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek
PROJECT : Debella Vanadium Project

HOLE NO : DEB21_03R
FILE / JOB NO : 121217.01
SHEET : 3 OF 7

POSITION : E: 593934.4, N: 7794572.1 (MGA94 Zone 54)
SURFACE ELEVATION : 129.49 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 24/8/2022
DATE COMPLETED : 26/8/2022
DATE LOGGED : 26/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Prickly Pear/Surface Set Diamond
BIT CONDITION : Good

DRILLING Progress (Core loss, run %, drill depth)	DEPTH (m)	GROUP SYMBOL	DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)	Weathering	ADDITIONAL DATA
53% LOSS	10.10m	CL	SANDY CLAY - very stiff, pale grey orange brown, low plasticity, fine grained sand, moist. With fine angular gravel. (WONDOOLA BEDS)		
	10.50m	SP	GRAVELLY SAND - estimated dense, pale grey orange brown, fine to medium grained, moist. Gravel portion is fine to medium, sub-angular (WONDOOLA BEDS)		
10.80 0% LOSS	11.00m		MUDSTONE - pale grey, red brown and orange brown, very fine grained (ALLARU MUDSTONE)	XW to HW	JT, 0°, CT, PR, RF JT, 10°, CT, PR, RF JT, 0°, CT, PR, RF JT, 0°, CT, PR, RF
12.30 0% LOSS	12.30m		CORE LOSS (0.35m) - Washed away by coring		
	12.65m		MUDSTONE - red brown and orange brown, very fine grained, horizontal bedding (ALLARU MUDSTONE)	XW to HW	
13.80 0% LOSS			- becoming orange brown, purple and red brown below 14m depth		JT, 70°, CN, PR, S JT, 0°, CN, PR, S

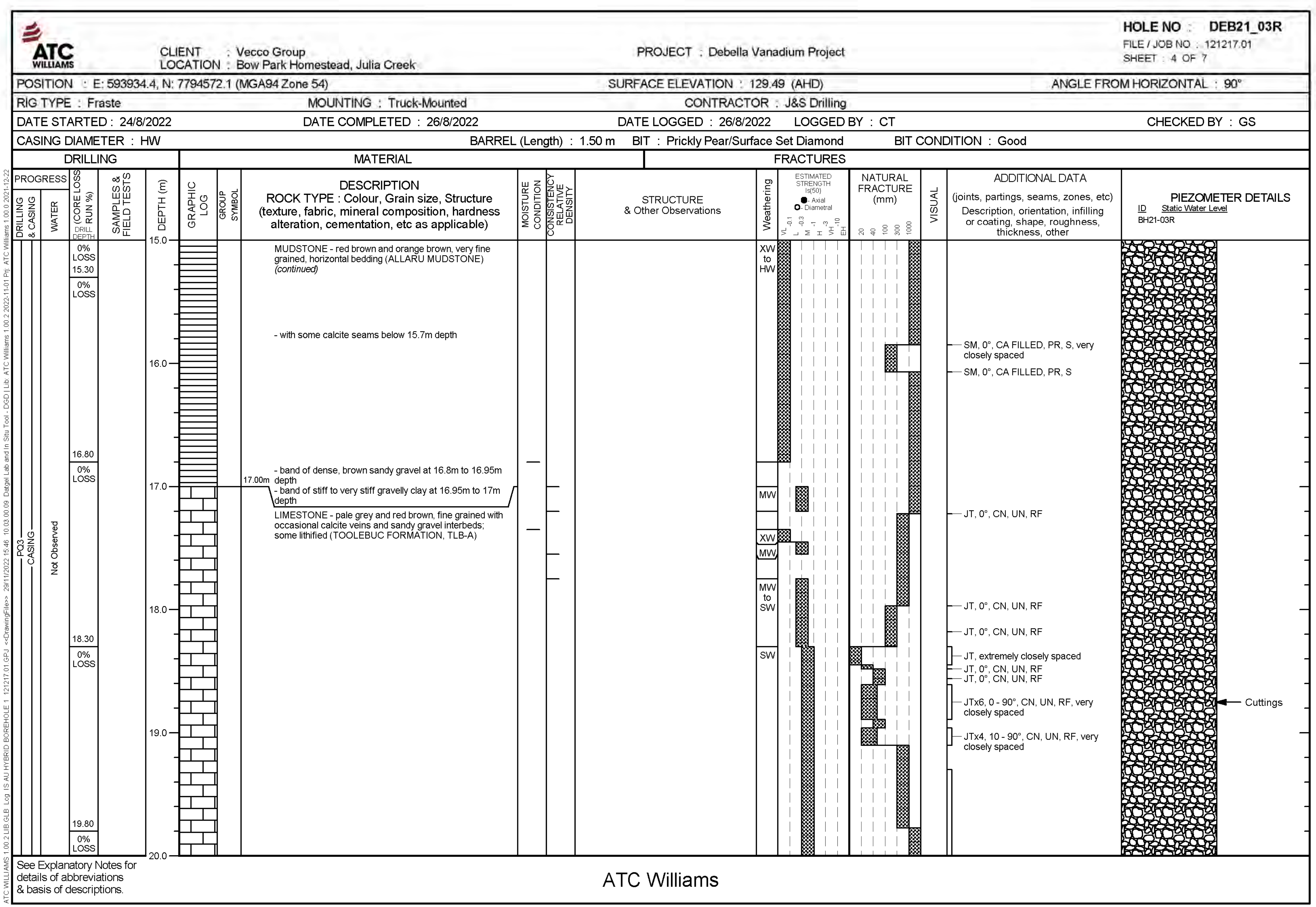
DRILLING & CASING: PQ3 — CASING
WATER: Not Observed

PIEZOMETER DETAILS
ID Static Water Level
BH21-03R

See Explanatory Notes for details of abbreviations & basis of descriptions.

ATC Williams

Figure 10-7: Borehole log – DEB21_03R (10 – 15 m)



HOLE NO : DEB21_03R
FILE / JOB NO : 121217.01
SHEET : 4 OF 7

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek
PROJECT : Debella Vanadium Project

POSITION : E: 593934.4, N: 7794572.1 (MGA94 Zone 54)
SURFACE ELEVATION : 129.49 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 24/8/2022
DATE COMPLETED : 26/8/2022
DATE LOGGED : 26/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Prickly Pear/Surface Set Diamond
BIT CONDITION : Good

MUDSTONE - red brown and orange brown, very fine grained, horizontal bedding (ALLARU MUDSTONE) *(continued)*

- with some calcite seams below 15.7m depth
- band of dense, brown sandy gravel at 16.8m to 16.95m depth
- band of stiff to very stiff gravelly clay at 16.95m to 17m depth

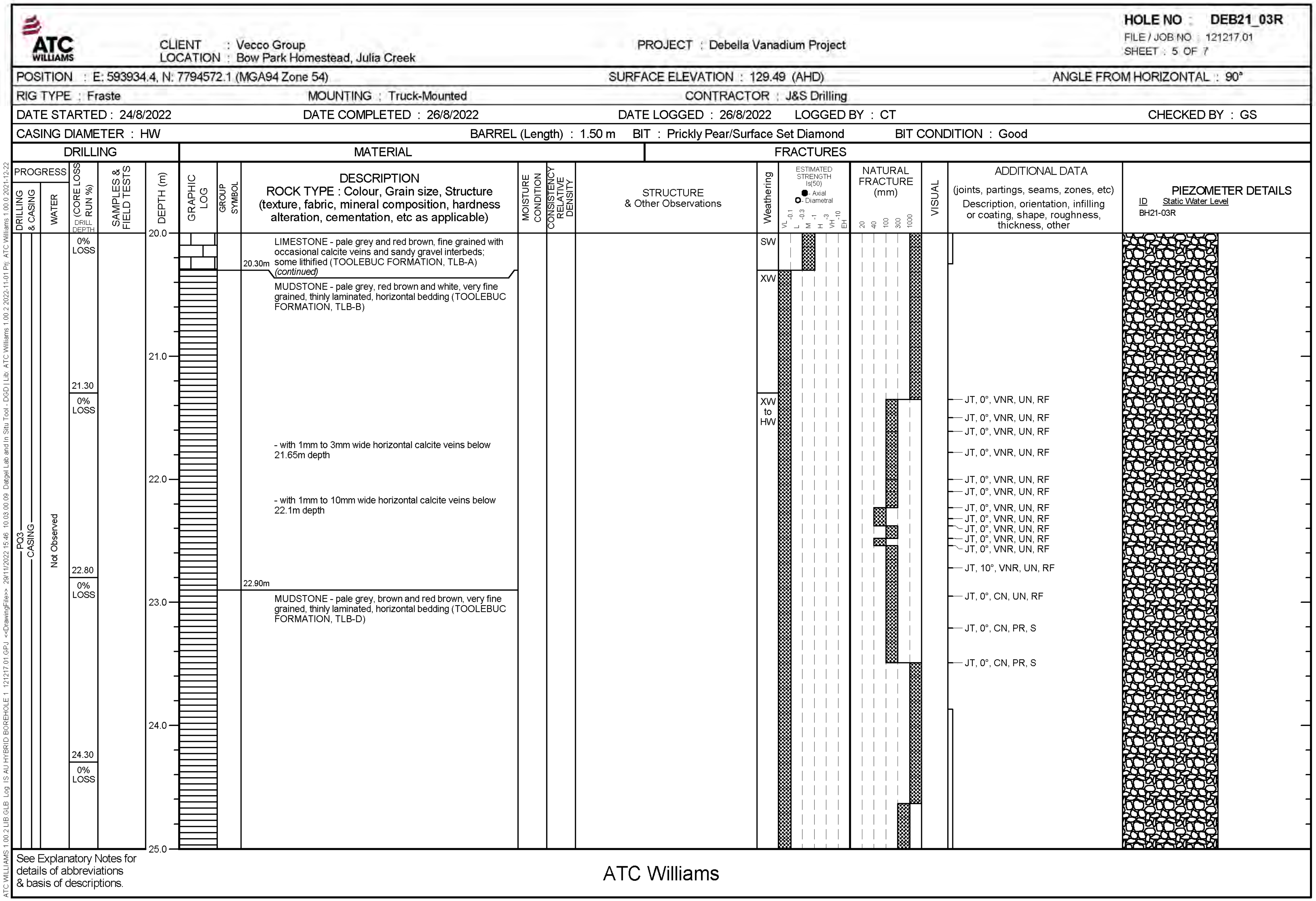
LIMESTONE - pale grey and red brown, fine grained with occasional calcite veins and sandy gravel interbeds; some lithified (TOOLEBUC FORMATION, TLB-A)

SM, 0°, CA FILLED, PR, S, very closely spaced
SM, 0°, CA FILLED, PR, S
JT, 0°, CN, UN, RF
JT, 0°, CN, UN, RF
JT, 0°, CN, UN, RF
JT, extremely closely spaced
JT, 0°, CN, UN, RF
JT, 0°, CN, UN, RF
JTx6, 0 - 90°, CN, UN, RF, very closely spaced
JTx4, 10 - 90°, CN, UN, RF, very closely spaced

See Explanatory Notes for details of abbreviations & basis of descriptions.

ATC Williams

Figure 10-8: Borehole log – DEB21_03R (15 – 20 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek

PROJECT : Debella Vanadium Project

HOLE NO : DEB21_03R
FILE / JOB NO : 121217.01
SHEET : 5 OF 7

POSITION : E: 593934.4, N: 7794572.1 (MGA94 Zone 54)
SURFACE ELEVATION : 129.49 (AHD)
ANGLE FROM HORIZONTAL : 90°

RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling

DATE STARTED : 24/8/2022
DATE COMPLETED : 26/8/2022
DATE LOGGED : 26/8/2022
LOGGED BY : CT
CHECKED BY : GS

CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Prickly Pear/Surface Set Diamond
BIT CONDITION : Good

Depth (m)	Core loss (run %) / drill depth	Description	Weathering	Additional data
20.0	0% LOSS	LIMESTONE - pale grey and red brown, fine grained with occasional calcite veins and sandy gravel interbeds; some lithified (TOOLEBUC FORMATION, TLB-A) *(continued)*	SW	
20.30m		MUDSTONE - pale grey, red brown and white, very fine grained, thinly laminated, horizontal bedding (TOOLEBUC FORMATION, TLB-B)	XW	
21.30	0% LOSS		XW to HW	JT, 0°, VNR, UN, RF JT, 0°, VNR, UN, RF JT, 0°, VNR, UN, RF JT, 0°, VNR, UN, RF
		- with 1mm to 3mm wide horizontal calcite veins below 21.65m depth		
		- with 1mm to 10mm wide horizontal calcite veins below 22.1m depth		JT, 0°, VNR, UN, RF JT, 0°, VNR, UN, RF JT, 0°, VNR, UN, RF JT, 0°, VNR, UN, RF JT, 0°, VNR, UN, RF JT, 0°, VNR, UN, RF JT, 0°, VNR, UN, RF JT, 10°, VNR, UN, RF
22.80	0% LOSS			
22.90m		MUDSTONE - pale grey, brown and red brown, very fine grained, thinly laminated, horizontal bedding (TOOLEBUC FORMATION, TLB-D)		JT, 0°, CN, UN, RF JT, 0°, CN, PR, S JT, 0°, CN, PR, S
24.30	0% LOSS			
25.0				

DRILLING & CASING: PQ3 CASING
WATER: Not Observed

PIEZOMETER DETAILS
ID Static Water Level
BH21-03R

See Explanatory Notes for details of abbreviations & basis of descriptions.

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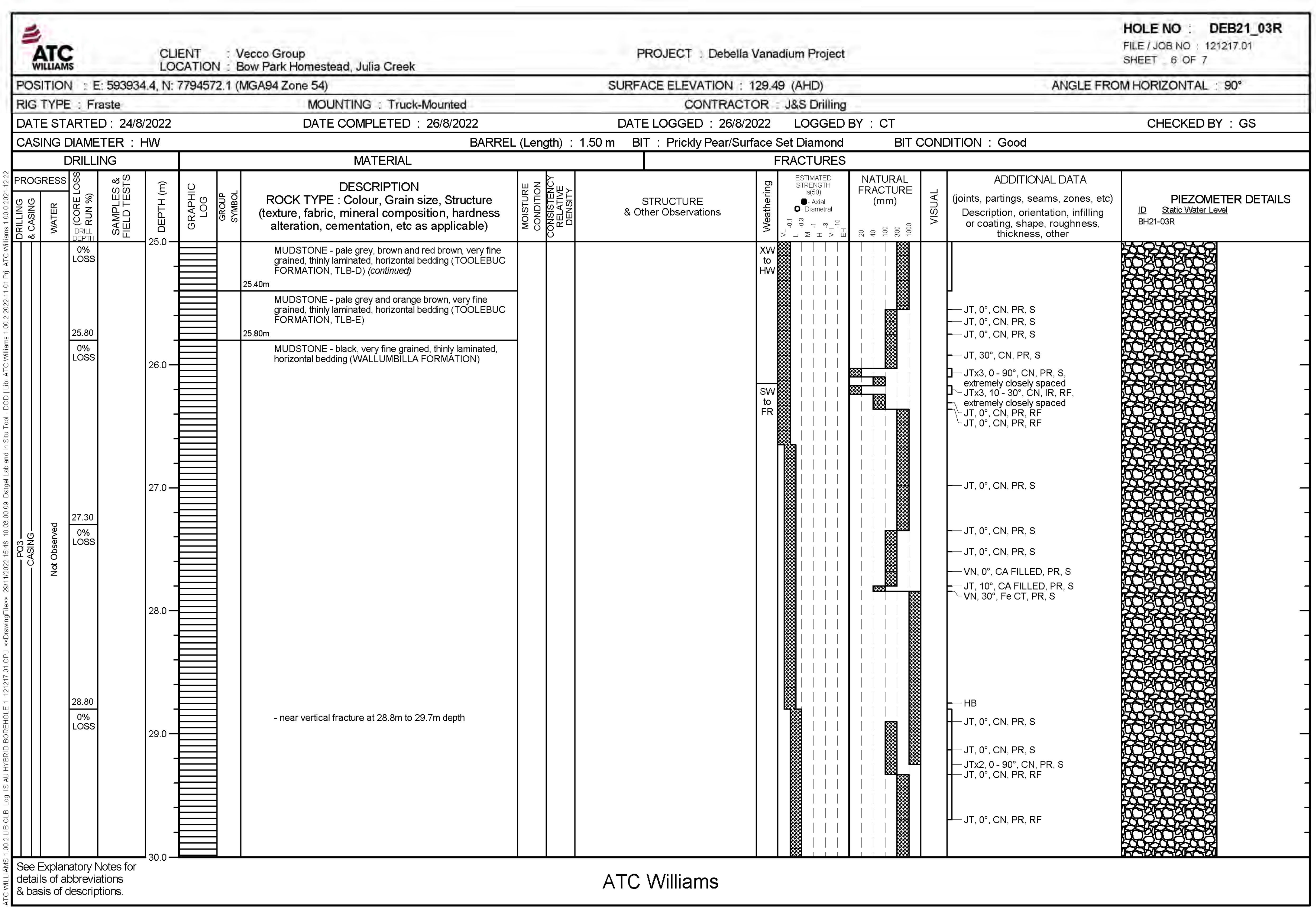
Figure 10-9: Borehole log – DEB21_03R (20 – 25 m)



HOLE NO : DEB21_03R
FILE / JOB NO : 121217.01
SHEET : 6 OF 7

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek
PROJECT : Debella Vanadium Project

POSITION : E: 593934.4, N: 7794572.1 (MGA94 Zone 54)
SURFACE ELEVATION : 129.49 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 24/8/2022
DATE COMPLETED : 26/8/2022
DATE LOGGED : 26/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Prickly Pear/Surface Set Diamond
BIT CONDITION : Good

DRILLING: (CORE LOSS RUN %) DRILL DEPTH	MATERIAL: DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)	FRACTURES: Weathering
0% LOSS	MUDSTONE - pale grey, brown and red brown, very fine grained, thinly laminated, horizontal bedding (TOOLEBUC FORMATION, TLB-D) *(continued)*	XW to HW
	25.40m	
25.80	MUDSTONE - pale grey and orange brown, very fine grained, thinly laminated, horizontal bedding (TOOLEBUC FORMATION, TLB-E)	
0% LOSS	25.80m	
	MUDSTONE - black, very fine grained, thinly laminated, horizontal bedding (WALLUMBILLA FORMATION)	SW to FR
27.30		
0% LOSS		
28.80		
0% LOSS	- near vertical fracture at 28.8m to 29.7m depth	

PROGRESS: DRILLING & CASING; WATER; SAMPLES & FIELD TESTS; DEPTH (m); GRAPHIC LOG; GROUP SYMBOL; MOISTURE CONDITION; CONSISTENCY RELATIVE DENSITY; STRUCTURE & Other Observations; ESTIMATED STRENGTH Is(50) ● - Axial ○ - Diametral; NATURAL FRACTURE (mm); VISUAL

ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other

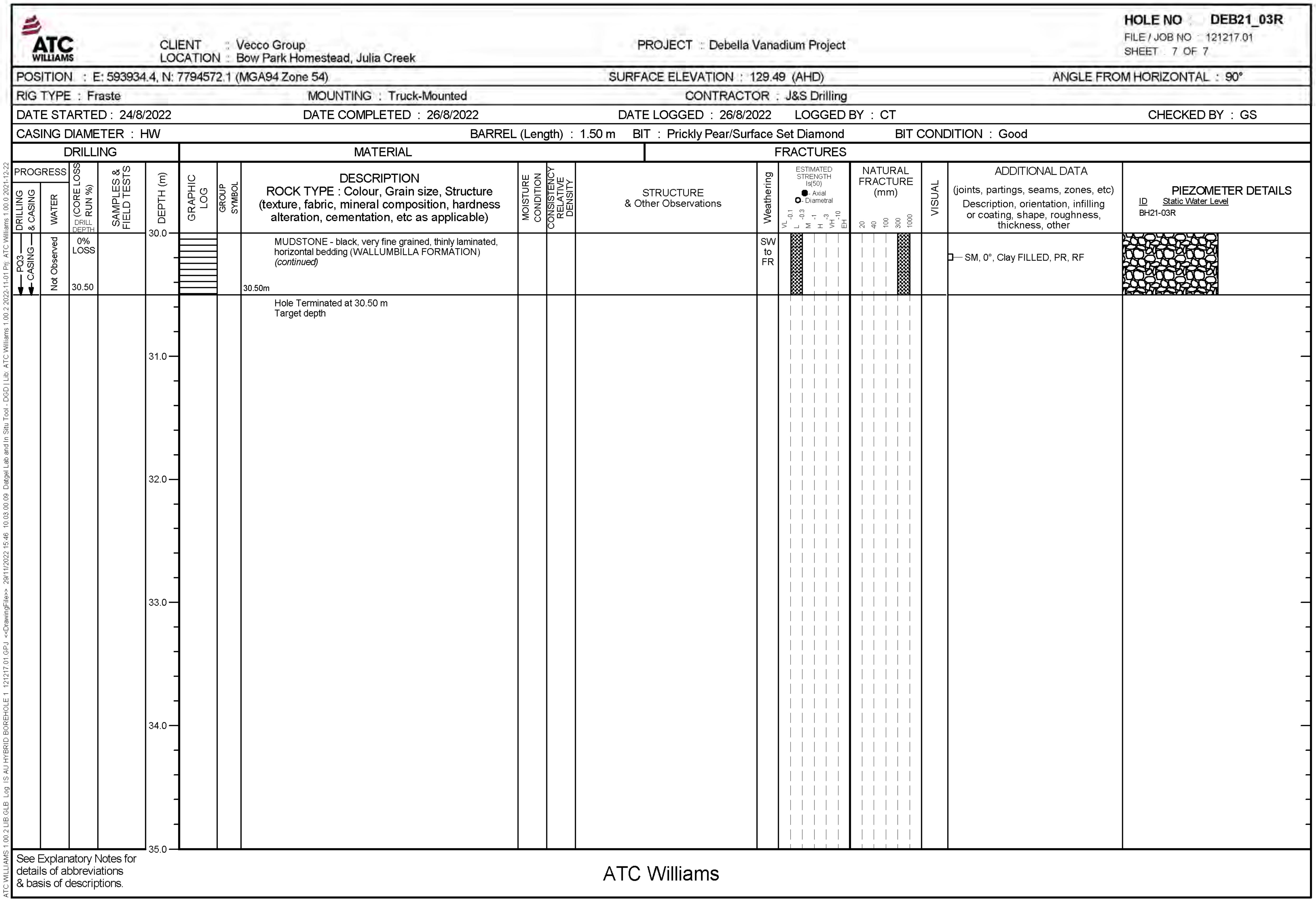
- JT, 0°, CN, PR, S
- JT, 0°, CN, PR, S
- JT, 0°, CN, PR, S
- JT, 30°, CN, PR, S
- JTx3, 0 - 90°, CN, PR, S, extremely closely spaced
- JTx3, 10 - 30°, CN, IR, RF, extremely closely spaced
- JT, 0°, CN, PR, RF
- JT, 0°, CN, PR, RF
- JT, 0°, CN, PR, S
- JT, 0°, CN, PR, S
- JT, 0°, CN, PR, S
- VN, 0°, CA FILLED, PR, S
- JT, 10°, CA FILLED, PR, S
- VN, 30°, Fe CT, PR, S
- HB
- JT, 0°, CN, PR, S
- JT, 0°, CN, PR, S
- JTx2, 0 - 90°, CN, PR, S
- JT, 0°, CN, PR, RF
- JT, 0°, CN, PR, RF

PIEZOMETER DETAILS
ID Static Water Level
BH21-03R

See Explanatory Notes for details of abbreviations & basis of descriptions.

ATC Williams

Figure 10-10: Borehole log – DEB21_03R (25 – 30 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek

PROJECT : Debella Vanadium Project

HOLE NO : DEB21_03R
FILE / JOB NO : 121217.01
SHEET : 7 OF 7

POSITION : E: 593934.4, N: 7794572.1 (MGA94 Zone 54)
SURFACE ELEVATION : 129.49 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 24/8/2022
DATE COMPLETED : 26/8/2022
DATE LOGGED : 26/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Prickly Pear/Surface Set Diamond
BIT CONDITION : Good

DRILLING					MATERIAL						FRACTURES					
PROGRESS DRILLING & CASING	WATER	(CORE LOSS RUN %) DRILL DEPTH	SAMPLES & FIELD TESTS	DEPTH (m)	GRAPHIC LOG	GROUP SYMBOL	DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)	MOISTURE CONDITION	CONSISTENCY RELATIVE DENSITY	STRUCTURE & Other Observations	Weathering	ESTIMATED STRENGTH Is(50) ● - Axial ○ - Diametral VL -0.1 L -0.3 M -1 H -3 VH -10 EH	NATURAL FRACTURE (mm) 20 40 100 300 1000	VISUAL	ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other	PIEZOMETER DETAILS ID Static Water Level BH21-03R
PQ3 CASING	Not Observed	0% LOSS 30.50		30.0			MUDSTONE - black, very fine grained, thinly laminated, horizontal bedding (WALLUMBILLA FORMATION) *(continued)* 30.50m				SW to FR				SM, 0°, Clay FILLED, PR, RF	
				31.0			Hole Terminated at 30.50 m Target depth									
				32.0												
				33.0												
				34.0												
				35.0												

See Explanatory Notes for details of abbreviations & basis of descriptions.

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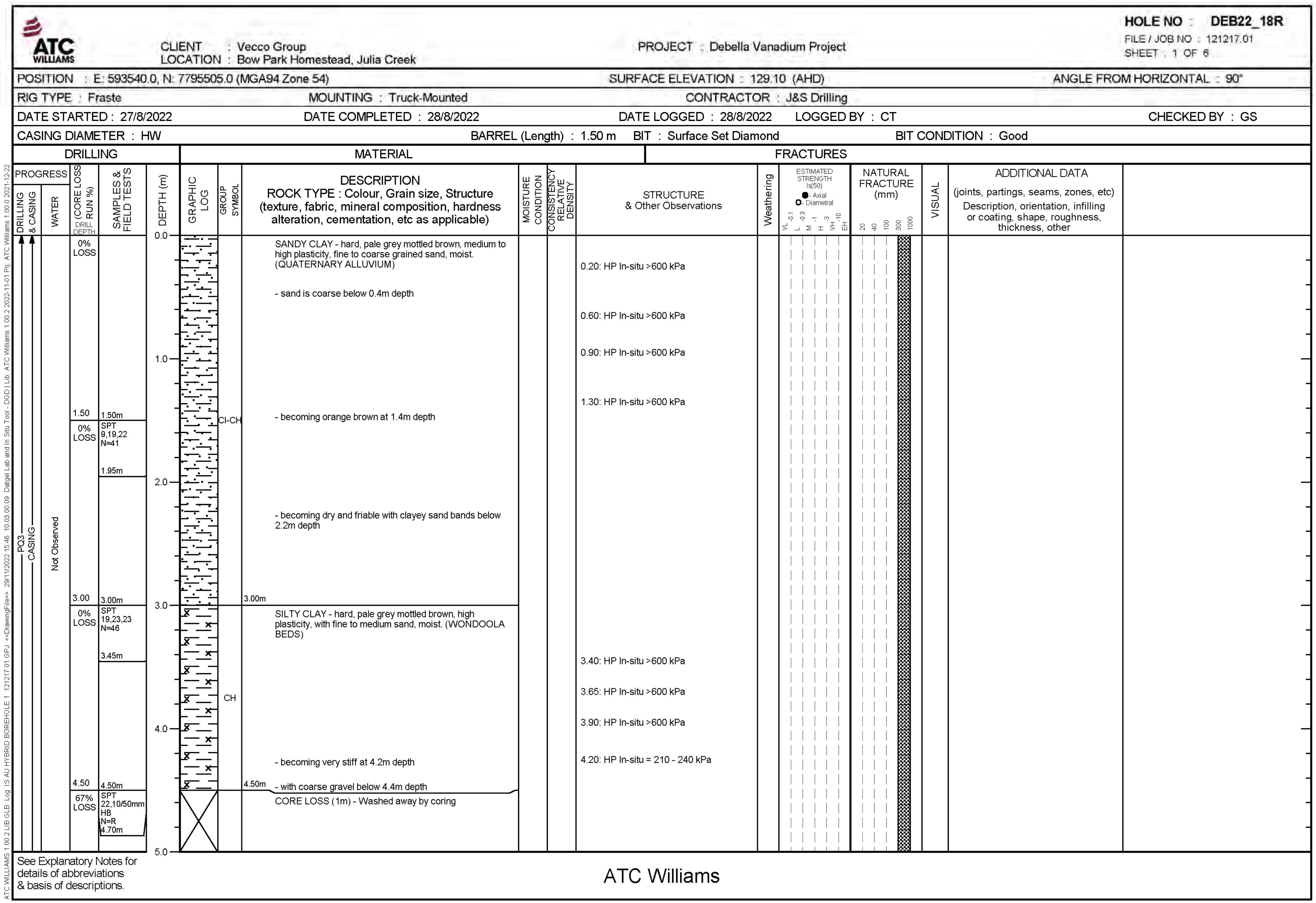
Figure 10-11: Borehole log – DEB21_03R (30 – 30.5 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek

PROJECT : Debella Vanadium Project

HOLE NO : DEB22_18R
FILE / JOB NO : 121217.01
SHEET : 1 OF 6

POSITION : E: 593540.0, N: 7795505.0 (MGA94 Zone 54)
SURFACE ELEVATION : 129.10 (AHD)
ANGLE FROM HORIZONTAL : 90°

RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling

DATE STARTED : 27/8/2022
DATE COMPLETED : 28/8/2022
DATE LOGGED : 28/8/2022
LOGGED BY : CT
CHECKED BY : GS

CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Surface Set Diamond
BIT CONDITION : Good

DRILLING: PROGRESS DRILLING & CASING	WATER	(CORE LOSS RUN %) DRILL DEPTH	SAMPLES & FIELD TESTS	DEPTH (m)	GROUP SYMBOL	MATERIAL: DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)	MOISTURE CONDITION	CONSISTENCY RELATIVE DENSITY	STRUCTURE & Other Observations	FRACTURES: Weathering	ESTIMATED STRENGTH Is(50) ● - Axial ○ - Diametral VL L M H VH EH	NATURAL FRACTURE (mm) 20 40 100 300 1000	VISUAL	ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other
PQ3 CASING	Not Observed	0% LOSS		0.0	CI-CH	SANDY CLAY - hard, pale grey mottled brown, medium to high plasticity, fine to coarse grained sand, moist. (QUATERNARY ALLUVIUM) - sand is coarse below 0.4m depth			0.20: HP In-situ >600 kPa 0.60: HP In-situ >600 kPa 0.90: HP In-situ >600 kPa 1.30: HP In-situ >600 kPa					
		1.50 0% LOSS	1.50m SPT 9,19,22 N=41 1.95m	1.0 2.0		- becoming orange brown at 1.4m depth - becoming dry and friable with clayey sand bands below 2.2m depth								
		3.00 0% LOSS	3.00m SPT 19,23,23 N=46 3.45m	3.0 4.0	3.00m CH	SILTY CLAY - hard, pale grey mottled brown, high plasticity, with fine to medium sand, moist. (WONDOOLA BEDS) - becoming very stiff at 4.2m depth			3.40: HP In-situ >600 kPa 3.65: HP In-situ >600 kPa 3.90: HP In-situ >600 kPa 4.20: HP In-situ = 210 - 240 kPa					
		4.50 67% LOSS	4.50m SPT 22,10/50mm HB N=R 4.70m	5.0	4.50m	- with coarse gravel below 4.4m depth CORE LOSS (1m) - Washed away by coring								

See Explanatory Notes for
details of abbreviations
& basis of descriptions.

ATC Williams

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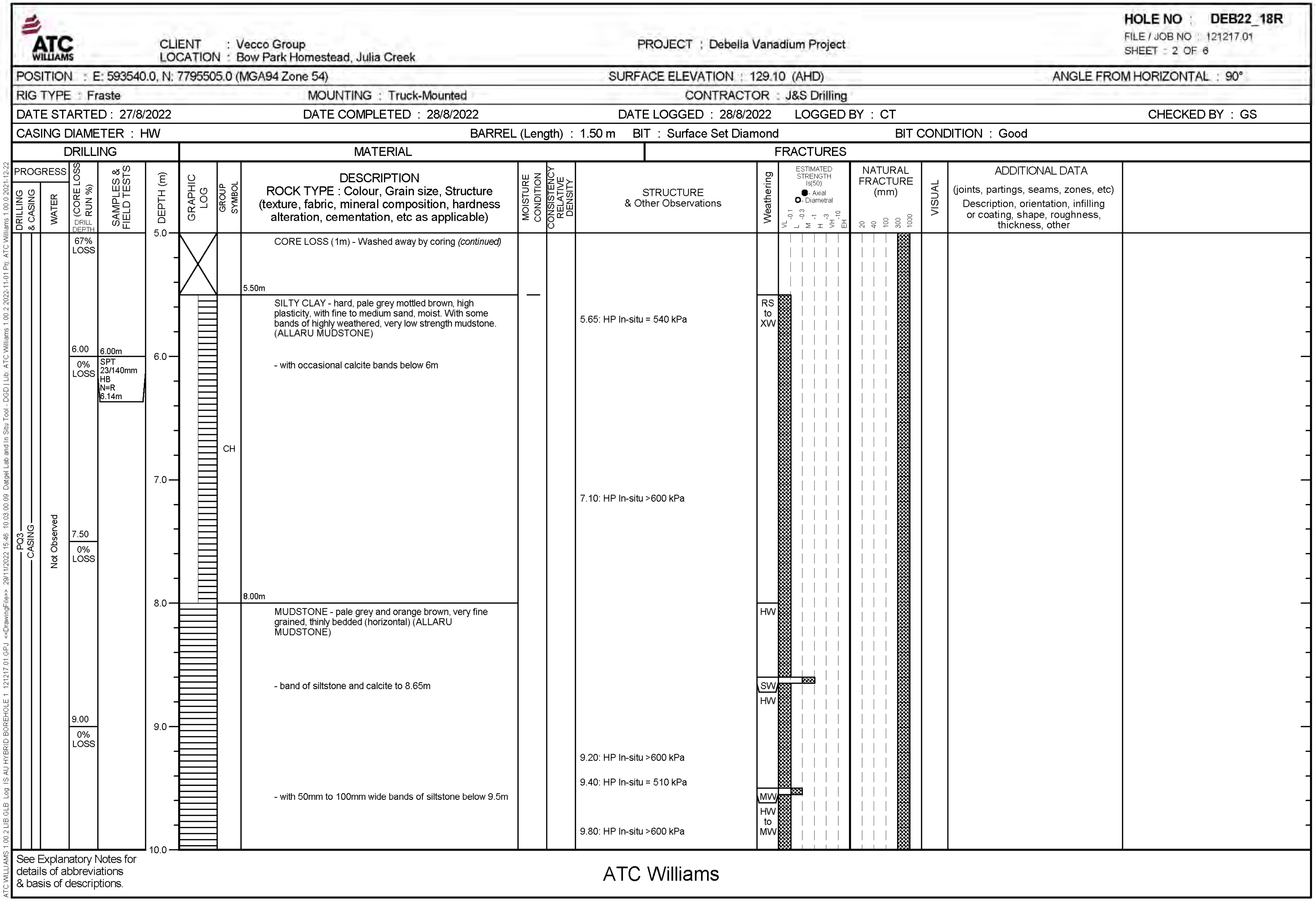
Figure 10-12: Borehole log – DEB21_18R (0 – 5 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek

PROJECT : Debella Vanadium Project

HOLE NO : DEB22_18R
FILE / JOB NO : 121217.01
SHEET : 2 OF 6

POSITION : E: 593540.0, N: 7795505.0 (MGA94 Zone 54)
SURFACE ELEVATION : 129.10 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 27/8/2022
DATE COMPLETED : 28/8/2022
DATE LOGGED : 28/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Surface Set Diamond
BIT CONDITION : Good

DEPTH (m)	PROGRESS: DRILLING & CASING	WATER	(CORE LOSS RUN %) DRILL DEPTH	SAMPLES & FIELD TESTS	GRAPHIC LOG	GROUP SYMBOL	DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)	MOISTURE CONDITION	CONSISTENCY RELATIVE DENSITY	STRUCTURE & Other Observations	Weathering	ESTIMATED STRENGTH Is(50) ●- Axial ○- Diametral VL -0.1 L -0.3 M -1 H -3 VH -10 EH	NATURAL FRACTURE (mm) 20 40 100 300 1000	VISUAL	ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other
5.0	PQ3 CASING	Not Observed	67% LOSS				CORE LOSS (1m) - Washed away by coring *(continued)*								
5.50m							SILTY CLAY - hard, pale grey mottled brown, high plasticity, with fine to medium sand, moist. With some bands of highly weathered, very low strength mudstone. (ALLARU MUDSTONE)			5.65: HP In-situ = 540 kPa	RS to XW				
6.0			6.00 0% LOSS	6.00m SPT 23/140mm HB N=R 6.14m			- with occasional calcite bands below 6m								
7.0						CH				7.10: HP In-situ >600 kPa					
			7.50 0% LOSS												
8.00m							MUDSTONE - pale grey and orange brown, very fine grained, thinly bedded (horizontal) (ALLARU MUDSTONE)				HW				
							- band of siltstone and calcite to 8.65m				SW HW				
9.0			9.00 0% LOSS							9.20: HP In-situ >600 kPa 9.40: HP In-situ = 510 kPa					
							- with 50mm to 100mm wide bands of siltstone below 9.5m			9.80: HP In-situ >600 kPa	MW HW to MW				
10.0															

See Explanatory Notes for
details of abbreviations
& basis of descriptions.

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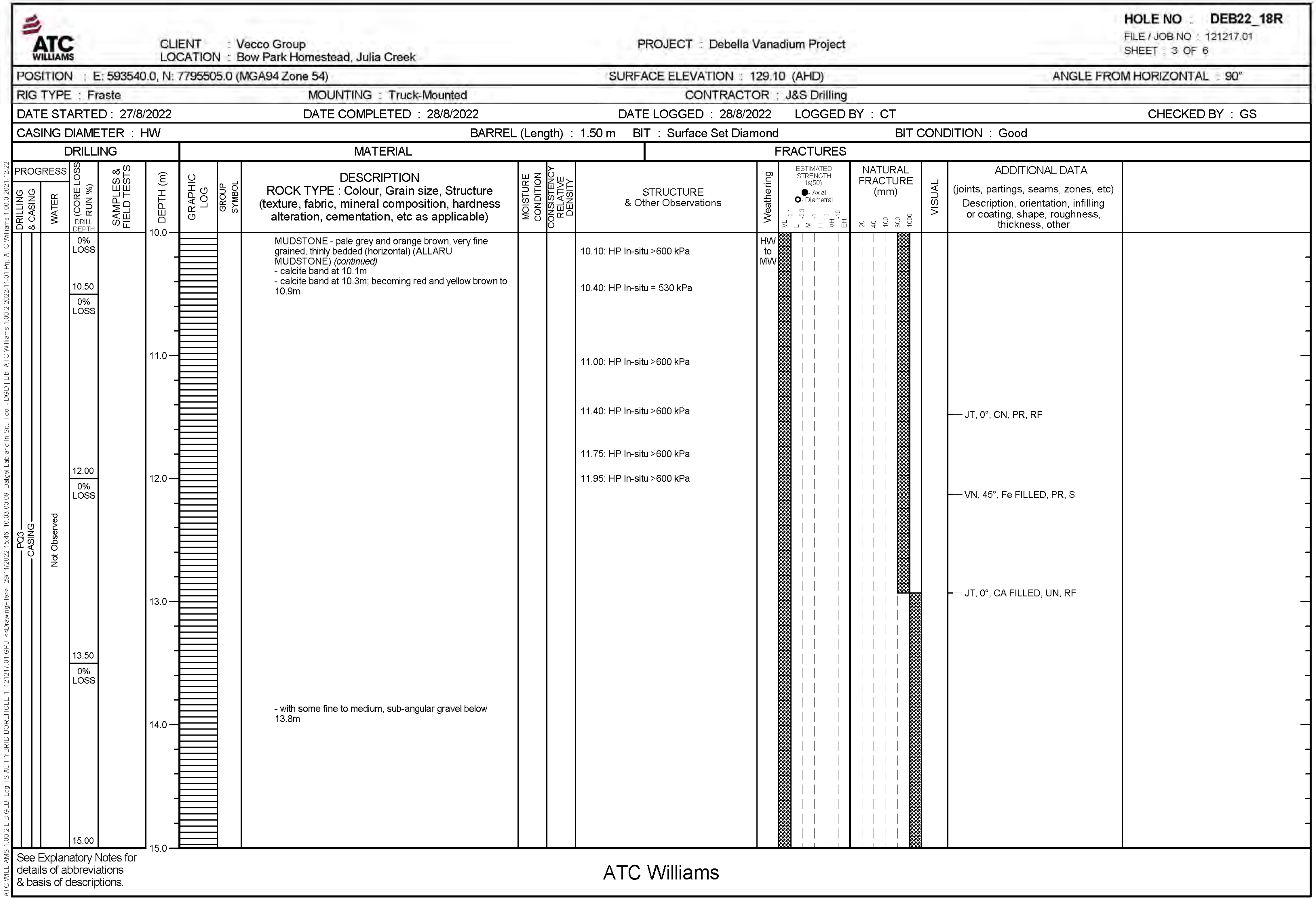
Figure 10-13: Borehole log – DEB21_18R (5 – 10 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek

PROJECT : Debella Vanadium Project

HOLE NO : DEB22_18R
FILE / JOB NO : 121217.01
SHEET : 3 OF 6

POSITION : E: 593540.0, N: 7795505.0 (MGA94 Zone 54)
SURFACE ELEVATION : 129.10 (AHD)
ANGLE FROM HORIZONTAL : 90°

RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling

DATE STARTED : 27/8/2022
DATE COMPLETED : 28/8/2022
DATE LOGGED : 28/8/2022
LOGGED BY : CT
CHECKED BY : GS

CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Surface Set Diamond
BIT CONDITION : Good

DRILLING: PROGRESS (DRILLING & CASING, WATER); CORE LOSS (RUN %) / DRILL DEPTH; SAMPLES & FIELD TESTS

MATERIAL: DEPTH (m); GRAPHIC LOG; GROUP SYMBOL; DESCRIPTION – ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable); MOISTURE CONDITION; CONSISTENCY RELATIVE DENSITY; STRUCTURE & Other Observations

FRACTURES: Weathering; ESTIMATED STRENGTH Is(50) (● - Axial, ○ - Diametral; VL -0.1 L -0.3 M -1 H -3 VH -10 EH); NATURAL FRACTURE (mm) (20, 40, 100, 300, 1000); VISUAL; ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other

Drilling: PQ3 – CASING. Water: Not Observed.

Drill depth	Core loss (Run %)
10.00–10.50	0% LOSS
10.50–12.00	0% LOSS
12.00–13.50	0% LOSS
13.50–15.00	0% LOSS

Depth 10.0–15.0 m:

MUDSTONE - pale grey and orange brown, very fine grained, thinly bedded (horizontal) (ALLARU MUDSTONE) *(continued)*
- calcite band at 10.1m
- calcite band at 10.3m; becoming red and yellow brown to 10.9m

- with some fine to medium, sub-angular gravel below 13.8m

Structure & Other Observations:
10.10: HP In-situ >600 kPa
10.40: HP In-situ = 530 kPa
11.00: HP In-situ >600 kPa
11.40: HP In-situ >600 kPa
11.75: HP In-situ >600 kPa
11.95: HP In-situ >600 kPa

Weathering: HW to MW

Additional Data:
JT, 0°, CN, PR, RF
VN, 45°, Fe FILLED, PR, S
JT, 0°, CA FILLED, UN, RF

See Explanatory Notes for details of abbreviations & basis of descriptions.

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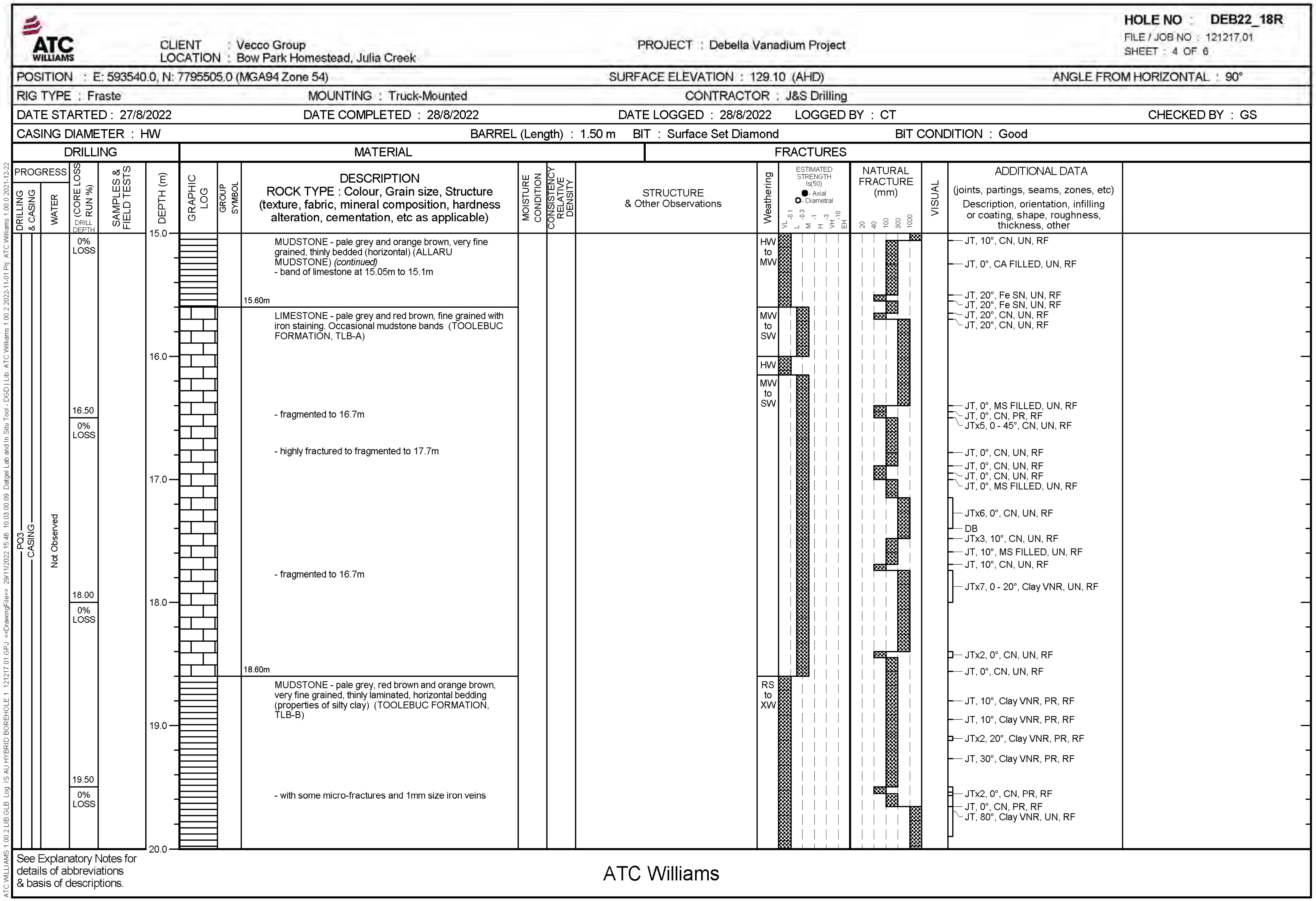
Figure 10-14: Borehole log – DEB21_18R (10 – 15 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek

PROJECT : Debella Vanadium Project

HOLE NO : DEB22_18R
FILE / JOB NO : 121217.01
SHEET : 4 OF 6

POSITION : E: 593540.0, N: 7795505.0 (MGA94 Zone 54)
SURFACE ELEVATION : 129.10 (AHD)
ANGLE FROM HORIZONTAL : 90°

RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling

DATE STARTED : 27/8/2022
DATE COMPLETED : 28/8/2022
DATE LOGGED : 28/8/2022
LOGGED BY : CT
CHECKED BY : GS

CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Surface Set Diamond
BIT CONDITION : Good

DRILLING | MATERIAL | FRACTURES

PROGRESS: DRILLING & CASING: PQ3 — CASING; WATER: Not Observed

(CORE LOSS RUN %) / DRILL DEPTH:
- 0% LOSS
- 16.50
- 0% LOSS
- 18.00
- 0% LOSS
- 19.50
- 0% LOSS

DEPTH (m)	DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)
15.0	MUDSTONE - pale grey and orange brown, very fine grained, thinly bedded (horizontal) (ALLARU MUDSTONE) *(continued)* - band of limestone at 15.05m to 15.1m
15.60m	LIMESTONE - pale grey and red brown, fine grained with iron staining. Occasional mudstone bands (TOOLEBUC FORMATION, TLB-A) - fragmented to 16.7m - highly fractured to fragmented to 17.7m - fragmented to 16.7m
18.60m	MUDSTONE - pale grey, red brown and orange brown, very fine grained, thinly laminated, horizontal bedding (properties of silty clay) (TOOLEBUC FORMATION, TLB-B) - with some micro-fractures and 1mm size iron veins
20.0	

Weathering: HW to MW; MW to SW; HW; MW to SW; RS to XW

ESTIMATED STRENGTH Is(50) ● - Axial ○ - Diametral (VL -0.1, L -0.3, M -1, H -3, VH -10, EH)

NATURAL FRACTURE (mm) (20, 40, 100, 300, 1000)

ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other
- JT, 10°, CN, UN, RF
- JT, 0°, CA FILLED, UN, RF
- JT, 20°, Fe SN, UN, RF
- JT, 20°, Fe SN, UN, RF
- JT, 20°, CN, UN, RF
- JT, 20°, CN, UN, RF
- JT, 0°, MS FILLED, UN, RF
- JT, 0°, CN, PR, RF
- JTx5, 0 - 45°, CN, UN, RF
- JT, 0°, CN, UN, RF
- JT, 0°, CN, UN, RF
- JT, 0°, CN, UN, RF
- JT, 0°, MS FILLED, UN, RF
- JTx6, 0°, CN, UN, RF
- DB
- JTx3, 10°, CN, UN, RF
- JT, 10°, MS FILLED, UN, RF
- JT, 10°, CN, UN, RF
- JTx7, 0 - 20°, Clay VNR, UN, RF
- JTx2, 0°, CN, UN, RF
- JT, 0°, CN, UN, RF
- JT, 10°, Clay VNR, PR, RF
- JT, 10°, Clay VNR, PR, RF
- JTx2, 20°, Clay VNR, PR, RF
- JT, 30°, Clay VNR, PR, RF
- JTx2, 0°, CN, PR, RF
- JT, 0°, CN, PR, RF
- JT, 80°, Clay VNR, UN, RF

See Explanatory Notes for details of abbreviations & basis of descriptions.

ATC Williams

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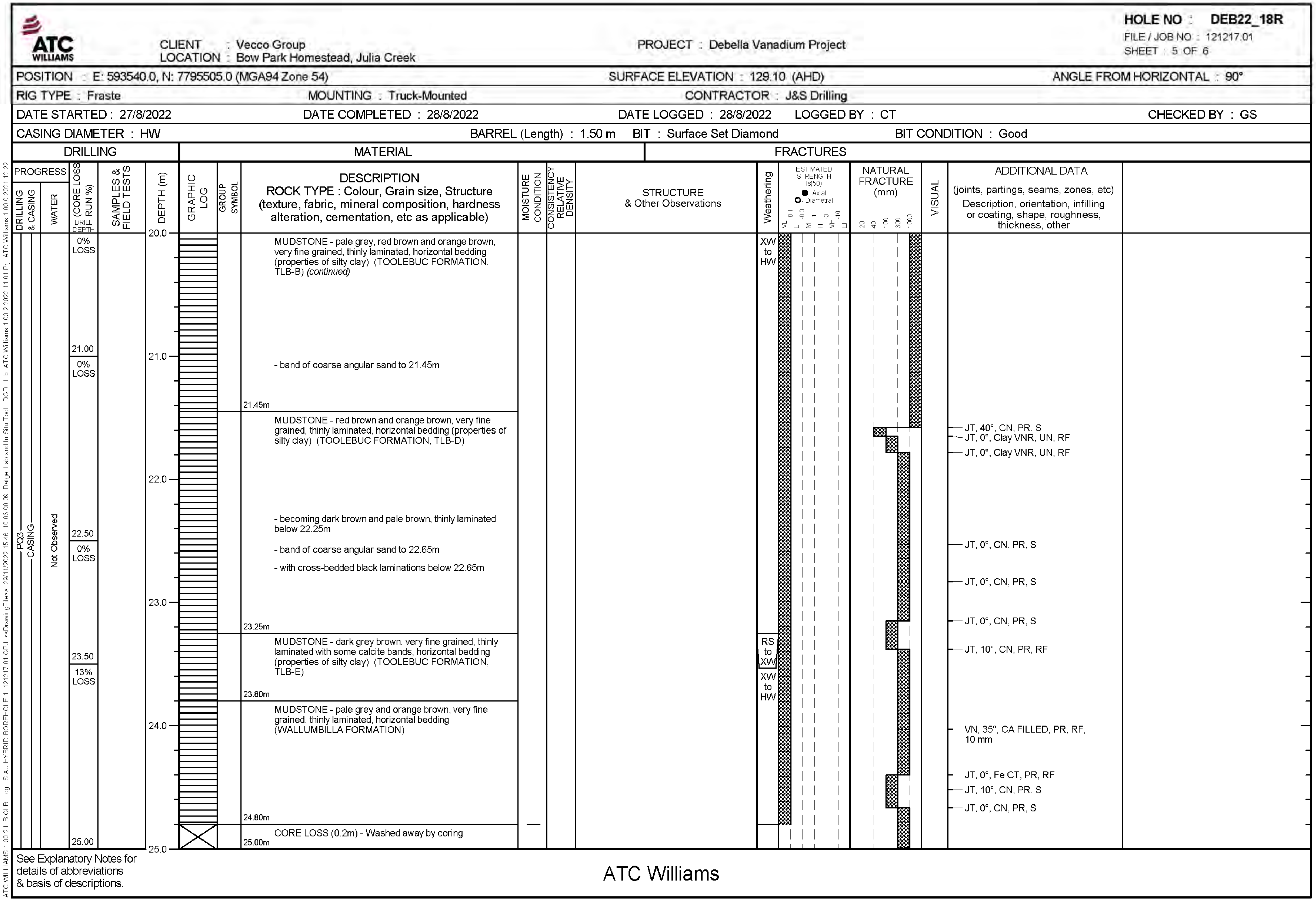
Figure 10-15: Borehole log – DEB21_18R (15 – 20 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek
PROJECT : Debella Vanadium Project
HOLE NO : DEB22_18R
FILE / JOB NO : 121217.01
SHEET : 5 OF 6

POSITION : E: 593540.0, N: 7795505.0 (MGA94 Zone 54)
SURFACE ELEVATION : 129.10 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 27/8/2022
DATE COMPLETED : 28/8/2022
DATE LOGGED : 28/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Surface Set Diamond
BIT CONDITION : Good

DRILLING						MATERIAL						FRACTURES				
PROGRESS: DRILLING & CASING	PROGRESS: WATER	(CORE LOSS RUN %) DRILL DEPTH	SAMPLES & FIELD TESTS	DEPTH (m)	GRAPHIC LOG	GROUP SYMBOL	DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)	MOISTURE CONDITION	CONSISTENCY RELATIVE DENSITY	STRUCTURE & Other Observations	Weathering	ESTIMATED STRENGTH Is(50) ● - Axial ○ - Diametral VL -0.1 L -0.3 M -1 H -3 VH -10 EH	NATURAL FRACTURE (mm) 20 40 100 300 1000	VISUAL	ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other	
PQ3 CASING	Not Observed	0% LOSS		20.0			MUDSTONE - pale grey, red brown and orange brown, very fine grained, thinly laminated, horizontal bedding (properties of silty clay) (TOOLEBUC FORMATION, TLB-B) *(continued)*				XW to HW					
		21.00 0% LOSS		21.0			- band of coarse angular sand to 21.45m									
						21.45m	MUDSTONE - red brown and orange brown, very fine grained, thinly laminated, horizontal bedding (properties of silty clay) (TOOLEBUC FORMATION, TLB-D)								JT, 40°, CN, PR, S JT, 0°, Clay VNR, UN, RF JT, 0°, Clay VNR, UN, RF	
				22.0			- becoming dark brown and pale brown, thinly laminated below 22.25m									
		22.50 0% LOSS					- band of coarse angular sand to 22.65m								JT, 0°, CN, PR, S	
							- with cross-bedded black laminations below 22.65m								JT, 0°, CN, PR, S	
				23.0		23.25m									JT, 0°, CN, PR, S	
		23.50 13% LOSS					MUDSTONE - dark grey brown, very fine grained, thinly laminated with some calcite bands, horizontal bedding (properties of silty clay) (TOOLEBUC FORMATION, TLB-E)				RS to XW				JT, 10°, CN, PR, RF	
				24.0		23.80m	MUDSTONE - pale grey and orange brown, very fine grained, thinly laminated, horizontal bedding (WALLUMBILLA FORMATION)				XW to HW				VN, 35°, CA FILLED, PR, RF, 10 mm JT, 0°, Fe CT, PR, RF JT, 10°, CN, PR, S JT, 0°, CN, PR, S	
		25.00		25.0		24.80m	CORE LOSS (0.2m) - Washed away by coring	—								
						25.00m										

See Explanatory Notes for details of abbreviations & basis of descriptions.

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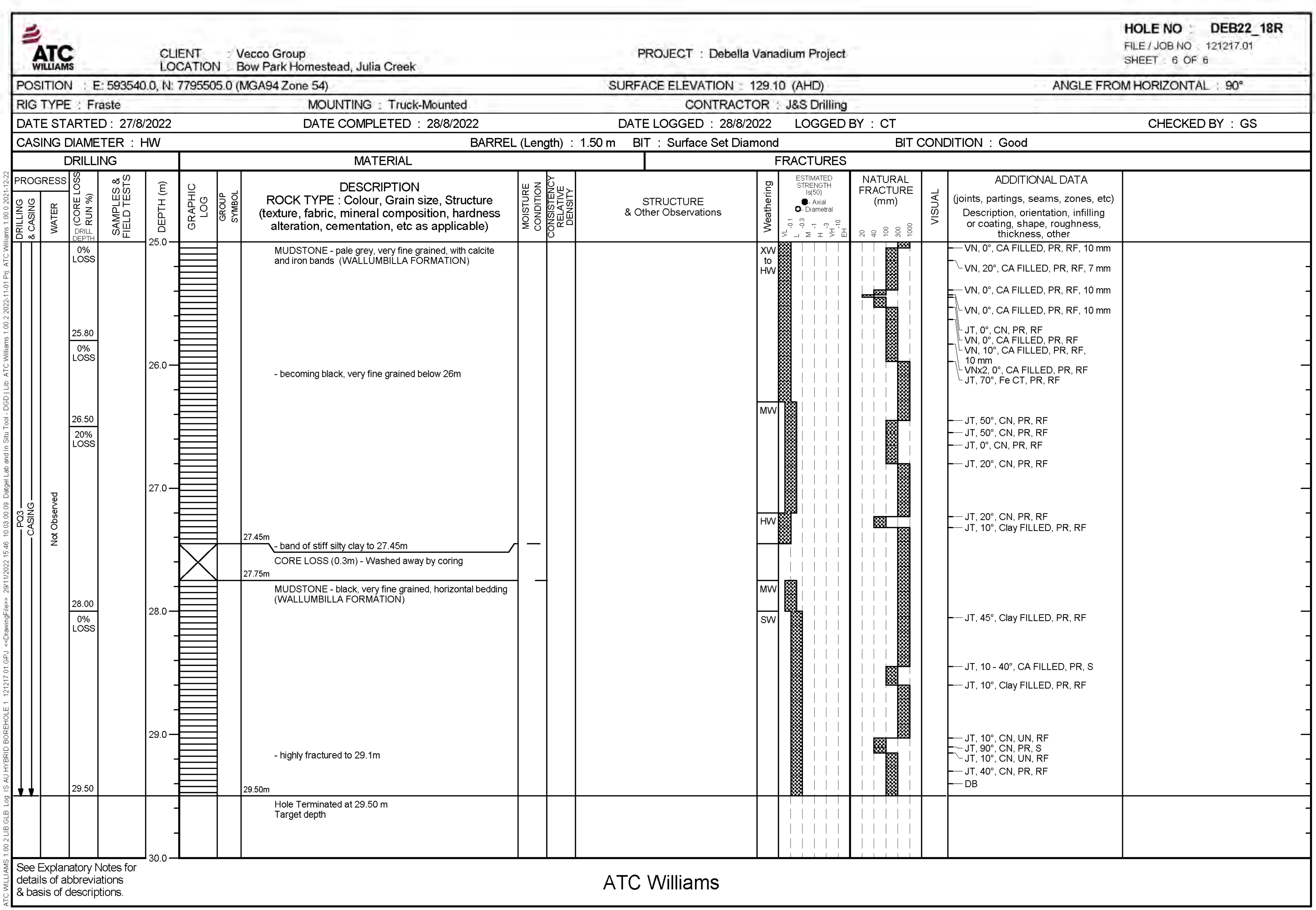
Figure 10-16: Borehole log – DEB21_18R (20 – 25 m)



ATC WILLIAMS

HOLE NO : DEB22_18R
FILE / JOB NO : 121217.01
SHEET : 6 OF 6

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek
PROJECT : Debella Vanadium Project

POSITION : E: 593540.0, N: 7795505.0 (MGA94 Zone 54)
SURFACE ELEVATION : 129.10 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 27/8/2022
DATE COMPLETED : 28/8/2022
DATE LOGGED : 28/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Surface Set Diamond
BIT CONDITION : Good

DRILLING: PROGRESS (DRILLING & CASING; WATER)	(CORE LOSS RUN %) / DRILL DEPTH	DEPTH (m)	MATERIAL: DESCRIPTION — ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)	Weathering	ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other
PQ3 CASING; Not Observed	0% LOSS	25.0	MUDSTONE - pale grey, very fine grained, with calcite and iron bands (WALLUMBILLA FORMATION)	XW to HW	VN, 0°, CA FILLED, PR, RF, 10 mm VN, 20°, CA FILLED, PR, RF, 7 mm VN, 0°, CA FILLED, PR, RF, 10 mm VN, 0°, CA FILLED, PR, RF, 10 mm JT, 0°, CN, PR, RF VN, 0°, CA FILLED, PR, RF VN, 10°, CA FILLED, PR, RF, 10 mm VNx2, 0°, CA FILLED, PR, RF JT, 70°, Fe CT, PR, RF
	25.80 0% LOSS	26.0	- becoming black, very fine grained below 26m		
	26.50 20% LOSS			MW	JT, 50°, CN, PR, RF JT, 50°, CN, PR, RF JT, 0°, CN, PR, RF JT, 20°, CN, PR, RF
		27.0		HW	JT, 20°, CN, PR, RF JT, 10°, Clay FILLED, PR, RF
			27.45m - band of stiff silty clay to 27.45m		
			CORE LOSS (0.3m) - Washed away by coring		
			27.75m MUDSTONE - black, very fine grained, horizontal bedding (WALLUMBILLA FORMATION)	MW	
	28.00 0% LOSS	28.0		SW	JT, 45°, Clay FILLED, PR, RF JT, 10 - 40°, CA FILLED, PR, S JT, 10°, Clay FILLED, PR, RF
		29.0	- highly fractured to 29.1m		JT, 10°, CN, UN, RF JT, 90°, CN, PR, S JT, 10°, CN, UN, RF JT, 40°, CN, PR, RF DB
	29.50		29.50m		
		30.0	Hole Terminated at 29.50 m Target depth		

See Explanatory Notes for details of abbreviations & basis of descriptions.

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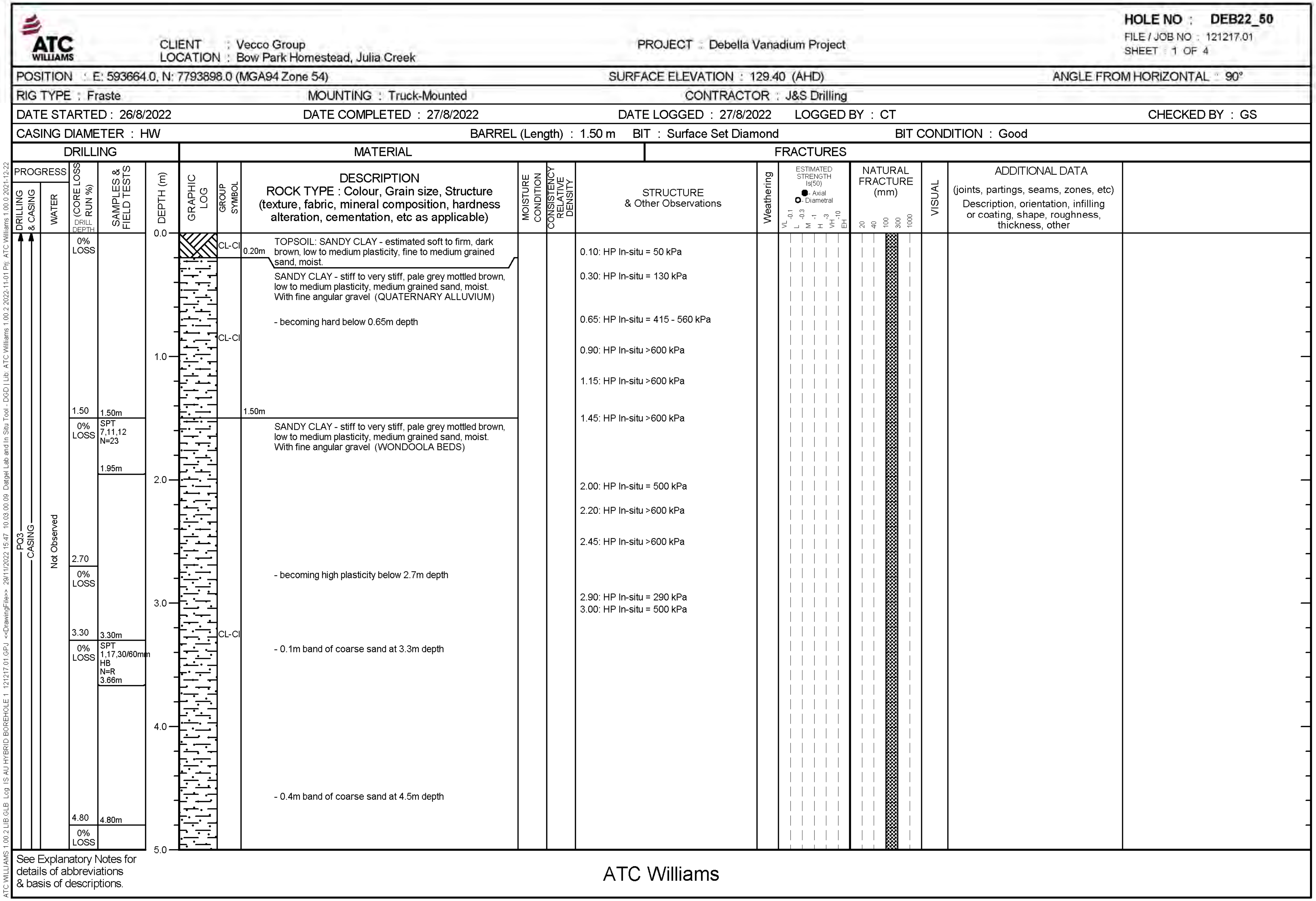
Figure 10-17: Borehole log – DEB21_18R (25 – 29.5 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek
PROJECT : Debella Vanadium Project
HOLE NO : DEB22_50
FILE / JOB NO : 121217.01
SHEET : 1 OF 4

POSITION : E: 593664.0, N: 7793898.0 (MGA94 Zone 54)
SURFACE ELEVATION : 129.40 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 26/8/2022
DATE COMPLETED : 27/8/2022
DATE LOGGED : 27/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Surface Set Diamond
BIT CONDITION : Good

DRILLING: PROGRESS — DRILLING & CASING: PQ3, CASING; WATER: Not Observed

(CORE LOSS RUN %) DRILL DEPTH	SAMPLES & FIELD TESTS	DEPTH (m)	GROUP SYMBOL	DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)	STRUCTURE & Other Observations
0% LOSS		0.0	CL-CI	0.20m TOPSOIL: SANDY CLAY - estimated soft to firm, dark brown, low to medium plasticity, fine to medium grained sand, moist.	0.10: HP In-situ = 50 kPa
			CL-CI	SANDY CLAY - stiff to very stiff, pale grey mottled brown, low to medium plasticity, medium grained sand, moist. With fine angular gravel (QUATERNARY ALLUVIUM)	0.30: HP In-situ = 130 kPa
				- becoming hard below 0.65m depth	0.65: HP In-situ = 415 - 560 kPa
		1.0			0.90: HP In-situ >600 kPa 1.15: HP In-situ >600 kPa
1.50	1.50m			1.50m	1.45: HP In-situ >600 kPa
0% LOSS	SPT 7,11,12 N=23 1.95m			SANDY CLAY - stiff to very stiff, pale grey mottled brown, low to medium plasticity, medium grained sand, moist. With fine angular gravel (WONDOOLA BEDS)	
		2.0			2.00: HP In-situ = 500 kPa 2.20: HP In-situ >600 kPa 2.45: HP In-situ >600 kPa
2.70				- becoming high plasticity below 2.7m depth	
0% LOSS		3.0			2.90: HP In-situ = 290 kPa 3.00: HP In-situ = 500 kPa
3.30	3.30m		CL-CI		
0% LOSS	SPT 1,17,30/60mm HB N=R 3.66m			- 0.1m band of coarse sand at 3.3m depth	
		4.0		- 0.4m band of coarse sand at 4.5m depth	
4.80	4.80m				
0% LOSS		5.0			

See Explanatory Notes for details of abbreviations & basis of descriptions.

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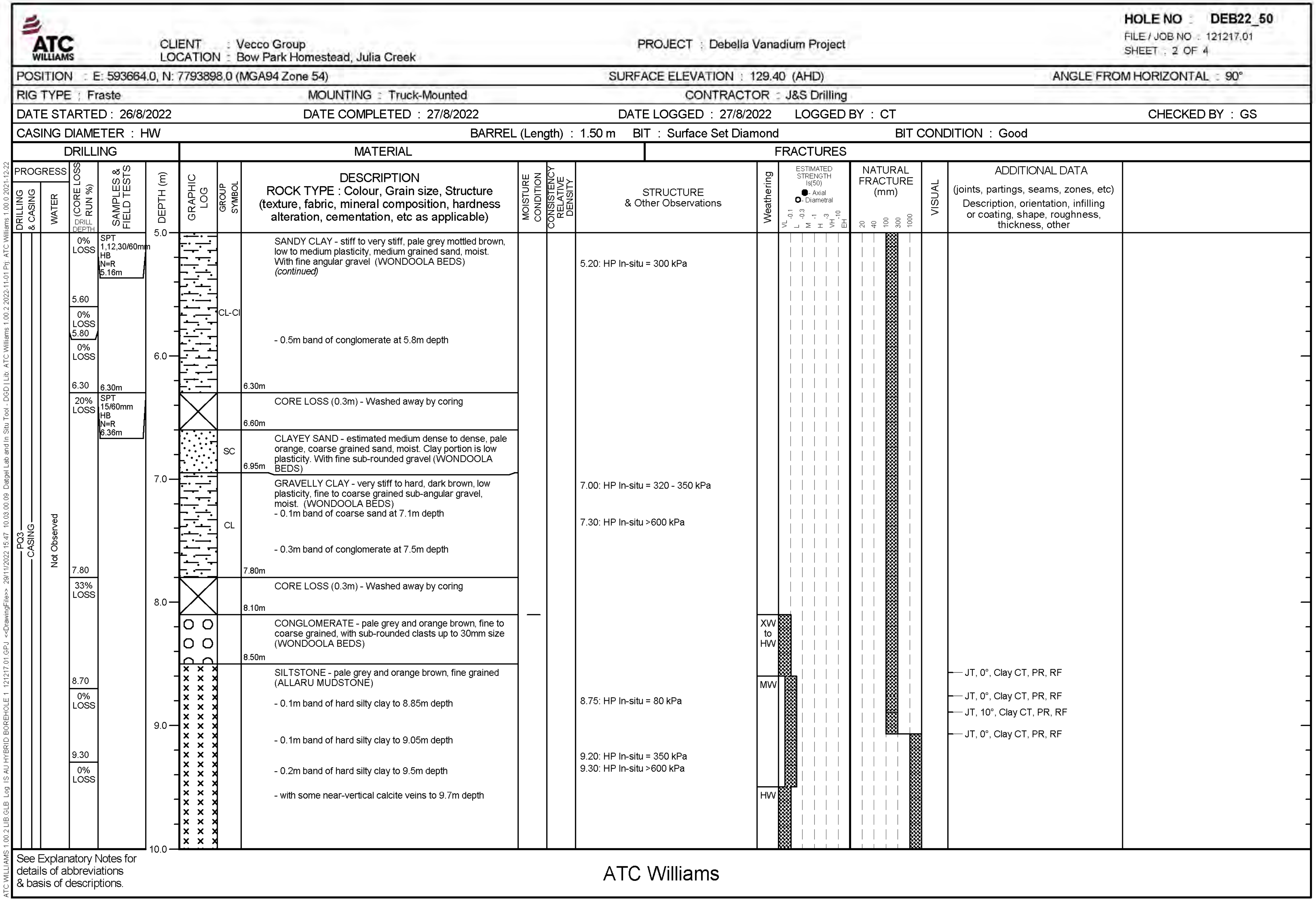
Figure 10-18: Borehole log – DEB22_50 (0 – 5 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek
PROJECT : Debella Vanadium Project
HOLE NO : DEB22_50
FILE / JOB NO : 121217.01
SHEET : 2 OF 4

POSITION : E: 593664.0, N: 7793898.0 (MGA94 Zone 54)
SURFACE ELEVATION : 129.40 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 26/8/2022
DATE COMPLETED : 27/8/2022
DATE LOGGED : 27/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Surface Set Diamond
BIT CONDITION : Good

DRILLING: PROGRESS – DRILLING & CASING: PQ3 CASING; WATER: Not Observed

DEPTH (m)	(CORE LOSS RUN %) DRILL DEPTH	SAMPLES & FIELD TESTS	GROUP SYMBOL	DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)	STRUCTURE & Other Observations	Weathering	ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other
5.0 – 6.30m	0% LOSS 5.60 0% LOSS 5.80 0% LOSS 6.30	SPT 1,12,30/60mm HB N=R 5.16m 6.30m	CL-CI	SANDY CLAY - stiff to very stiff, pale grey mottled brown, low to medium plasticity, medium grained sand, moist. With fine angular gravel (WONDOOLA BEDS) *(continued)* - 0.5m band of conglomerate at 5.8m depth	5.20: HP In-situ = 300 kPa		
6.30m – 6.60m	20% LOSS	SPT 15/60mm HB N=R 6.36m		CORE LOSS (0.3m) - Washed away by coring			
6.60m – 6.95m			SC	CLAYEY SAND - estimated medium dense to dense, pale orange, coarse grained sand, moist. Clay portion is low plasticity. With fine sub-rounded gravel (WONDOOLA BEDS)			
6.95m – 7.80m	7.80		CL	GRAVELLY CLAY - very stiff to hard, dark brown, low plasticity, fine to coarse grained sub-angular gravel, moist. (WONDOOLA BEDS) - 0.1m band of coarse sand at 7.1m depth - 0.3m band of conglomerate at 7.5m depth	7.00: HP In-situ = 320 - 350 kPa 7.30: HP In-situ >600 kPa		
7.80m – 8.10m	33% LOSS			CORE LOSS (0.3m) - Washed away by coring			
8.10m – 8.50m				CONGLOMERATE - pale grey and orange brown, fine to coarse grained, with sub-rounded clasts up to 30mm size (WONDOOLA BEDS)		XW to HW	
8.50m – 10.0	8.70 0% LOSS 9.30 0% LOSS			SILTSTONE - pale grey and orange brown, fine grained (ALLARU MUDSTONE) - 0.1m band of hard silty clay to 8.85m depth - 0.1m band of hard silty clay to 9.05m depth - 0.2m band of hard silty clay to 9.5m depth - with some near-vertical calcite veins to 9.7m depth	8.75: HP In-situ = 80 kPa 9.20: HP In-situ = 350 kPa 9.30: HP In-situ >600 kPa	MW HW	JT, 0°, Clay CT, PR, RF JT, 0°, Clay CT, PR, RF JT, 10°, Clay CT, PR, RF JT, 0°, Clay CT, PR, RF

See Explanatory Notes for
details of abbreviations
& basis of descriptions.

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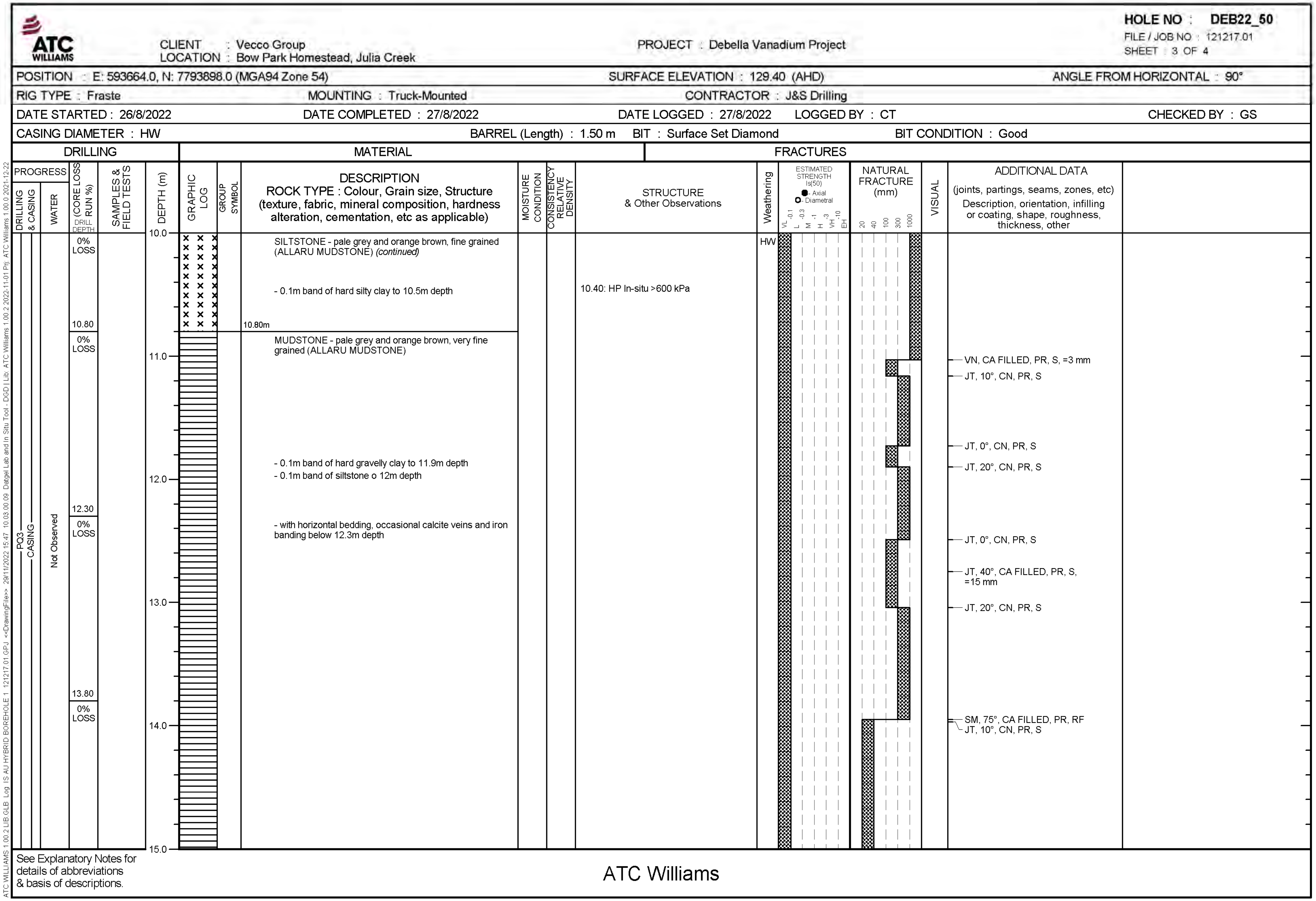
Figure 10-19: Borehole log – DEB22_50 (5 – 10 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek
PROJECT : Debella Vanadium Project
HOLE NO : DEB22_50
FILE / JOB NO : 121217.01
SHEET : 3 OF 4

POSITION : E: 593664.0, N: 7793898.0 (MGA94 Zone 54)
SURFACE ELEVATION : 129.40 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 26/8/2022
DATE COMPLETED : 27/8/2022
DATE LOGGED : 27/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Surface Set Diamond
BIT CONDITION : Good

DRILLING: PROGRESS (DRILLING & CASING, WATER); (CORE LOSS RUN %) DRILL DEPTH; SAMPLES & FIELD TESTS; DEPTH (m)
MATERIAL: GRAPHIC LOG; GROUP SYMBOL; DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable); MOISTURE CONDITION; CONSISTENCY RELATIVE DENSITY; STRUCTURE & Other Observations
FRACTURES: Weathering; ESTIMATED STRENGTH Is(50) ● - Axial ○ - Diametral (VL 0.1, L 0.3, M 1, H 3, VH 10, EH); NATURAL FRACTURE (mm) (20, 40, 100, 300, 1000); VISUAL; ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other

PQ3 — CASING — Not Observed

Core loss: 0% LOSS; 10.80 0% LOSS; 12.30 0% LOSS; 13.80 0% LOSS

Depth: 10.0, 11.0, 12.0, 13.0, 14.0, 15.0

SILTSTONE - pale grey and orange brown, fine grained (ALLARU MUDSTONE) *(continued)*

- 0.1m band of hard silty clay to 10.5m depth

10.80m

MUDSTONE - pale grey and orange brown, very fine grained (ALLARU MUDSTONE)

- 0.1m band of hard gravelly clay to 11.9m depth
- 0.1m band of siltstone o 12m depth
- with horizontal bedding, occasional calcite veins and iron banding below 12.3m depth

10.40: HP In-situ >600 kPa

HW

VN, CA FILLED, PR, S, =3 mm
JT, 10°, CN, PR, S
JT, 0°, CN, PR, S
JT, 20°, CN, PR, S
JT, 0°, CN, PR, S
JT, 40°, CA FILLED, PR, S, =15 mm
JT, 20°, CN, PR, S
SM, 75°, CA FILLED, PR, RF
JT, 10°, CN, PR, S

See Explanatory Notes for details of abbreviations & basis of descriptions.

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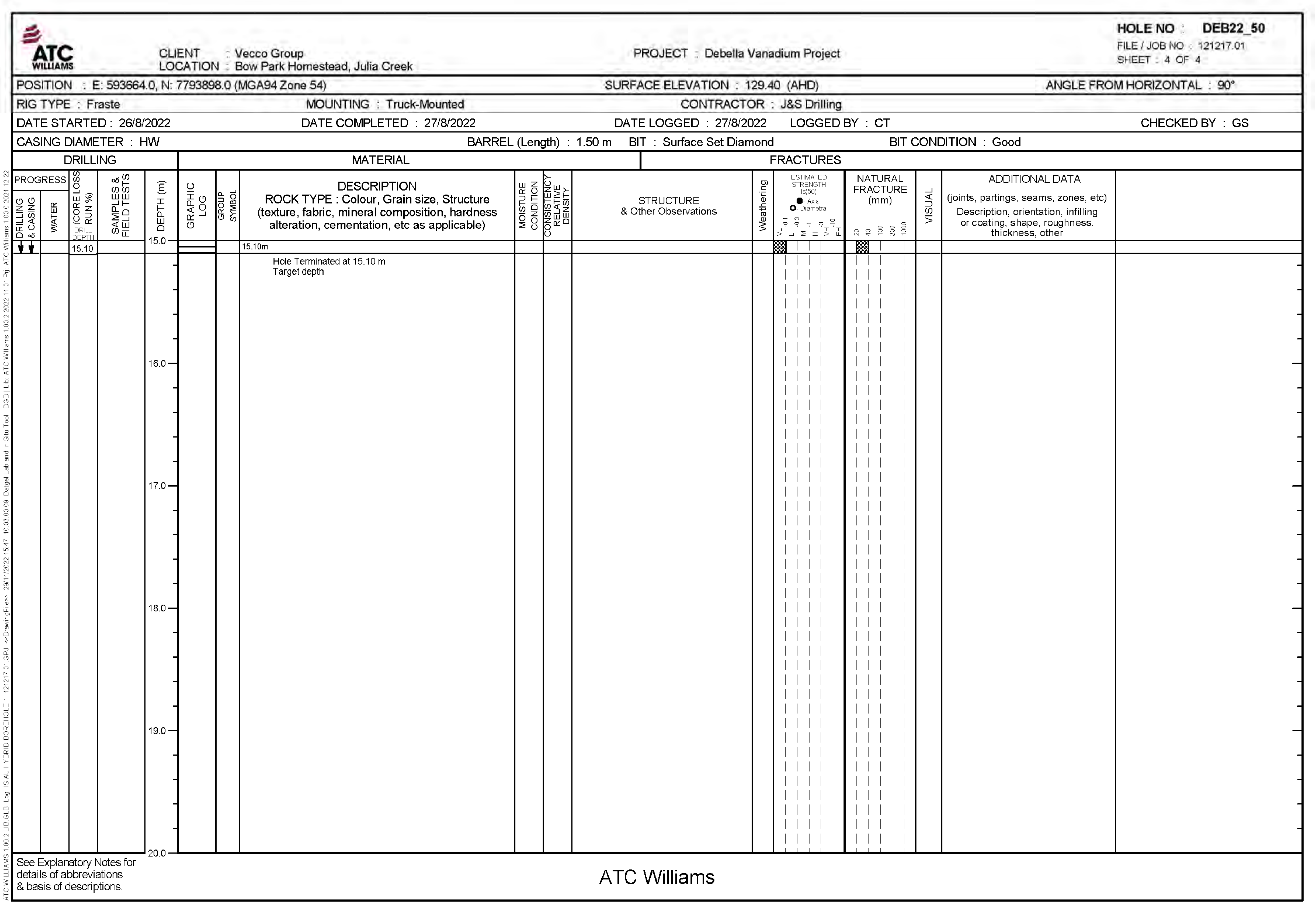
Figure 10-20: Borehole log – DEB22_50 (10 – 15 m)



ATC WILLIAMS

CLIENT : Vecco Group
LOCATION : Bow Park Homestead, Julia Creek

PROJECT : Debella Vanadium Project

HOLE NO : DEB22_50
FILE / JOB NO : 121217.01
SHEET : 4 OF 4

POSITION : E: 593664.0, N: 7793898.0 (MGA94 Zone 54)
SURFACE ELEVATION : 129.40 (AHD)
ANGLE FROM HORIZONTAL : 90°
RIG TYPE : Fraste
MOUNTING : Truck-Mounted
CONTRACTOR : J&S Drilling
DATE STARTED : 26/8/2022
DATE COMPLETED : 27/8/2022
DATE LOGGED : 27/8/2022
LOGGED BY : CT
CHECKED BY : GS
CASING DIAMETER : HW
BARREL (Length) : 1.50 m
BIT : Surface Set Diamond
BIT CONDITION : Good

DRILLING					MATERIAL						FRACTURES					
PROGRESS: DRILLING & CASING	PROGRESS: WATER	(CORE LOSS RUN %) DRILL DEPTH	SAMPLES & FIELD TESTS	DEPTH (m)	GRAPHIC LOG	GROUP SYMBOL	DESCRIPTION ROCK TYPE : Colour, Grain size, Structure (texture, fabric, mineral composition, hardness alteration, cementation, etc as applicable)	MOISTURE CONDITION	CONSISTENCY RELATIVE DENSITY	STRUCTURE & Other Observations	Weathering	ESTIMATED STRENGTH Is(50) ●- Axial ○- Diametral VL 0.1 L 0.3 M 1 H 3 VH 10 EH	NATURAL FRACTURE (mm) 20 40 100 300 1000	VISUAL	ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other	
▼ ▼		15.10		15.0			15.10m Hole Terminated at 15.10 m Target depth					▩	▩			
				16.0												
				17.0												
				18.0												
				19.0												
				20.0												

See Explanatory Notes for details of abbreviations & basis of descriptions.

ATC Williams

ATC WILLIAMS 1.00.2 LIB.GLB Log IS AU HYBRID BOREHOLE 1 121217.01.GPJ <<DrawingFile>> 29/11/2022 15:47 10.03.00.09 Datgel Lab and In Situ Tool - DGD | Lib: ATC Williams 1.00.2 2022-11-01 Prj: ATC Williams 1.00.0 2021-12-22

Figure 10-21: Borehole log – DEB22_50 (15 – 15.1 m)

10.3 Attachment C: Lithological logs

10.3.1 Attachment Ci: Lithological logs - Batch 1

	TEST PIT LOG	**TEST PIT:**	Hole ID: **DEB21_05** Top of Hole: **0.0 m** End of Hole: **35.0 m**
Client:	VECCO	Coordinates:	594591.3 East 7793968.28 North
Project:	2021080_Vecco Debella		
Site:		GCS:	
Method:		Logged by:	
Contractor:		Datum:	GDA94; Zone 54
Log Date:	12/2021	Page:	1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
0.5		🟫	Topsoil 0 - 0.5 m 21.3 kg / 30 kg Quaternary alluvium	D	VS	2		2021080_001
1.0		🟫	Subsoil 0.5 - 1. m 20.5 kg / 30 kg Quaternary alluvium	D	VS	2		2021080_002
2.0		▒	Sand 1 - 2 m 17.6 kg / 30 kg Quaternary Wondoola Beds	D	VS	2		2021080_003
7.0		▒	Sand 2 - 7 m 22.1 kg / 30 kg Quaternary Wondoola Beds	D	VS	2		2021080_004
10.0		▒	Sand-Mudstone Transition 7 - 10 m 22.5 kg / 20 kg Quaternary Wondoola Beds	D	VS	2		2021080_005
18-21		▤	Limestone Roof 19 (18?) - 21 m 8.7 kg / 23 kg Cretaceous Allaru Mudstone	D	VS	2.3		2021080_006
26-27		▥	Orebody 26 - 27 m 0.235 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9		2021080_007
28.0		▥	Orebody 27 - 28 m 0.66 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9		2021080_008

29.0			Orebody 28 - 29 m 0.565 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9	 	2021080_009
30.0			Orebody 29 - 30 m 0.31 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9		2021080_010
31.0			Orebody 30 - 31 m 0.58 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9		2021080_011
32.0			Mudstone Floor WLA 31 - 32 m 0.36 kg / 2.1 kg Cretaceous Wallumbilla Formation	W	VS	2.1		2021080_012
33.0			Mudstone Floor WLA 32 - 33 m 0.8 kg / 2.1 kg Cretaceous Wallumbilla Formation	W	VS	2.1		2021080_013
34.0			Mudstone Floor WLA 33 - 34 m 6.7 kg / 2.1 kg Cretaceous Wallumbilla Formation	M	VS	2.1		2021080_014
35.0			Mudstone Floor WLA 34 - 35 m 7 kg / 2.1 kg Cretaceous Wallumbilla Formation End of hole at 35.0 mbgl.	M	VS	2.1		2021080_015

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-22: Lithological log for DEB21_05 (0 to 35 m)

	TEST PIT LOG	TEST PIT:	Hole ID: **DEB21_12** Top of Hole: **0.0 m** End of Hole: **35.0 m**
Client: Project: Site: Method: Contractor: Log Date:	VECCO 2021080_Vecco Debella 12/2021	Coordinates: GCS: Logged by: Datum: Page:	593155.7 East 7794038.1 North GDA94; Zone 54 1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
0.5		🟫	Topsoil 0 - 0.5 m 22 kg / 30 kg Quaternary alluvium	D	VS	2		2021080_016
1.0		🟫	Subsoil 0.5 - 1 m 20.8 kg / 30 kg Quaternary alluvium	D	VS	2		2021080_017
2.0-8.0		▨	Sand 2 - 8 m 34 kg / 24 kg Quaternary Wondoola Beds	D	VS	2		2021080_018
11.0-12.0		▨	Mudstone ALM 11 - 12 m 3.3 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_019
13.0		▨	Mudstone ALM 12 - 13 m 2.6 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_020
14.0		▨	Mudstone ALM 13 - 14 m 3 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_021
15.0		▨	Mudstone ALM 14 - 15 m 4 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_022
16.0		▨	Mudstone ALM 15 - 16 m 3.1 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_023
17.0		▨	Mudstone ALM 16 - 17 m 2.6 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_024

18.0			Limestone Roof 17 - 18 m 2 kg / 4.6 kg Cretaceous Allaru Mudstone	D	VS	2.3		2021080_025
19.0			Limestone Roof 18 - 19 m 2.3 kg / 4.6 kg Cretaceous Allaru Mudstone	D	VS	2.3		2021080_026
20.0-21.0			Limestone Roof 20 - 21 m 2.2 kg / 4.6 kg Cretaceous Allaru Mudstone	D	VS	2.3		2021080_027
22.0			Limestone Roof 21 - 22 m 1.14 kg / 2.3 kg Cretaceous Allaru Mudstone	M	VS	2.3	 	2021080_028
23.0			Limestone Roof 22 - 23 m 2 kg / 2.3 kg Cretaceous Allaru Mudstone	W	VS	2.3	 	2021080_029
24.0			Orebody 23 - 24 m 1 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9	 	2021080_030
25.0			Orebody 24 - 25 m 0.5 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9	SAMPLE TOO STICKY TO PHOTOGRAPH	2021080_031
26.0			Orebody 25 - 26 m 1 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9	SAMPLE TOO STICKY TO PHOTOGRAPH	2021080_032
27.0			Orebody 26 - 27 m 1 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9	SAMPLE TOO STICKY TO PHOTOGRAPH	2021080_033
28.0			Orebody 27 - 28 m 1 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9	SAMPLE TOO STICKY TO PHOTOGRAPH	2021080_034

29.0		▥	Orebody 28 - 29 m 1 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9	SAMPLE TOO STICKY TO PHOTOGRAPH	2021080_035
30.0		▥	Orebody 29 - 30 m 1 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9	SAMPLE TOO STICKY TO PHOTOGRAPH	2021080_036
31.0		▥	Orebody 30 - 31 m 1 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9	SAMPLE TOO STICKY TO PHOTOGRAPH	2021080_037
32.0		▦	Mudstone Floor WLA 31 - 32 m 1 kg / 1.9 kg Cretaceous Wallumbilla Formation	W	VS	2.1	SAMPLE TOO STICKY TO PHOTOGRAPH	2021080_038
33.0		▦	Mudstone Floor WLA 32 - 33 m 1 kg / 2.1 kg Cretaceous Wallumbilla Formation	W	VS	2.1	SAMPLE TOO STICKY TO PHOTOGRAPH	2021080_039
34.0		▦	Mudstone Floor WLA 33 - 34 m 1 kg / 2.1 kg Cretaceous Wallumbilla Formation	W	VS	2.1	SAMPLE TOO STICKY TO PHOTOGRAPH	2021080_040
35.0		▦	Mudstone Floor WLA 34 - 35 m 1 kg / 2.1 kg Cretaceous Wallumbilla Formation End of hole at 35.0 mbgl.	W	VS	2.1	SAMPLE TOO STICKY TO PHOTOGRAPH	2021080_041

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-23: Lithological log for DEB21_12 (0 to 35 m)

	TEST PIT LOG	TEST PIT:	Hole ID: DEB21_17 Top of Hole: 0.0 m End of Hole: 44.0 m
Client: Project: Site: Method: Contractor: Log Date:	VECCO 2021080_Vecco Debella 12/2021	Coordinates: GCS: Logged by: Datum: Page:	UNKNOWN GDA94; Zone 54 1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
0.5			Topsoil 0 - 0.5 m 9.3 kg / 30 kg Quaternary alluvium	D	VS	2		2021080_042
1.0			Subsoil 0.5 - 1 m 10 kg / 30 kg Quaternary alluvium	D	VS	2		2021080_043
2.0			Subsoil 1 - 2 m 7.2 kg / 20 kg Quaternary alluvium	D	VS	2		2021080_044
3.0			Silt (Sand) 2 - 3 m 5.5 kg / 10 kg Quaternary Wondoola Beds	D	VS	2		2021080_045
4.0			Silt (Sand) 3 - 4 m 6.8 kg / 10 kg Quaternary Wondoola Beds	D	VS	2	 	2021080_046
5.0			Silt (Sand) 4 - 5 m 6.2 kg / 10 kg Quaternary Wondoola Beds	D	VS	2		2021080_047
6.0			Silt (Sand) 5 - 6 m 1.8 (18?) kg / 10 kg Quaternary Wondoola Beds	D	VS	2		2021080_048

7.0	Silt (Sand) 6 - 7 m 3 kg / 4 kg Quaternary Wondoola Beds	D	VS	2		2021080_ 049
8.0	Silt (Sand) 7 - 8 m 4 kg / 4 kg Quaternary Wondoola Beds	D	VS	2		2021080_ 050
9.0	Silt (Sand) - Mudstone Transition 8 - 9 m 2.4 kg / 4 kg Quaternary Wondoola Beds	D	VS	2		2021080_ 051
10.0	Mudstone ALM 9 - 10 m 2.2 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 052
11.0	Mudstone ALM 10 - 11 m 3.5 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 053
12.0	Mudstone ALM 11 - 12 m 7 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 054
13.0	Mudstone ALM 12 - 13 m 4.5 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 055
14.0	Mudstone ALM 13 - 14 m 2 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 056
15.0	Mudstone ALM 14 - 15 m 4.5 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 057

16.0			Mudstone ALM 15 - 16 m 2.5 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 058
17.0			Mudstone ALM 16 - 17 m 4 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 059
18.0			Mudstone ALM 17 - 18 m 4 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 060
19.0			Mudstone ALM 18 - 19 m 2 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 061
20.0			Mudstone ALM 19 - 20 m 3.2 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 062
21.0			Mudstone ALM 20 - 21 m 3.5 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 063
22.0			Mudstone ALM 21 - 22 m 3.5 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 064
23.0			Mudstone ALM 22 - 23 m 3 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 065
24.0			Mudstone ALM 23 - 24 m 2.5 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_ 066

25.0		▦	Mudstone ALM 24 - 25 m 2 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_067
26.0		▦	Mudstone ALM 25 - 26 m 3.5 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_068
27.0		▦	Mudstone ALM 26 - 27 m 4.5 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_069
28.0		▦	Mudstone ALM 27 - 28 m 3 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.1		2021080_070
29.0		▤	Limestone Roof 28 - 29 m 2.6 kg / 4.2 kg Cretaceous Allaru Mudstone	D	VS	2.3		2021080_071
30.0		▤	Limestone Roof 29 - 30 m 9 kg / 4.6 kg Cretaceous Allaru Mudstone	D	VS	2.3		2021080_072
31.0		▤	Limestone Roof 30 - 31 m 4.5 kg / 4.6 kg Cretaceous Allaru Mudstone	D	VS	2.3		2021080_073
32.0		▤	Limestone Roof 31 - 32 m 6.2 kg / 4.6 kg Cretaceous Allaru Mudstone	D	VS	2.3		2021080_074
33.0		▤	Limestone Roof 32 - 33 m 5.7 kg / 4.6 kg Cretaceous Allaru Mudstone	D	VS	2.3		2021080_075

34.0		▤	Limestone Roof 33 - 34 m 5.4 kg / 4.6 kg Cretaceous Allaru Mudstone	D	VS	2.3		2021080_ 076
35.0		▥	Orebody 34 - 35 m 6.7 kg / 3.8 kg Cretaceous Toolebuc Formation	D	VS	1.9		2021080_ 077
36.0		▥	Orebody 35 - 36 m 0.5 kg / 3.8 kg Cretaceous Toolebuc Formation	W	VS	1.9		2021080_ 078
37.0		▥	Orebody 36 - 37 m 0.5 kg / 1.9 kg Cretaceous Toolebuc Formation	W	VS	1.9		2021080_ 079
38.0		▥	Orebody 37 - 38 m 0.5 kg / 2.1 kg Cretaceous Toolebuc Formation	W	VS	1.9		2021080_ 080
39.0		▥	Orebody 38 - 39 m 2 kg / 2.1 kg Cretaceous Toolebuc Formation	W	VS	1.9		2021080_ 081
40.0		▥	Orebody 39 - 40 m 0.5 kg / 2.1 kg Cretaceous Toolebuc Formation	M	VS	1.9		2021080_ 082
41.0		▦	Mudstone Floor WLA 40 - 41 m 0.5 kg / 2.1 kg Cretaceous Wallumbilla Formation	M	VS	2.1		2021080_ 083
42.0		▦	Mudstone Floor WLA 41 - 42 m 0.7 kg / 2.1 kg Cretaceous Wallumbilla Formation	M	VS	2.1		2021080_ 084

43.0		▦	Mudstone Floor WLA 42 - 43 m 0.8 kg / 2.1 kg Cretaceous Wallumbilla Formation	M	VS	2.1		2021080_ 085
44.0		▦	Mudstone Floor WLA 43 - 44 m 0.5 kg / 2.1 kg Cretaceous Wallumbilla Formation End of hole at 44.0 mbgl.	M	VS	2.1		2021080_ 086
Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose								

Figure 10-24: Lithological log for DEB21_17 (0 to 44 m)

10.3.2 Attachment Cii: Lithological logs – Batch 2

	TEST PIT LOG	TEST PIT:	Hole ID: **DEB21_01** Top of Hole: **0.0 m** End of Hole: **11.0 m**

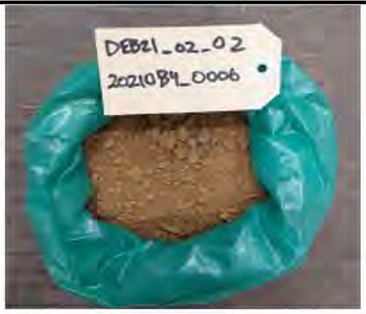
Client:	VECCO	Coordinates:	593254	East
Project:	2021084_Vecco Debella Physical		7795173	North
Site:		GCS:		
Method:		Logged by:		
Contractor:		Datum:	GDA94; Zone 54	
Log Date:	07/2022	Page:	1 of 1	

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
1.0		🟫	Topsoil 0.0 - 1.0 m 5.8 kg Quaternary alluvium	D	VS	VL		2021084_001
2.0		🟫	Subsoil 1.0 - 2.0 m 5.5 kg Quaternary alluvium	D	VS	L		2021084_002
10.0		░	Sand 2 - 10 m 6.0 kg Quaternary Wondoola Beds	D	VS	VL		2021084_003
11.0		░	Sand-Mudstone Transition 10 - 11 m 5.3 kg Quaternary Wondoola Beds	W	VS	VL		2021084_004
		▒	Mudstone ALM 11+ m Cretaceous Allaru Mudstone				Sample not received	N/A

Moisture: D - dry; M - moist; W - wet \| Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft \| Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-25: Lithological log for DEB21_01 (0 to 11 m)

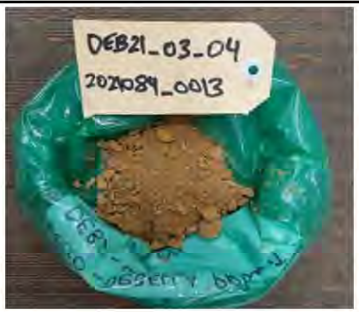
	TEST PIT LOG	**TEST PIT:**	Hole ID: **DEB21_02** Top of Hole: **0.0 m** End of Hole: **23.0 m**
Client:	VECCO	Coordinates:	593588 East 7794872 North
Project:	2021084_Vecco Debella Physical		
Site:		GCS:	
Method:		Logged by:	
Contractor:		Datum:	GDA94; Zone 54
Log Date:	07/2022	Page:	1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
1.0		🟫	Topsoil 0.0 - 1.0 m 5.7 kg Quaternary alluvium	D	VS	VL		2021084_005
2.0		🟫	Subsoil 1.0 - 2.0 m 5.5 kg Quaternary alluvium	D	VS	VL		2021084_006
6.0		▨	Sand 2 - 6 m 5.9 kg Quaternary Wondoola Beds	D	VS	VL		2021084_007
7.0		▨	Sand-Mudstone Transition 6 - 7 m 5.2 kg Quaternary Wondoola Beds	D	VS	VL		2021084_008
23.0		▨	Mudstone ALM 7 - 23 m 5.7 kg Cretaceous Allaru Mudstone	D	VS	VL		2021084_009

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-26: Lithological log for DEB21_02 (0 to 23 m)

	TEST PIT LOG	**TEST PIT:**	Hole ID: **DEB21_03** Top of Hole: **0.0 m** End of Hole: **18.0 m**
Client:	VECCO	Coordinates:	593922 East 7794571 North
Project:	2021084_Vecco Debella Physical		
Site:		GCS:	
Method:		Logged by:	
Contractor:		Datum:	GDA94; Zone 54
Log Date:	07/2022	Page:	1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
1.0			Topsoil 0.0 - 1.0 m 1.3 kg Quaternary alluvium	D	VS	VL		2021084_010
3.0			Subsoil 1.0 - 3.0 m 4.2 kg Quaternary alluvium	D	VS	VL		2021084_011
11.0			Sand 3 - 11 m 5.6 kg Quaternary Wondoola Beds	D	VS	VL		2021084_012
12.0			Sand-Mudstone Transition 11 - 12 m 1.5 kg Quaternary Wondoola Beds	D	VS	VL		2021084_013
18.0			Mudstone ALM 12 - 18 m 5.0 kg Cretaceous Allaru Mudstone	D	VS	L		2021084_014

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-27: Lithological log for DEB21_03 (0 to 18 m)

	TEST PIT LOG	**TEST PIT:**	Hole ID: **DEB21_04** Top of Hole: **0.0 m** End of Hole: **23.0 m**
Client:	VECCO	Coordinates:	594257 East 7794269 North
Project:	2021084_Vecco Debella Physical		
Site:		GCS:	
Method:		Logged by:	
Contractor:		Datum:	GDA94; Zone 54
Log Date:	07/2022	Page:	1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
1.0			Topsoil 0.0 - 1.0 m 1.5 kg Quaternary alluvium	D	VS	L		2021084_015
3.0			Subsoil 1.0 - 3.0 m 3.3 kg Quaternary alluvium	D	VS	VL		2021084_016
8.0			Sand 3 - 8 m 4.4 kg Quaternary Wondoola Beds	D	VS	VL		2021084_017
9.0			Sand-Mudstone Transition 8 - 9 m 0.9 kg Quaternary Wondoola Beds	D	VS	VL		2021084_018
23.0			Mudstone ALM 9 - 23 m 3.9 kg Cretaceous Allaru Mudstone	D	VS	L		2021084_019

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-28: Lithological log for DEB21_04 (0 to 24 m)

	TEST PIT LOG	**TEST PIT:**	Hole ID: **DEB21_06** Top of Hole: **0.0 m** End of Hole: **22.0 m**
Client:	VECCO	Coordinates:	594224 East 7794905 North
Project:	2021084_Vecco Debella Physical		
Site:		GCS:	
Method:		Logged by:	
Contractor:		Datum:	GDA94; Zone 54
Log Date:	07/2022	Page:	1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
1.0			Topsoil 0.0 - 1.0 m 6.6 kg Quaternary alluvium	D	VS	VL		2021084_020
2.0			Subsoil 1.0 - 2.0 m 6.3 kg Quaternary alluvium	D	VS	VL		2021084_021
7.0			Sand 2 - 7 m 4.3 kg Quaternary Wondoola Beds	D	VS	VL		2021084_022
8.0			Sand-Mudstone Transition 7 - 8 m 5.1 kg Quaternary Wondoola Beds	D	VS	VL		2021084_023
22.0			Mudstone ALM 8 - 22 m 5.2 kg Cretaceous Allaru Mudstone	D	VS	VL		2021084_024

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-29: Lithological log for DEB21_06 (0 to 22 m)

	TEST PIT LOG	**TEST PIT:**	Hole ID: **DEB21_07** Top of Hole: **0.0 m** End of Hole: **12.0 m**
Client:	VECCO	Coordinates:	594525 East 7795239 North
Project:	2021084_Vecco Debella Physical		
Site:		GCS:	
Method:		Logged by:	
Contractor:		Datum:	GDA94; Zone 54
Log Date:	07/2022	Page:	1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
0.5			Topsoil 0 - 0.5 m 9.9 kg Quaternary alluvium	D	VS	VL		2021084_025
3.0			Subsoil 0.5 - 3.0 m 15.0 kg Quaternary alluvium	D	VS	VL		2021084_026
8.0			Sand 3 - 8 m 5.3 kg Quaternary Wondoola Beds	D	VS	VL		2021084_027
9.0			Sand-Mudstone Transition 8 - 9 m 3.9 kg Quaternary Wondoola Beds	D	VS	L		2021084_028
12.0			Mudstone ALM 9 - 12 m 3.1 kg Cretaceous Allaru Mudstone	D	VS	L		2021084_029

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-30: Lithological log for DEB21_07 (0 to 12 m)

	TEST PIT LOG	**TEST PIT:**	Hole ID: **DEB21_14** Top of Hole: **0.0 m** End of Hole: **22.0 m**
Client:	VECCO	Coordinates:	592078 East 7793812 North
Project:	2021084_Vecco Debella Physical		
Site:		GCS:	
Method:		Logged by:	
Contractor:		Datum:	GDA94; Zone 54
Log Date:	07/2022	Page:	1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
1.0			Topsoil 0.0 - 1.0 m 2.2 kg Quaternary alluvium	D	VS	L		2021084_030
2.0			Subsoil 1.0 - 2.0 m 2.2 kg Quaternary alluvium	D	VS	L		2021084_031
12.0			Sand 2 - 12 m 5.2 kg Quaternary Wondoola Beds	D	VS	VL		2021084_032
13.0			Sand-Mudstone Transition 12 - 13 m 4.4 kg Quaternary Wondoola Beds	D	VS	VL		2021084_033
22.0			Mudstone ALM 13 - 22 m 4.4 kg Cretaceous Allaru Mudstone	D	VS	L		2021084_034

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-31: Lithological log for DEB21_14 (0 to 22 m)

	TEST PIT LOG	**TEST PIT:**	Hole ID: **DEB21_15** Top of Hole: **0.0 m** End of Hole: **30.0 m**

Client:	VECCO	Coordinates:	592350 East
Project:	2021084_Vecco Debella Physical		7792185 North
Site:		GCS:	
Method:		Logged by:	
Contractor:		Datum:	GDA94; Zone 54
Log Date:	07/2022	Page:	1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
1.0		🟫	Topsoil 0.0 - 1.0 m 0.7 kg Quaternary alluvium	D	VS	VL	No photo available	2021084_035
3.0		🟫	Subsoil 1.0 - 3.0 m 0.8 kg Quaternary alluvium	D	VS	VL	No photo available	2021084_036
9.0		▨	Sand 3 - 9 m 0.7 kg Quaternary Wondoola Beds	D	VS	VL	No photo available	2021084_037
10.0		▨	Sand-Mudstone Transition 9 - 10 m 0.8 kg Quaternary Wondoola Beds	D	VS	VL	No photo available	2021084_038
24.0		▦	Mudstone ALM 10 - 24 m 0.6 kg Cretaceous Allaru Mudstone	D	VS	VL	No photo available	2021084_039
29.0		▦	Mudstone ALM 28 - 29 m 0.2 kg Cretaceous Allaru Mudstone	D	VS	VL	No photo available	2021084_040
30.0		▦	Mudstone ALM 29 - 30 m 0.2 kg Cretaceous Toolebuc Formation	W	VS	VL	No photo available	2021084_041

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-32: Lithological log for DEB21_15 (0 to 30 m)

	TEST PIT LOG	**TEST PIT:**	Hole ID: **DEB22_12** Top of Hole: **0.0 m** End of Hole: **19.0 m**
Client:	VECCO	Coordinates:	592703 East 7792836 North
Project:	2021084_Vecco Debella Physical		
Site:		GCS:	
Method:		Logged by:	
Contractor:		Datum:	GDA94; Zone 54
Log Date:	07/2022	Page:	1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
1.0			Topsoil 0.0 - 1.0 m 4.3 kg Quaternary alluvium	D	VS	VL		2021084_042
2.0			Subsoil 1.0 - 2.0 m 5.4 kg Quaternary alluvium	D	VS	VL		2021084_043
8.0			Sand 2 - 8 m 7.6 kg Quaternary Wondoola Beds	M	VS	L		2021084_044
9.0			Sand-Mudstone Transition 8 - 9 m 4.8 kg Quaternary Wondoola Beds	W	VS	VL		2021084_045
19.0			Mudstone ALM 9 - 19 m 5.2 kg Cretaceous Allaru Mudstone	D	VS	L		2021084_046

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-33: Lithological log for DEB22_12 (0 to 19 m)

	TEST PIT LOG	**TEST PIT:**	Hole ID: **DEB22_15** Top of Hole: **0.0 m** End of Hole: **14.0 m**

Client:	VECCO	Coordinates:	592352	East
Project:	2021084_Vecco Debella Physical		7793164	North
Site:		GCS:		
Method:		Logged by:		
Contractor:		Datum:	GDA94; Zone 54	
Log Date:	07/2022	Page:	1 of 1	

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
2.0			Topsoil 0.0 - 2.0 m 4.0 kg Quaternary alluvium	D	VS	L		2021080_ 047
3.0			Subsoil 2.0 - 3.0 m 1.6 kg Quaternary alluvium	D	VS	L		2021084_ 048
7.0			Sand 3 - 7 m 4.5 kg Quaternary Wondoola Beds	D	VS	VL		2021084_ 049
8.0			Sand-Mudstone Transition 7 - 8 m 3.3 kg Quaternary Wondoola Beds	W	VS	VL		2021084_ 050
14.0			Mudstone ALM 8 - 14 m 4.9 kg Cretaceous Allaru Mudstone	W	VS	VL		2021084_ 051

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-34: Lithological log for DEB22_15 (0 to 14 m)

	TEST PIT LOG	TEST PIT:	Hole ID: **DEB22_17** Top of Hole: **0.0 m** End of Hole: **22.0 m**
Client: Project: Site: Method: Contractor: Log Date:	VECCO 2021084_Vecco Debella Physical 07/2022	Coordinates: GCS: Logged by: Datum: Page:	593357 East 7792522 North GDA94; Zone 54 1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
1.0			Topsoil 0.0 - 1.0 m 5.0 kg Quaternary alluvium	D	VS	L		2021084_052
2.0			Subsoil 1.0 - 2.0 m 5.2 kg Quaternary alluvium	D	VS	L		2021084_053
10.0			Sand 2 - 10 m 6.5 kg Quaternary Wondoola Beds	D	VS	VL		2021084_054
11.0			Sand-Mudstone Transition 10 - 11 m 5.9 kg Quaternary Wondoola Beds	W	VS	VL		2021084_055
22.0			Mudstone ALM 11 - 22 m 1.5 kg Cretaceous Allaru Mudstone	D	VS	VL		2021084_056

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-35: Lithological log for DEB22_17 (0 to 22 m)

	TEST PIT LOG	**TEST PIT:**	Hole ID: **DEB22_18** Top of Hole: **0.0 m** End of Hole: **15.0 m**
Client:	VECCO	Coordinates:	593542 East
Project:	2021084_Vecco Debella Physical		7795509 North
Site:		GCS:	
Method:		Logged by:	
Contractor:		Datum:	GDA94; Zone 54
Log Date:	07/2022	Page:	1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
1.0		🟫	Topsoil 0.0 - 1.0 m 5.4 kg Quaternary alluvium	D	VS	VL		2021084_057
2.0		🟫	Subsoil 1.0 - 2.0 m 6.5 kg Quaternary alluvium	D	VS	VL		2021084_058
6.0		▒	Sand 2 - 6 m 5.9 kg Quaternary Wondoola Beds	D	VS	VL		2021084_059
7.0		▒	Sand-Mudstone Transition 6 - 7 m 1.5 kg Quaternary Wondoola Beds	D	VS	VL		2021084_060
15.0		▦	Mudstone ALM 7 - 15 m 5.3 kg Cretaceous Allaru Mudstone	D	VS	L		2021084_061

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-36: Lithological log for DEB22_18 (0 to 15 m)

RGS MINE WASTE AND WATER MANAGEMENT	TEST PIT LOG	TEST PIT:	Hole ID: **DEB22_19** Top of Hole: **0.0 m** End of Hole: **18.0 m**

Client:	VECCO	Coordinates:	593887 East 7795205 North
Project:	2021084_Vecco Debella Physical		
Site:		GCS:	
Method:		Logged by:	
Contractor:		Datum:	GDA94; Zone 54
Log Date:	07/2022	Page:	1 of 1

Depth	Unit	Graphic	Material	Moisture	Strength	Density	Notes and photographs	Sample no
1.0			Topsoil 0.0 - 1.0 m 7.2 kg Quaternary alluvium	D	VS	L		2021084_062
3.0			Subsoil 1.0 - 3.0 m 7.5 kg Quaternary alluvium	D	VS	VL		2021084_063
6.0			Sand 3 - 6 m 0.5 kg Quaternary Wondoola Beds	D	VS	VL		2021084_064
7.0			Sand-Mudstone Transition 6 - 7 m 6.7 kg Quaternary Wondoola Beds	D	VS	VL		2021084_065
18.0			Mudstone ALM 7 - 18 m 6.6 kg Cretaceous Allaru Mudstone	D	VS	VL		2021084_066

Moisture: D - dry; M - moist; W - wet | Strength: H - hard; VSt - very stiff; St - stiff; F - firm; S - soft; VS - very soft | Density: VD - very dense; MD - medium dense; L - loose; VL - very loose

Figure 10-37: Lithological log for DEB22_19 (0 to 18 m)

10.4 Attachment D: Mo, Sr, V – literature review

10.4.1 Introduction

This section contains a literature review for the occurrence and solubility of molybdenum (Mo), strontium (Sr), and vanadium (V) which are naturally enriched in the samples collected for the Vecco vanadium mine materials assessment. These elements are common in the Earth's crust but are often excluded from water quality guidelines as they are not regarded of significant environmental concern. This study provides possible explanations regarding the enrichment of Mo, Sr, and V in these samples and their mobility, but does not attempt to quantify the maximum concentrations of these elements in mine impacted water that could be discharged to the environment.

Site specific results discussed in this study are presented in full in **Section 4**.

10.4.2 Molybdenum

10.4.2.1 Occurrence

Molybdenum (Mo) occurs in igneous and metamorphic rocks commonly as molybdenite (MoS_2) and less frequently as wulfenite ($PbMoO_4$), which appears to be the most stable form of Mo in soils (Vlek and Lindsay 1977). Mo is typically found in igneous rocks generated under high temperature conditions and is often associated with either greisen or low-grade porphyry Cu-Au deposits. Molybdenite is a silvery-blue mineral with a metallic lustre that occurs disseminated in granite or surrounding country rocks or crystallised in quartz-ore veins. The mineral is deposited when large, watch-rich plutons formed by crustal melting become oversaturated, causing the release of mineralised fluids which then precipitate. Mo is occasionally a targeted ore (e.g., Climax mine, Colorado, USA), but in recent times it is more common for Mo to be recovered as an economic by-product of copper refining (e.g., Cadia mine, NSW, Australia).

Molybdenum is present in trace quantities (1 – 10 mg/kg) in most rocks and soils (Smedley and Kinniburgh, 2017). Mo can have an exceptionally high occurrence in oxic, alkaline conditions within volcanogenic sediments containing felsic volcanic ash. Mo can also occur in anoxic conditions where Mo has been released into solution by reductive dissolution of Mn and Fe oxides. Alternatively, anoxic conditions can be present in sediments rich in organic matter, such as carbonaceous muds, black shales, and shales (Ardakani et.al., 2020, Smedley and Kinniburgh, 2017). The degradation of organic matter under anoxic conditions is the most likely geochemical pathway for the occurrence of Mo at the Vecco vanadium mine.

Figure 10-38 shows the total (solid) concentration of Mo in samples from a 2-acid digest, compared with soluble Mo (filtered to 0.45 mm) concentrations after a 16 hour, 1:3 w:v leach. The graph demonstrates that Mo concentrations at Vecco are related to geology and occur most commonly in Allaru Mudstone (ALM) and the Toolebuc Formation (limestone roof, TLBA) including the orebody itself Wilat's Crossing shale (TLBB), and Arrolla shale (TLBD to TLBE). Mo is minor or absent in topsoil, subsoil, overburden silt and sand, and basement Wallumbilla Formation (WLA).

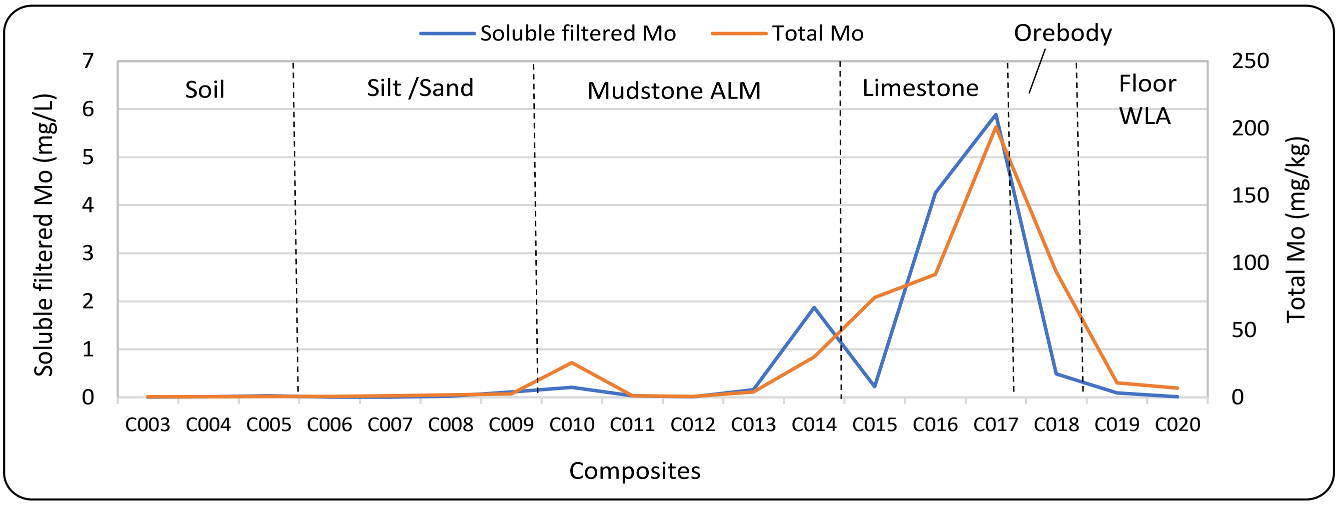


Figure 10-38: Relationship between water soluble (16 hr 1:3) 0.45 μm filtered Mo and total Mo

10.4.2.2 Solubility and reducing conditions

In the absence of solid phase Mo compounds, the solubility of Mo is controlled by specific adsorption to clay minerals (Vlek and Lindsay 1977). Mo has been utilised in recent years as a palaeoredox indicator for the reconstruction of depositional conditions of siltstone/shale strata that may contain hydrocarbons of economic interest (Ardakani et.al., 2020, Smedley and Kinniburgh, 2017). Despite this application, the mechanism of the highly efficient scavenging of Mo in euxinic (H_2S-rich) waters is not well understood.

Mo may form chemical compounds in a number of difference oxidation states, from -4 to +6 (-IV to +VI). The most common oxidation states for terrestrial occurrence are Mo(IV) in MoS_2 and Mo(VI) in $PbMoO_4$. Under oxide conditions, Mo(VI) is soluble in strong alkaline water, forming molybdates (MoO_4^{2-}). However, under anoxic, strongly reducing conditions such as those found in oceanic basins, molybdates are converted to thiomolybdates (MoO_nS_{4-n} where n is 0-3), which are less mobile. The following reactions are pH dependent (Mason, 1986):

$MoO_4^{2-} + H^+ + HS^- \rightleftharpoons H_2O + MoO_3S^{2-}$ Monothiomolybdate

$MoO_3S^{2-} + H^+ + HS^- \rightleftharpoons H_2O + MoO_2S_2^{2-}$ Dithiomolybdate

$MoO_2S_2^{2-} + H^+ + HS^- \rightleftharpoons H_2O + MoOS_3^{2-}$ Trithiomolybdate

$MoOS_3^{2-} + H^+ + HS^- \rightleftharpoons H_2O + MoS_4^{2-}$ Tetrathiomolybdate

As Mo(VI) is reduced to Mo(IV) and more sulfides (S^{2-}) are introduced into the coordination sphere, the Mo reaction site becomes crowded and substation becomes progressively more difficult. Consequently, monothiomolybdate is very transient, whereas tetrathiomolybdate requires several hours of gassing with H_2S to synthesize. Thiomolybdates are also pH sensitive to acid. For example, dithiomolybdate ($MoO_2S_2^{2-}$) can rapidly degrade to form molybdenum trisulfide (MoS_3) as a side reaction (Mason, 1986).

The concentration of Mo (VI) is well dispersed in oxygenated water. However, in anoxic water in the presence of sulfide (S^{2-}), O ions are replaced by S ions and the concentration of dissolved Mo(VI) in water gradually decreases and Mo(VI) sequestration in sediment occurs. Mo is used as a palaeoredox indicator by mapping the concentrations of Mo surrounded by oxygen (O) ions in an octahedral configuration (MoO_4^{2-}), compared to concentrations of Mo when surrounded by sulfur (S) ions in a tetrahedral configuration (MoS_4^{2-}). There is also a strong relationship between Mo and total organic carbon (TOC) in sediments deposited in euxinic waters (Ardakani et.al., 2020).

Figure 10-39 shows the relationship between pH and soluble Mo (filtered to 0.45 mm) concentrations after a 16 hour, 1:3 w:v leach. The samples are circumneutral to slightly alkaline (pH 7 to pH 8) with the exception of one limestone roof sample (C017) which is slightly more acidic (pH 6.3). This pH corresponds to a peak soluble Mo concentration of 5.89 mg/L, demonstrating that Mo has higher solubility at circumneutral pH than in alkaline conditions. Lehoux et. al., (2013) observed that adsorption of $MoO4_2^-$ is reduced at pH 5-7, especially if the sediments are low in clay.

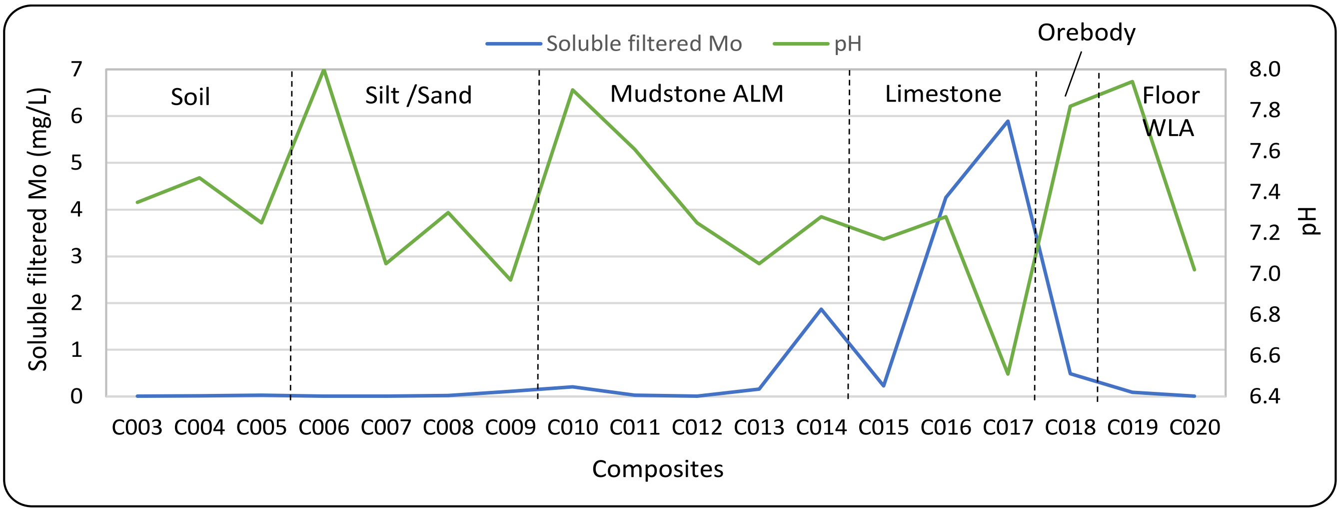


Figure 10-39: Relationship between water soluble (16 hr 1:3) 0.45 μm filtered Mo and pH

Figure 10-40 shows the relationship between total sulfur concentrations in samples from a 2-acid digest, compared with soluble Mo (filtered to 0.45 mm) concentrations after a 16 hour, 1:3 w:v leach. There appears to be a strong correlation, with the exception of the orebody (TLBB to TLBE) and the Wallumbilla Formation floor (WLA). There are two reasons why these samples may produce low concentrations of soluble Mo: (i) there is an unexplained increase in pH in C018 and C019 (**Figure 10-39**), which is likely to be inhibiting the pH sensitive thiomolybdate reactions; and (ii) there is a lower concentration of total Mo in the WLA unit (C019 and C020) (**Figure 10-38**), and therefore less Mo that could potentially become mobile.

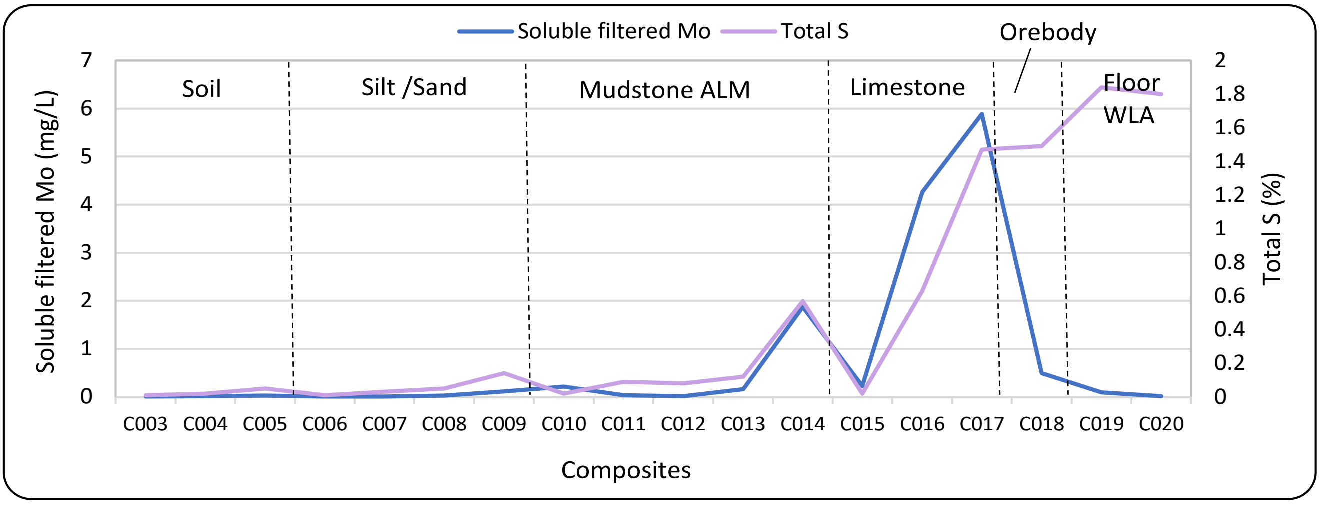


Figure 10-40: Relationship between water soluble (16 hr 1:3) 0.45 μm filtered Mo and total S

10.4.2.3 Oxidation and neutral metalliferous drainage

Molybdates (MoO_4^{2-}) are the most mobile forms of Mo and any residual MoS_2 or thiomolybdates present in mine waste are likely to be released into seepage and surface runoff in this form, after being oxidised through surface exposure. Fox and Doner (2003), for example, observed that Mo accumulated in sediments under reducing conditions became water-soluble when the samples were dried. In acidic conditions (> $pH_{1:5}$ 5), MoO_4^{2-} ions are adsorbed by clay minerals, particularly kaolinite and to a lesser extent, illite and smectite (Jones 1957). For this reason, Mo is rarely a problem where acidic metalliferous drainage occurs. However, under neutral metalliferous drainage conditions, MoO_4^{2-} is only weakly adsorbed to clay, and Mo can pose a more significant risk to the environment.

Wulfinite ($PbMoO_4$) and powellite ($CaMoO_4$) are secondary minerals that can act as effective sinks for Mo, removing it from mine impacted water by forming a solid precipitate. While $PbMoO_4$ is very stable and forms a solid quickly, other Pb precipitates such as angelsite ($PbSO_4$) and cerrusite ($PbCO_3$) will also be present at neutral pH conditions and may compete for Pb availability. As Pb is present only in low concentrations (below the limit of reporting) at the Vecco mine, this geochemical pathway is unlikely to occur.

Conlan et.al., (2012) found that $CaMoO_4$ formation is more effective at removing Mo than $PbMoO_4$, predominantly because Ca occurs at a higher concentration than Pb in mine waste. This reaction is more likely to occur at the mine as many of the rocks are rich in calcite ($CaCO_3$). However, the formation of $CaMoO_4$ is kinetically limited, as it requires that $CaCO_3$ is first dissolved into Ca^{2+} and CO_3^{2-} before MoO_4^{2-} can be removed from solution.

$CaCO_3 (s) + H^+ \rightarrow Ca^{2+} + HCO_3^-$

$Ca^{2+} + MoO_4^{2-} \rightarrow CaMoO_4 (s)$

These reactions were studied in a column experiment, whereby mine waste from the Antamine mine in Peru was investigated for Mo attenuation under active flow conditions. Results demonstrated that $PbMoO_4$ precipitated readily near the column inlet, removing all Pb readily from the feed solution. By contrast, $CaMoO_4$ precipitation occurred throughout the column, leading to more significant Mo removal overall, likely due to the development of stable nucleation sites within the bulk mine waste material.

$CaCO_3$ concentrations (measured by XRD) in the Vecco samples ranged from 9% to 84% and were highest in the limestone roof (TLBA) samples. It is expected that $CaMoO_4$ formation from the reaction of dissolved Ca^{2+} will remove MoO_4^{2-} ions from mine impacted water. Based on the findings of Conlan et.al., (2012), however, these reactions will not be rapid, and may occur over a period of months or years over which time water management will be required to avoid potential environmental impact.

10.4.2.4 Molybdenum uptake

Mo is an essential trace element for leguminous crops, due to its requirement in nitrogen fixation (Davies 1956). Grazing animals, however, can be affected by excess Mo, as they may suffer from molybdenosis, a secondary Cu deficiency which is more severe when sulfur is present (Conlan et. al., 2012).

10.4.3 Strontium

10.4.3.1 Occurrence

Strontium (Sr) is a chemical element of the second group (Group II: alkaline earth metals) of the periodic table. Other elements in the group include beryllium (Be), calcium (Ca), magnesium (Mg), barium (Ba) and radium (Ra). Sr has extreme reactivity with oxygen and water and occurs naturally only in compounds with other elements. Finely powdered strontium metal is pyrophoric, meaning that it will ignite spontaneously in air at room temperature. Volatile strontium salts impart a bright red colour to flames, and these salts are used in pyrotechnics and in the production of flares. Sr also has applications in ceramics, paint pigments, fluorescent lights, glassware, toothpastes, and in the treatment of calcified bone degenerative diseases.

In nature, Sr is found in non-radioactive minerals within igneous rocks associated with plagioclase feldspar ($NaAlSi_3O_8$ to $CaAl_2Si_2O_8$) (Davidson 1998) and in sedimentary rocks as celestite ($SrSO_4$) and strontianite ($SrCO_3$) (**Figure 10-41**). These sedimentary minerals are commonly associated with calcite and aragonite ($CaCO_3$ polymorphs) and/or dolomite $CaMg(CO_3)_2$ due to the tendency for Sr^{2+} to substitute for Ca^{2+} cations. This is because Sr^{2+} has an ionic radius of 1.12 Å, which is very close to that of Ca^{2+} (0.99 Å). $SrSO_4$ is a blue-grey mineral with tabular or fibrous crystals, whereas $SrCO_3$ is yellow brown and often columnar. Sr is abundant in the Earth's crust at 370 ppm by weight (Parthak et. al., 2020). $SrSO_4$ occurs more commonly as economic deposits, but $SrCO_3$ has better industrial use. $SrSO_4$ is converted to $SrCO_3$ via calcination with coal fines in a rotary kiln at a high temperature ~1100°C to expel out excess oxygen by forming CO_2 (Pathak et.al., 2020, Ober, 2010).

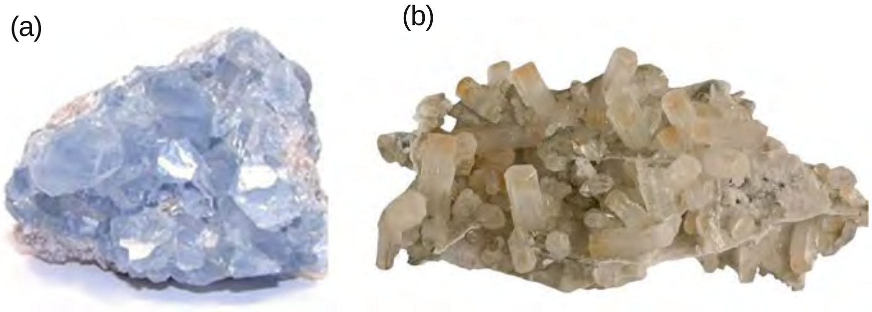


Figure 10-41: Minerall occurrence of (a) celesite ($SrSO_4$), and (b) strontianite ($SrCO_3$)

Natural strontium consists of four stable isotopes: ^{84}Sr (0.56%), ^{86}Sr (9.86%), ^{87}Sr (7.00%), and ^{88}Sr (82.58%). The percentage of isotopes in natural strontium varies because of the formation of ^{87}Sr after β-decay of a natural long- lived isotope, ^{87}Rb ($T_{1/2}$ ¼ 4.75 x 10^{10} years). $^{87}Sr/^{86}Sr$ ratios are commonly used to determine the likely provenance areas of sediment in natural systems, especially in marine and fluvial environments.

The other 34 isotopes of Sr are radioactive and have half-lives ranging from 230 ns to 28.9 years. ^{90}Sr has the longest half-life and is used in radioisotope thermoelectric generators (RTIGs) as it can be produced from spent nuclear fuel and radioactive waste. However, ^{90}Sr is also an environmental contaminant due to anthropogenic activities, such as nuclear weapons explosions, nuclear reactor releases and accidental fallout from nuclear power plants e.g., Chernobyl (1986) (10 PBq) and Fukushima (2011) (0.14 PBq). It is estimated that 622 PBq global fallout of ^{90}Sr has occurred to date, with considerable research dedicated to phytoremediation efforts (Pathak et.al., 2020) in nuclear powered countries.

10.4.3.2 Solubility

Strontium occurs in only one valence state, (II). It does not form strong organic or inorganic complexes and is commonly present in solution as $Sr^{2+.}$ The chemical properties of Sr are similar to Ca and Ba and it is often analysed in comparison with other group II elements. These properties, however, make the determination of Sr by chemical methods difficult, especially in environmental samples. For example, in groundwater, Sr^{2+} behaves chemically much like Ca^{2+}. However, the concentration is rarely solubility-limited in soil or groundwater systems because the solubility of common Sr phases is relatively high (Pathak et. al., 2020) (**Table 10-9**). Conversely, lower Ksp values for compounds indicates the water is likely to become supersaturated and to form a precipitate.

Table 10-9: Solubility products for alkaline earth elements

Compound	Solubility product (Ksp)			
	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}
MCO_3	2.1×10^{-5}	3.8×10^{-9}	1.1×10^{-10}	4.0×10^{-10}
MF_2	6.5×10^{-9}	4×10^{-11}	2.5×10^{-9}	1.1×10^{-6}
$M(OH)_2$	6.0×10^{-10} Freshly precipitated	5.5×10^{-6}	3.2×10^{-4}	5.0×10^{-3}
$M_3(PO_4)_2$	1×10^{-13}	2.0×10^{-29}	1×10^{-31}	6×10^{-39}
MSO_4	–	2.5×10^{-5}	3.2×10^{-7}	1.1×10^{-10}

M ¼ Mg^{2+}, Ca^{2+}, Sr^{2+}, or Ba^{2+}

At intermediate to acidic pH, dissolved Sr^{2+} is bound to soil particles by cation exchange which are controlled by sorption and ion exchange reactions with soil minerals. The parameters affecting strontium transport are cation exchange capacity (CEC), ionic strength, and pH (due to H+ competition for amphoteric sites). Clay minerals – illite, montmorillonite, kaolinite, and vermiculite – are responsible for most of the exchange capacity for Sr in soils (Pathak et. al., 2020). Oxides and organic matter may also be partially responsible, but mechanisms are not well understood. Organic compounds are thought to affect Sr mobility in soils and transfer to groundwaters. The average concentrations of Sr in seawater and surface freshwater are 8 and 0.08 mg/L, respectively (Pathak et. al., 2020, Springfield, 1966).

By comparison, at alkaline pH in the presence of Ca^{2+} ions, Sr^{2+} commonly forms coprecipitates with other Ca minerals such as calcite ($CaCO_3$), anhydrite ($CaSO_4$), and soil phosphates, which may contribute to Sr retardation and fixation in soils (Ober, 2010). Diagenetic and/or weathering processes may further distribute and re-distribute Sr among the major rock groups, particularly when Sr substitutes for Ca. Despite its ubiquitous nature in most rock types, Sr is predominantly found in carbonate sedimentary rocks. The Sr content of ancient marine limestones has averages between 400-700 ppm (Al-Hashimi, 1976). Age, salinity, clay mineral content, and depositional environment are factors considered to control the Sr content of limestones, as well as additional processes, for example, the mechanism of aragonite-calcite transformation, and diagenesis prevailing within buried sediments i.e., open or closed diagenesis (Al-Hashimi, 1976, Veizer, 1969).

In non-carbonate sedimentary rocks, the distribution of Sr is controlled by substitution with potassium (K), which is a component of feldspars. Evaporites can also contain both elemental Sr as well as isotopic Sr (Pathak et. al., 2020).

Figure 10-42 shows the total concentration of Sr (in mg/kg) and total Ca in solid samples after a 4-acid digest. Concentrations of total Ca are approximately ten times higher than total Sr, but there are some correlations. The highest total Sr concentrations are in the limestone roof and mudstone ALM samples, which are known to contain high proportions of $CaCO_3$. These results confirm the likely substitution of Ca^{2+} by Sr^{2+} into the $CaCO_3$ matrix.

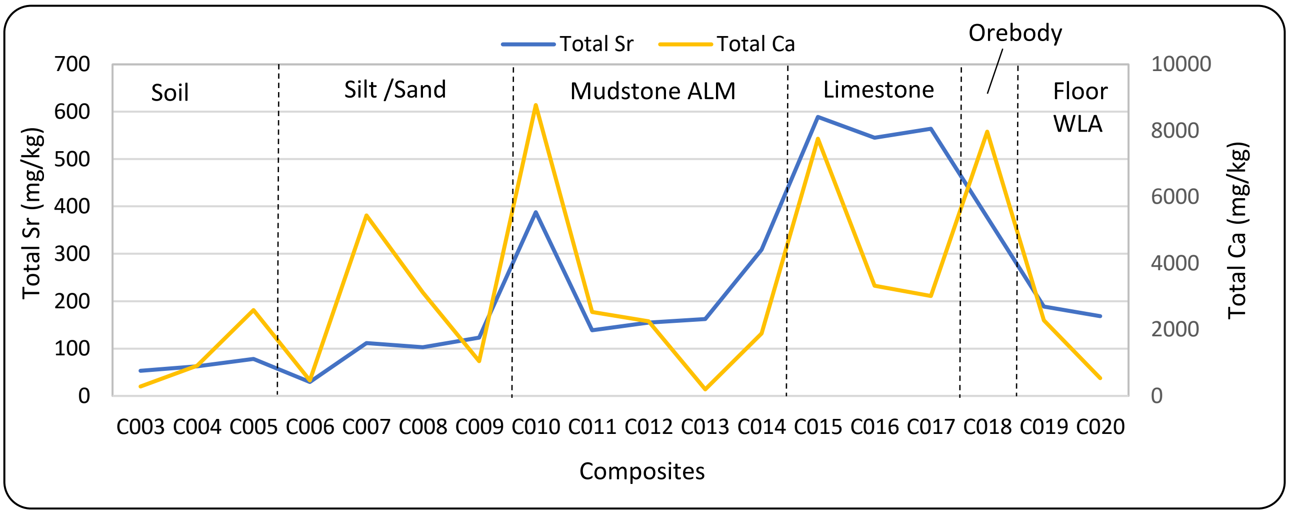


Figure 10-42: Results for total (2-acid digest) Sr and total Ca

Figure 10-43 shows the results for pH and soluble Sr (samples leached in de-ionised water for 16 hours at a 1:3 w:v ratio and then filtered to 0.45 μm). There is a poor correlation between these two parameters and therefore this has been interpreted that soluble Sr concentration is not controlled by pH.

There is also a weak correlation between cation exchange capacity (CEC) results for topsoil, subsoil, silt/sand, mudstone ALM and soluble Sr. However, topsoil has both the lowest CEC value (12.4 meq/100g) and soluble Sr (0.02 mg/L) compared to mudstone ALM (CEC 28.9 meq/100g and soluble Sr 0.66 mg/L).

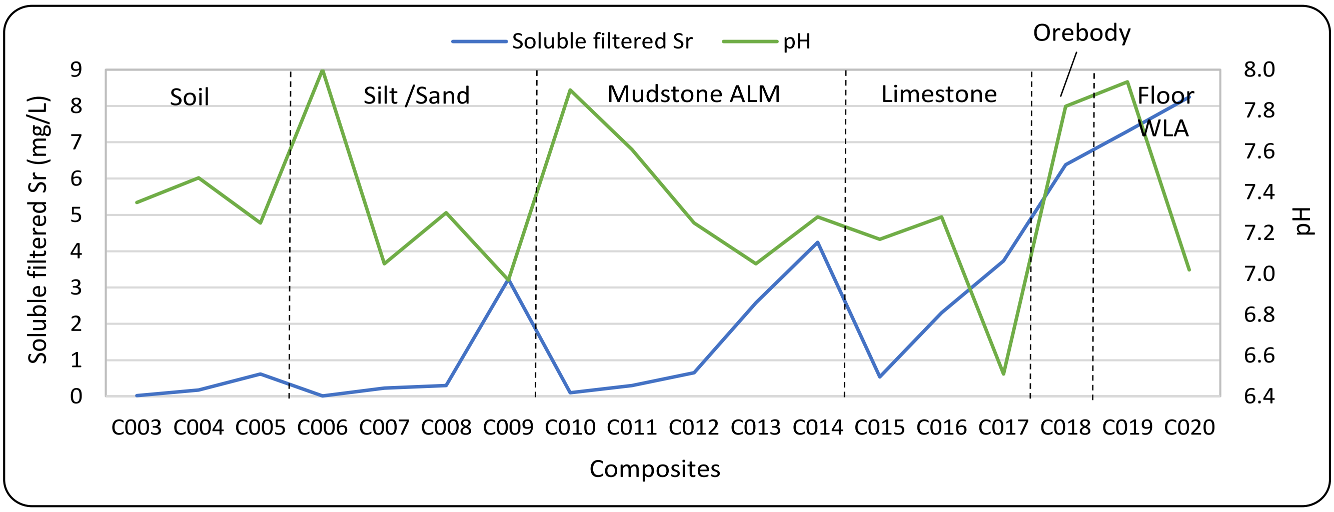


Figure 10-43: Results for pH and water soluble (16 hr 1:3) 0.45 μm filtered Sr

Figure 10-44 shows results for soluble Sr and soluble SO_4. These two parameters appear to have a strong correlation, even though the concentration of soluble SO_4 is several hundred times higher than soluble Sr. It is possible that the acid neutralising capacity of $CaCO_3$ is buffering the pH, which implies that pH may not directly control the mobility of Sr, but rather total actual acidity (TAA) as S^{2-} becomes oxidised. This relationship has not been extensively studied in the literature.

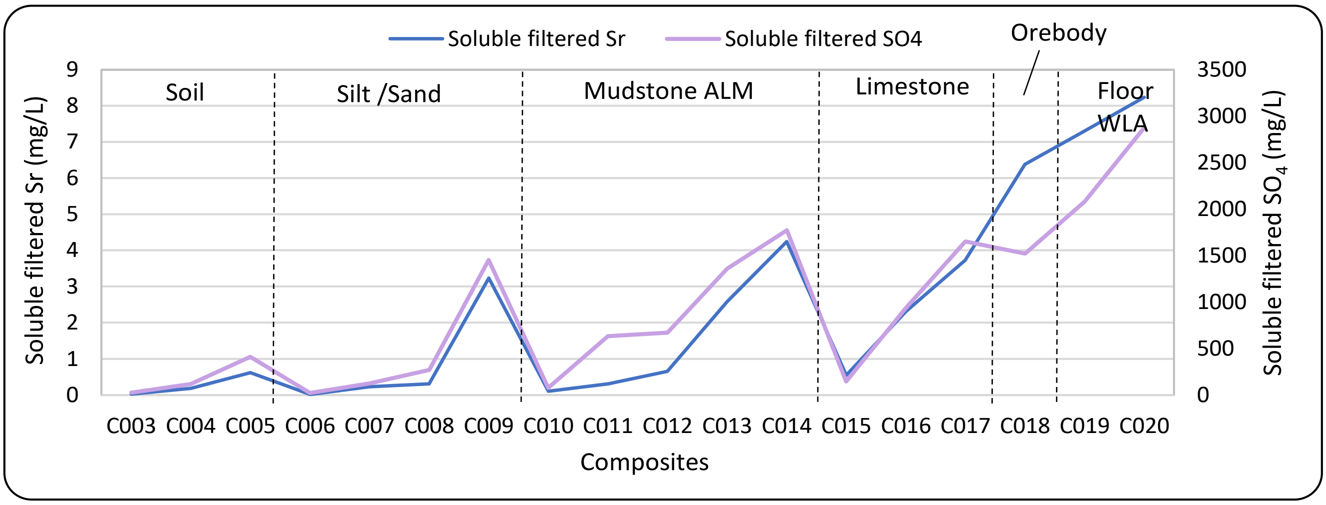


Figure 10-44: Results for water soluble (16 hr 1:3) 0.45 µm filtered Sr and soluble filtered SO_4

10.4.3.3 Strontium uptake

Sr^{2+} is not a biogenic cation, but it is easily consumed by plants due its similar chemistry to Ca^{2+}. Accumulation of Sr can occur in drinking water as well as in plants, such as crops and leafy vegetables. Concentrations up to total Sr up to 600 mg/kg of soil are assumed normal. Elevated uptake of Sr results in disorders of bone tissue, liver, and the brain in animals and humans. The redundant intake of Sr ions slowly results in calcification disorders, leading to deformation in bones and joints. This disorder is called strontium rachitis, or urov disease. (Pathak et al. 2020).

10.4.4 Vanadium

10.4.4.1 Occurrence

Vanadium (V) is a transition metal in the group 5 d-block of the periodic table and occurs in the same chemical group as niobium (Nb), protactinium (Pa) and tantalum (Ta). V is a steel-grey, corrosion-resistant metal, which exists in a wide range of oxidation states from -1 to +5. The most common oxidation states are V(III) +3, V(IV) +4, and V(V) +5 (Barceloux, 1999). Vanadium is not found in its metallic form in nature but occurs in over 60 minerals (such as mica, apatite, pyroxene, and amphibole) as a trace element in a range of different rock types, e.g., titaniferous magnetite, uraniferous sandstone and siltstone, black shales, bauxite, and phosphorites (FOREGS, 2005; Summerfield, 2017).

Ultramafic and mafic igneous rocks are parent rocks typically enriched in V compared to intermediate and felsic rocks. V also occurs in fossil fuels such as crude oil, coal and tar sands and can be used as a petroleum tracer. Anthropogenic sources of V in the atmosphere can be sourced from oil and gas fired burners. V can also be recovered from wastes such as fly ash from coal combustion and waste solutions from the processing of uranium ores. V is sold as vanadium pentoxide (V_2O_5) and, less commonly, as vanadium trioxide (V_2O_3) for non-steel applications and as the alloy ferrovanadium (FeV) as a component of hard steel alloys used in machines and tools. **Table 10-10** lists common V minerals, compounds, as well as cations and anions referred to in this review.

Table 10-10: Vanadium compounds, cations, and anions

Compound or ion	Oxidation state	Name	Notes
V	0	Metallic vanadium	Purified from metal iodide, VI_3
$(Fe,V)_3O_4$	+3	Magnetite	V substitutes for Fe in some Fe oxides
VS_4	+4	Patronite	Large deposit of V ore in Peru mined in the 1920s
$K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$	+5 or +4	Carnotite	Uranium ore which produces V ore as a side product
$Pb_5(VO_4)_3Cl$	+5 or +4	Vanadinite	Rare V-bearing mineral, occasionally mined
V_2O_5	+5	Vanadium pentoxide	Used as a catalyst to produce sulfuric acid from S, O_2, and H_2O
V_2O_3	+3	Vanadium trioxide	Gradually oxidises when exposed to air
FeV	+3	Ferrovanadium	Additive in steel and titanium alloys, used in jet engines and high-speed surgical tools
NH_4VO_3	+5	Ammonium metavanadate	Precipitate commonly used to extract V which is then reduced with Zn
$NaVO_3$	+5	Sodium metavanadate	Precipitate that can be mixed with sulfuric acid to produce V_2O_5
VO_2^+	+4	Vanadyl oxocation	Dominates at pH < 4. Forms under moderately reducing conditions
$VO(OH)^+$	+4	Vanadyl hydroxy cation	Forms at neutral to alkaline pH under moderately reducing conditions
$V(OH)_3^+$.	+3	Vanadium (III) cation	Forms at neutral to alkaline pH only under strongly reducing conditions
$H_2VO_4^-$	+5	Vanadate oxyanion	Dominant anion at pH 4-7. Forms under oxidising conditions
HVO_4^{2-}	+5	Vanadate oxyanion	Dominant anion at pH 8-11. Forms under oxidising conditions
VO_4^{3-}	+5	Vanadate oxyanion	Dominant anion at pH 12-14. Forms under oxidising conditions
$VO(OH)_2$	+4	Vanadyl (IV) hydroxide	Precipitate that can be roasted at 700°C to produce $VO_2 + H_2O$
$V(OH)_3$	+3	Vanadium (III) hydroxide	Precipitate used to separate V from seawater

10.4.4.2 Vanadium oxidation states, reduction, and deposition

The chemistry of V is complex and is not well understood in the literature because V has three possible oxidation states: V(III), V(IV), and V(V), which are both redox and pH sensitive, and in each oxidation state, many complexes, ion pairs, polymers, and solids exist (Shaheen et al, 2019, Wanty and Goldhaber, 1992). V(V) and V(IV) are dominant under oxidising and moderately reducing conditions. V(IV) is stable in acidic medium but will gradually convert to V(V) above pH 5. V(III) exists only in strongly reducing conditions in environments such as saturated soils or peat, is relatively immobile and insoluble, and is easily oxidised to V(IV) or V(V) in the presence of low levels of oxygen (Shaheen et al, 2019)..

V(IV) is referred to as 'vanadyl' and is an oxocation (VO^{2+}) that occurs in moderately reducing environments and prevails at solution pH below 4, whereas V(V) is referred to as 'vanadate' and occurs in oxidising conditions as the oxyanion vanadate ($H_2VO_4^-$), which dominates above pH 4 (Larrson et.al., 2013). **Table 10-10** shows some of the variations of V(IV) vanadyl and V(V) vanadate and the redox and pH conditions that produce these cations and anions. As mentioned previously, under strongly reducing conditions the reduced form V(III) tends to form insoluble precipitates, so whenever V is mobile and transported it is likely to be in an oxidised form, either as V(IV) or V(V) (Breit and Wanty, 1991).

Figure 10-45 is a model that attempts to explain the chemical processes and oxidation states of V as it is converted from V(V) to V(III) when accumulating in sediments in a marine environment. The redox conditions change from oxic (near the water's surface) to anoxic (at depth), and finally to euxinic (at base). Vanadate oxyanions ($H_2VO_4^-$) transported in seawater can be adsorbed by particles or dissolved organic compounds (such as carboxylic acids) to form strong organic complexes that gradually settle through the water column.

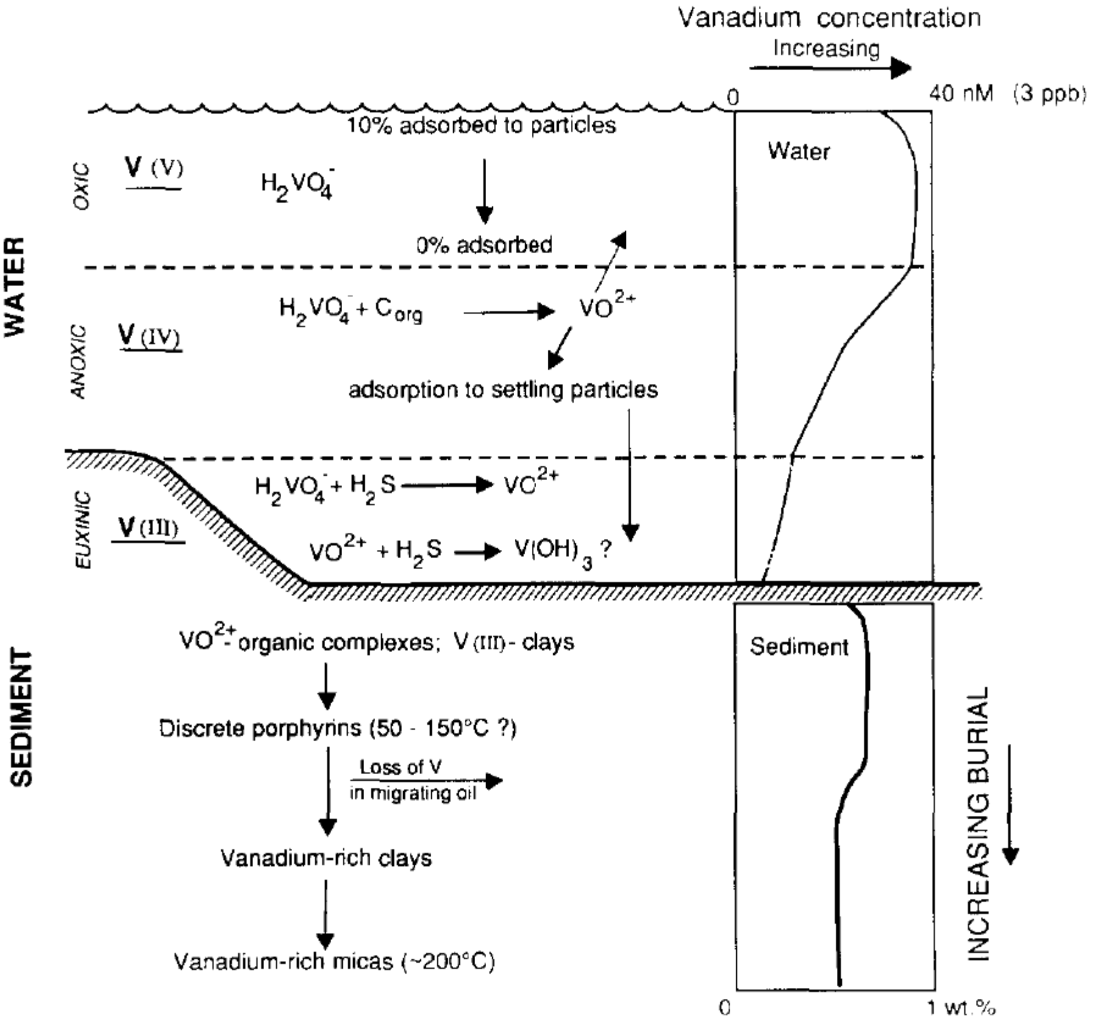


Figure 10-45: Model of vanadium accumulation

The sedimentation rate and the extent of the anoxic water control the reduction of vanadate V(V) to vanadyl V(IV) as the redox conditions gradually change with depth. Under moderately reducing, anoxic conditions, VO^{2+} or $VO(OH)^-$ predominate depending on pH, and any H_2S in the pore waters may reduce some of the V(IV) to V(III), consequently favouring partition of some of the V into clay minerals. Maturation during early diagenesis destroys the organic acid ligands that complex V and it is released to enter unmetallated porphyrins and other poorly understood refractory complexes ((Wisawapipat and Kretzschmar, 2017, Breit and Wanty, 1991).

Breit and Wanty (1991) studied sandstone-hosted V deposits and the thermodynamic data of V and predicted that H_2S was capable of reducing V(IV) to V(III). This was evidenced by the fact that pyrite (FeS_2) formed cogenetic with the V minerals, which verified the presence of H_2S during mineralisation. Complexes between V(IV) and short-chain organic acids are likely to play an important role in transporting the vanadyl (VO_2^+ or $VO(OH)^+$) ion, and metabolism of the organic acids by sulfate-reducing bacteria was suggested as the most likely source of H_2S. Corroborating previous work by Premovic and Pavlov (1986), organic matter was concluded to enhance the solubility of V. In addition, organic matter was observed to play a direct role in transporting V(V) and V(IV) in their suspended state as well as an indirect role in producing V(III).

Possible reactions for the reduction of V(IV) to V(III) include:

$VO(OH)^+ + ½\ H_2S \leftrightarrow V(OH)_2^+ + ½\ S^0$ ($K = 10^{2.99}$)

$VO(OH)^+ + ½\ HS^- + ½\ H^+ \leftrightarrow V(OH)_2^+ + ½\ S^0$ ($K = 10^{6.09}$)

Values of equilibrium constant (K) greater than 10^3 indicate a strong tendency for reactants to form products. By contrast, K values less than 10^{-3} indicate that reactants do not form products readily. (It should be noted that equilibrium constants vary with temperature and are usually measured at 25°C unless stated otherwise.) These K values verify that at least some of the V(IV) is reduced to V(III), although experimentally it was found that this reaction is quite slow. In a heterogenous system with $pH > 5.6$, the reaction was significantly faster and increased with pH, from acidic to near-neutral conditions. Wanty and Goldhaber (1992) thought that the most likely reducing agent is HS^-, and that the sulfur product may end up as several metastable species (e.g., polymeric) depending on the solution pH. Fox and Doner (2003) suggested there are several competing reactions including both dissolution or desorption and precipitation or adsorption occurring simultaneously.

Breit and Wanty (1991) noted that V-rich carbonaceous rocks have high contents of organically bound sulfur and are commonly interbedded with phosphate-rich rocks. Rocks enriched in phosphate are typically stratigraphically above or below carbonaceous units rich in V content. The spatial association suggests that V and P accumulations are genetically related but result from slightly different depositional environments. Presumably both V and P are added to the sediment by the settling of mainly biogenic particles. Results by Breit and Wanty (1991) suggest that V is concentrated in strongly reducing sediments while P accumulations are the result of sediment reworking under less reducing conditions. Carbonaceous rocks are commonly enriched in Ag, Cr, Mo, Ni, U, V and Zn and it was noted that V accumulates relative to Ni (i.e., high V/Ni ratio) in strongly reducing, H_2S-rich environments as H_2S inhibits competing ions, such as Ni, from bonding with organic complexes.

Graphs in **Figure 10-46** and **Figure 10-47** illustrate the relationships between the total V concentration in solid sediments and the concentration of V in water after a 16 hour 1:3 (w:v) leach event.

Figure 10-46 shows the total unfiltered soluble V is typically proportional to total V, which verifies that these concentrations are directly limited by the solubility of V from the sediments. The unfiltered soluble V concentrations include small particles >0.45 μm such as colloids, suspended clays, and organic compounds which are likely transport mechanisms for V(IV) and V(V), based on literature findings described above.

Figure 10-47 confirms there is only partial correlation between soluble filtered (<0.45 μm) V and total V, verifying there are other competing reactions at work. The concentration of soluble filtered V in silt/sand and mudstone ALM is relatively high, suggesting that these units are low in compounds that complex V. This means that some of the soluble V from the silt/sand and mudstone ALM remains dissolved in solution and could potentially impact aquatic life if it were to be released into natural waterways.

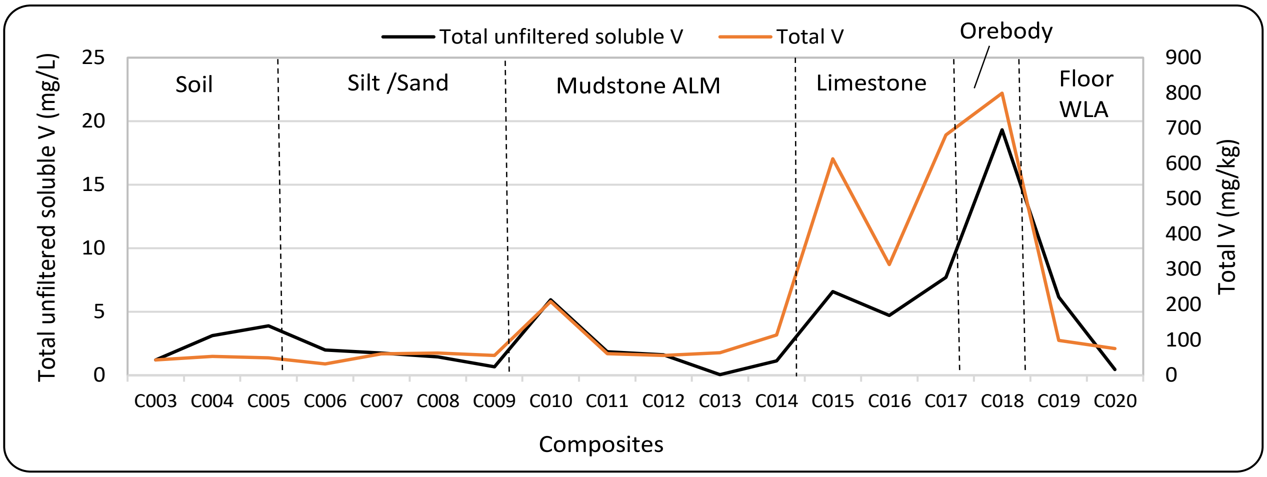


Figure 10-46: Results for total unfiltered water soluble (16 hr 1:3) V and total V

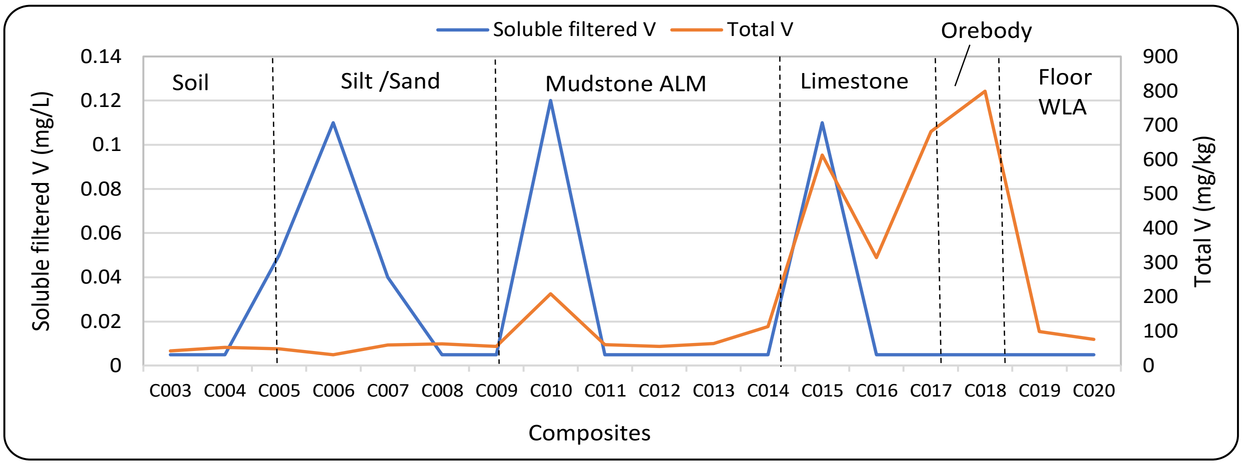


Figure 10-47: Results for water soluble (16 hr 1:3) 0.45 μm filtered V and total V

By comparison, the concentration of soluble filtered V in the orebody shale in relatively low, verifying that most V that becomes soluble is immediately complexed or adsorbed and does not contribute towards dissolved toxicity levels. As the orebody shale and floor are high in total sulfur and compared to the silt/sand and mudstone ALM (**Figure 10-40**), it is also possible that dissolved V is being reduced to V(III) by HS^- and becoming immobile.

10.4.4.3 Vanadium complexation, adsorption, and substitution

Typical concentration ranges of total V in soils worldwide vary widely from >1 mg/kg to >460 mg/kg with an average value of 108 mg/kg. High concentrations between 600 to 5000 mg/kg have been found in contaminated soils near vanadium mines. Limestone soils contain the highest concentrations of V, while peat soils have the least V. (Shaheen et al, 2019; Poledniok and Buhl, 2002).

In soils, V typically occurs in two redox forms, V(IV) and V(V), which have contrasting geochemical properties. Under oxic conditions, V(V) is the most stable redox form, but it may be reduced to V(IV) by humic substances. V (IV) mainly occurs as the vanadyl oxo-cation (VO^{2+}), which is strongly bound by different organic ligands and persists under extremely acidic conditions (pH <4.0). At neutral or alkaline pH, V (V) commonly occurs as vanadate anions (HVO_4^{2-} or $H_2VO_4^-$) but can exist in multiple oxidation states depending on redox conditions and pH. Vanadate anions are strongly bound by Fe, Al, and Mn oxides and hydroxides and can adsorb to goethite, ferrihydrite, gibbsite, and/or Fe(III)-natural organic matter complexes. The nearly identical ionic radii of V(III) (64.0 pm) and high-spin Fe (III) (64.5 pm) facilitate V substitution in the octahedral sites of these minerals, explaining the close association between V and Fe in soils and terrestrial environments (Shaheen et al, 2019; Wisawapipat and Kretzschmar, 2017; Baken, 2012; FOREGS, 2005; Premovic and Pavlov 1986).

(Baken, (2012) observed that the sorption of added V(V) in different soils increased with increasing clay, organic matter and poorly crystalline Fe and Al oxyhydroxide contents but appeared unrelated to soil pH in the range between 4 and 7. Since H+ is produced but consumed during redox reactions, pH is thought to affect the protonation state of functional groups on the soil particle surfaces thus influencing the adsorption-desorption behaviour of different V ion species. Shaheen et al, (2019) proposed that soil organic matter reduced V(V) to V(IV) and acted as a sorbent, which lowered its mobility and bioavailability. However, the formation of V complexes with fulvic acids and other soluble organics enhanced its solubility. While soil organic matter had a high affinity for V, there was a positive correlation between dissolved organic carbon (DOC) concentrations and increasing V(V) levels in soils rich in soil organic matter, which was regarded as being indicative of an oxidation-induced breakdown of solid phase organic matter.

Kaolinite clays constitute an important host phase for structural V(IV) and sorbent for V(V) in highly weathered tropical soils. V(IV) occupies mainly octahedral sites of kaolinite, whereas the binding of V(V) to poorly ordered kaolinite is the main binding mechanism to effectively immobilise V(V) in stable oxic environments where kaolinite is abundant. Lowering the pH below 8.5 is thought to inhibit V release, which undergoes enhanced adsorption to clays and Fe (hydr)oxides at circumneutral pH ((Wisawapipat and Kretzschmar, 2017; Lehoux et al, 2013). These findings verify that the highest mobilities of V(IV) and V(V) are at alkaline pH.

Sulfur (S) content appears to be less important for V cycling in soils but further research of the impact of SO_4 on V mobility is needed. Analysis of the speciation of V under euxinic conditions requires careful handling, as V(III) is easily oxidised to higher oxidation states, which is likely a reason why V chemistry in sulfidic soils has been largely unexplored (Shaheen et al, 2019).

Transport of dissolved V in modern surface waters is strongly dependent on oxidation state and water composition. Vanadate species (V(V)) are anions in the range of natural pH and the amount dissolved in oxic waters is rarely limited by the solubility of V(V) species. Vanadyl ion V(IV) adsorbs more strongly to suspended particles than vanadate V(V), but its stability as an adsorbed species is limited in oxic waters. Both V(IV) and V(III) are less soluble than V(V) because of their tendency to form insoluble oxyhydroxides in the pH range of natural waters. Dissolved V does not form strong complexes with common inorganic ligands but may be complexed by organic compounds. Therefore, dissolved V(V) in contact with natural organic compounds is likely to be reduced and complexed (Breit and Wanty, 1991).

The relationships between soluble filtered V concentrations and pH are in **Figure 10-48** and soluble filtered V concentrations with clay content are in **Figure 10-49**.

Figure 10-48 shows that in non-carbonaceous material types (i.e., silt/sand and mudstone ALM) concentrations of soluble filtered V increase with pH. However, in carbonaceous materials (i.e., limestone (TLBA), to mudstone floor WLA (TLBE)), there is a poor correlation between soluble filtered V and pH. This is likely because carbonaceous materials contain higher total S concentrations, and where H_2S is present, V(V) may undergo reduction to V(IV) before it becomes adsorbed.

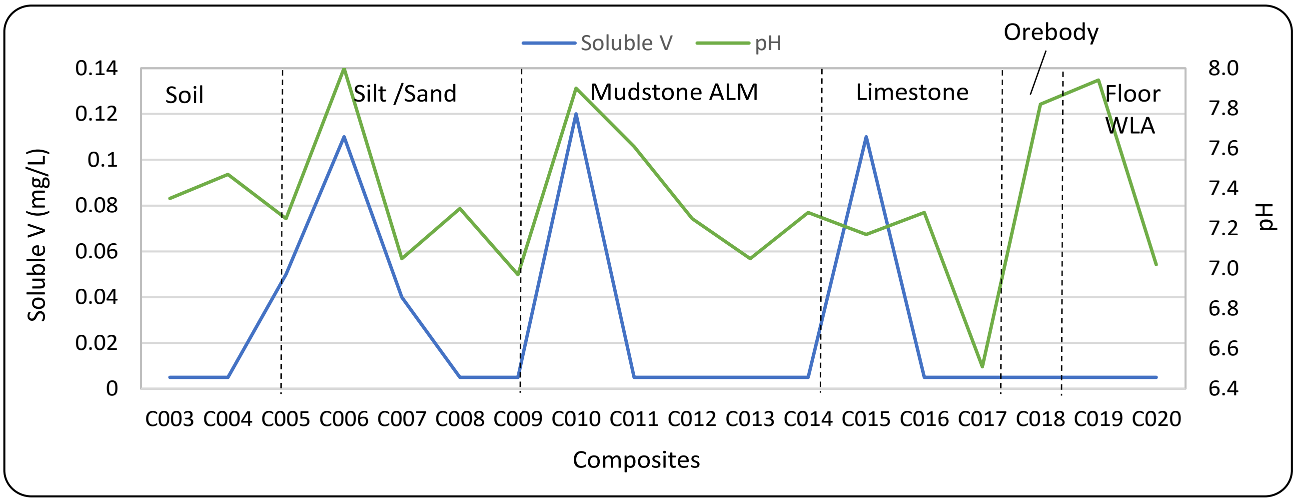


Figure 10-48: Results for water soluble (16 hr 1:3) 0.45 μm filtered V and pH

Figure 10-49 demonstrates that clay content has a strong influence on the mobility of soluble filtered V. Clay contents were not available for the orebody and mudstone floor WLA samples due to low sample mass. Nevertheless, the graph shows that clay contents above 30% adsorb nearly all of the soluble filtered V (e.g., C003, C008, C011-C014), whereas samples with low clay contents below 30% produce relatively high soluble filtered V concentrations (e.g., C006, C010, and C015).

These findings agree with the suggested mechanisms in the literature review, which conclude that V solubility is complex, and dependent on several different factors such as oxidation state, redox conditions, and the presence or absence of organic compounds, suspended particles, sediment clay content, Fe hydroxides, and sulfide anions.

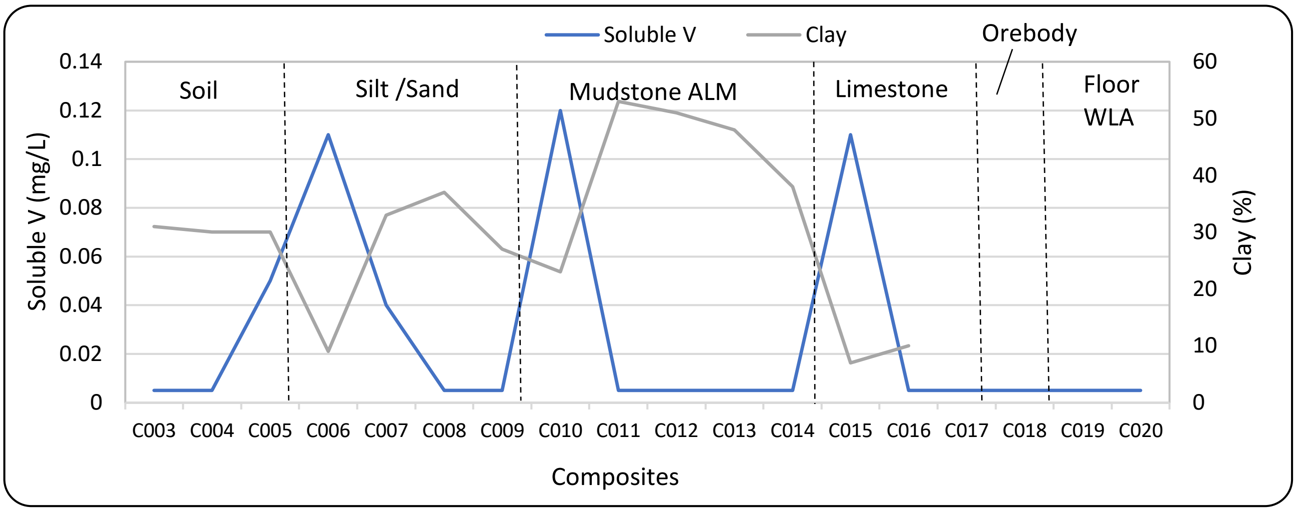


Figure 10-49: Results for water soluble (16 hr 1:3) 0.45 μm filtered V and clay content

10.4.4.4 Vanadium toxicity and deficiency

In plants at elevated concentrations, V causes reddening of the aerial parts, stunted growth and eventual death of plants. Pentavalent V(V) compounds are the most toxic. The phytotoxic effects of V(V) may in part be explained by its capacity to inhibit phosphate-metabolising systems. The reduction of V(V) to V(IV) in plant roots has been observed and interpreted as a detoxification mechanism because V(IV) is less toxic to plants than V(V). Gradual immobilisation reactions of phosphate, an anion structurally similar to vanadate, are well known and have been attributed to diffusion into soil particles. ((Larrson et.al., 2013; Baken, 2012)

In humans, the lungs absorb soluble V compounds well, and the effect of exposure to dust (V_2O_5) is upper respiratory tract irritation including the onset of asthma. Inhaling fumes can also cause a greenish-black discolouration of the tongue. However, the absorption of V salts from the gastrointestinal tract is poor and excess V is mainly excreted via the kidneys in urine. A V deficiency disease has not been identified in humans, but it is thought that V is probably an essential trace element for most forms of life ((Venkataraman and Sudha, 2005; Barceloux, 1999).

On October 4, 2010, a spill of up to 1 million m^3 of bauxite residue from the Ajka repository, western Hungary illustrated the effects of large-scale V contamination of downstream rivers and floodplains. The red mud residue was highly alkaline (pH 13) and contained potentially toxic levels of Al, As, Mo, and V. Gypsum ($CaSO_4$) was successfully used as an amendment on contaminated soils to lower the pH and displace NaOH to allow plant growth. Overall, the buffering capacity of the soils varied widely, although there were noted increases in salinity. The red mud also created dust issues when it dried, and irritation of the upper respiratory tract was observed, but the dust particles were too large to imbed deeply into the lungs. (Lehoux, et.al., 2013; Gelencsér et. al., 2011).

10.4.5 Conclusions

Water soluble (16 hr 1:3) 0.45 μm filtered molybdenum (Mo) concentrations are highest at circumneutral pH and are most likely to cause neutral metalliferous drainage issues from limestone units and also transitional material between mudstone ALM and limestone. Mo is mobile as molybdate (MoO_4^-) which is only weakly adsorbed by clay at neutral pH. Reactive sulfur (as sulfide S^{2-}) may be replacing O^{2-} and acting as a reducing agent to immobilise Mo as thiomolybdates (MoS_4^{2-}) in the deeper units (TLBB to TLBE).

Water soluble (16 hr 1:3) 0.45 μm filtered strontium (Sr) is probably controlled by soluble sulfate (SO_4) concentrations, which increase in the lower units (TLBB to TLBE) and therefore increase with depth. Higher concentrations of soluble Sr are likely in the orebody shale and mudstone floor WLA units and are low in the overburden units. Total (2-acid digest) Sr seems to have a positive correlation with total Ca and can be soluble in neutral or alkaline conditions but is not strongly influenced by pH.

Water soluble (16 hr 1:3) 0.45 μm filtered vanadium (V) concentrations are highest at alkaline pH and are strongly influenced by kaolinite clay content. Overburden units that are low in clay (e.g., silt/sand, limestone, and transition materials) produce higher levels of soluble V. Although orebody shale and mudstone floor WLA (TLBB to TLBE) can have an alkaline pH and low clay, the presence of reactive sulfur (as H_2S or HS^-) may be reducing V from mobile vanadates ($H_2VO_4^-$ and HVO_4^{2-}) to an insoluble precipitate (e.g., $V(OH)_3$). Therefore, despite being high in total V, the TLBB to TLBE units produce low soluble V concentrations.

10.4.6 References

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10.5 Attachment E: TS and CRS plots

10.5.1 TS plots

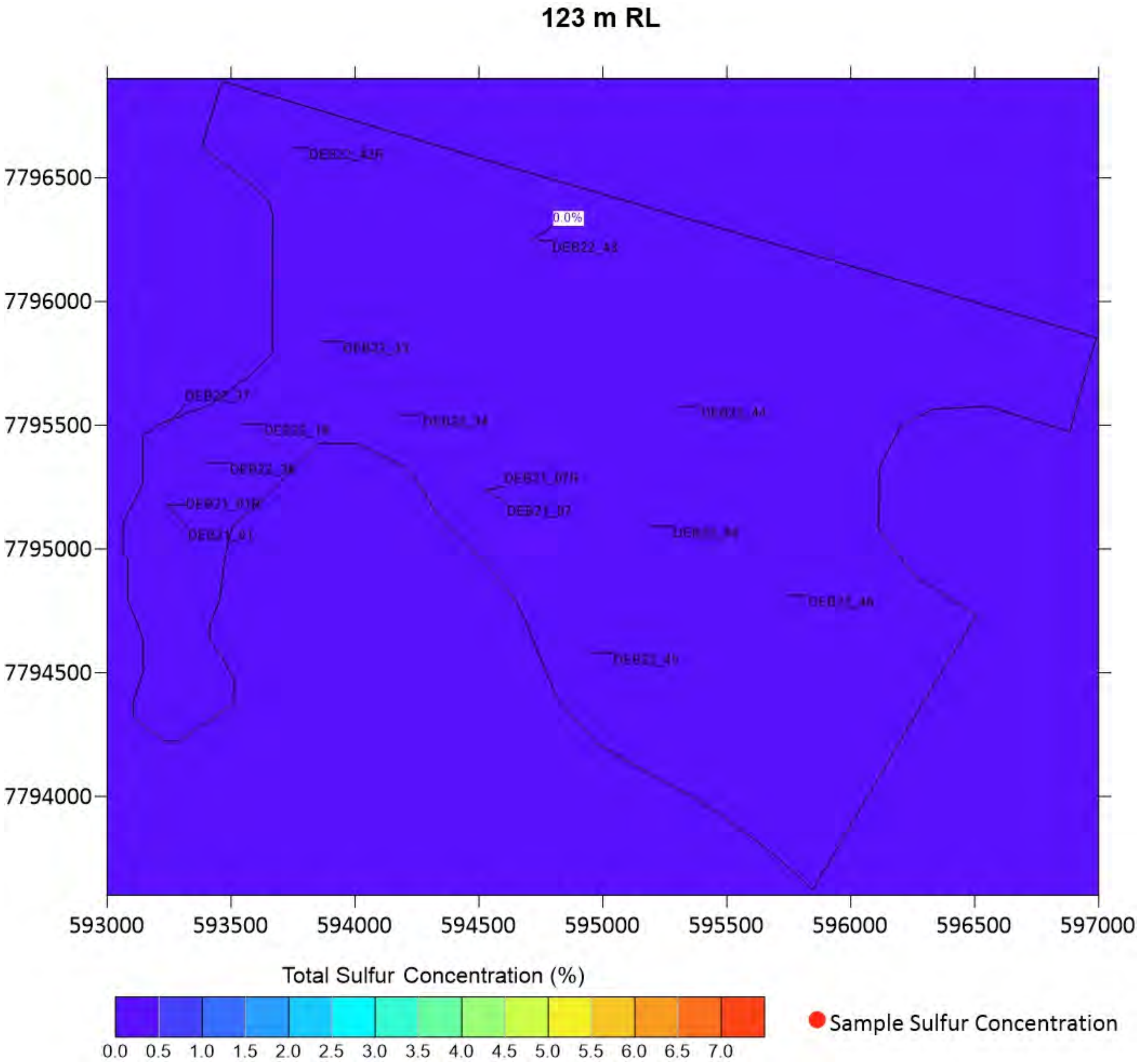

Figure 10-50: TS contour plot at 123 m RL

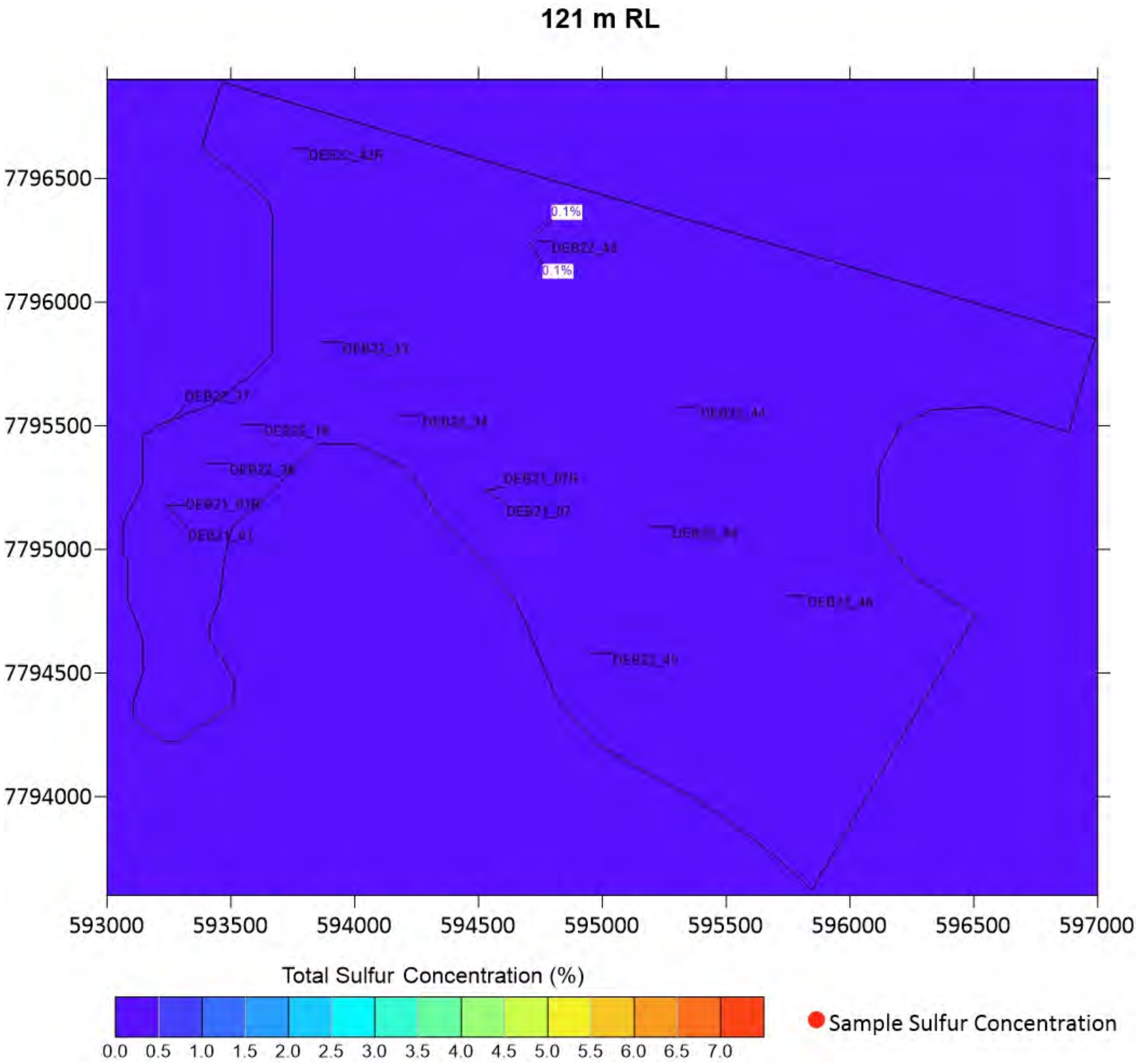

Figure 10-51: TS contour plot at 121 m RL

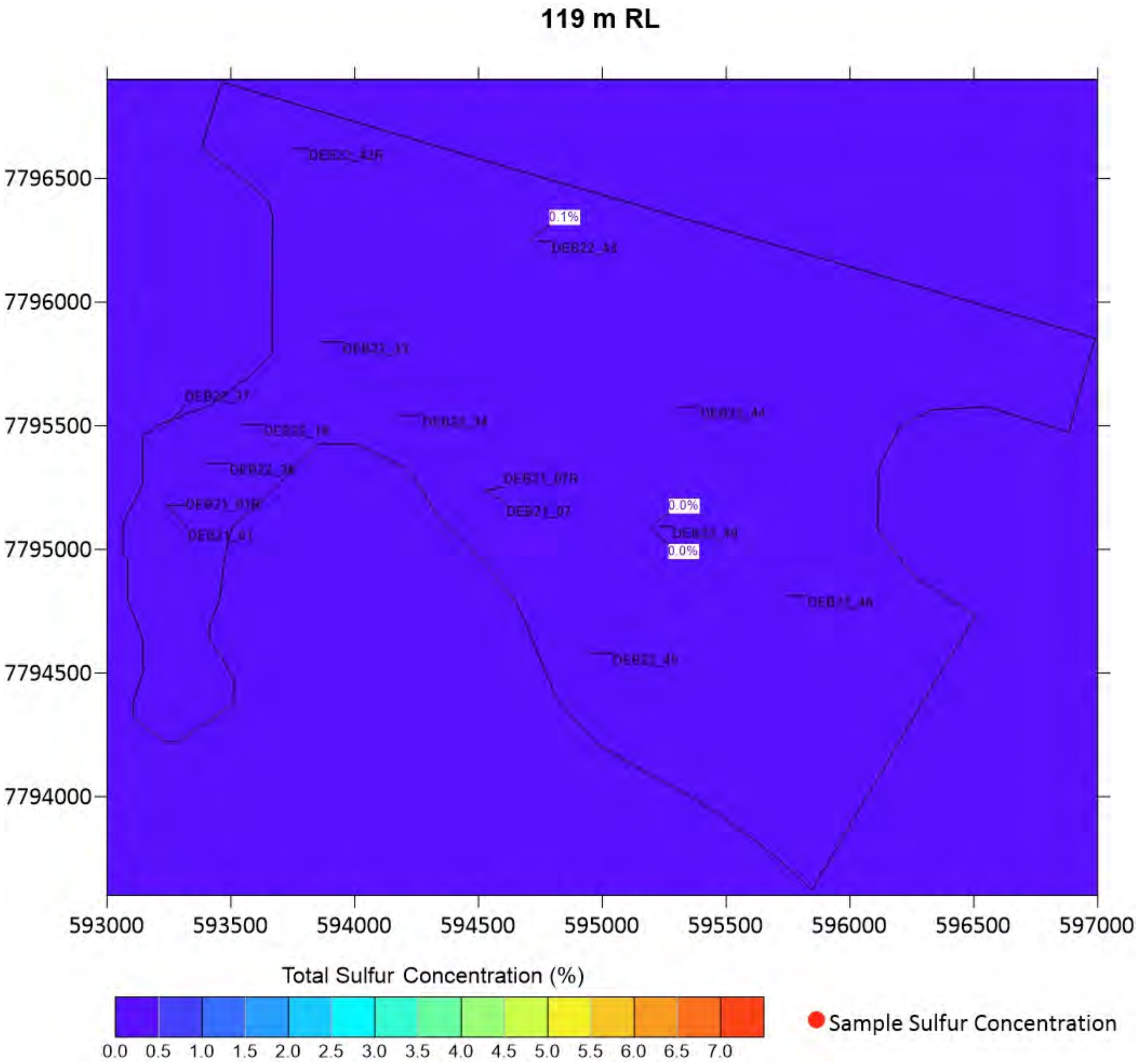

Figure 10-52: TS contour plot at 119 m RL

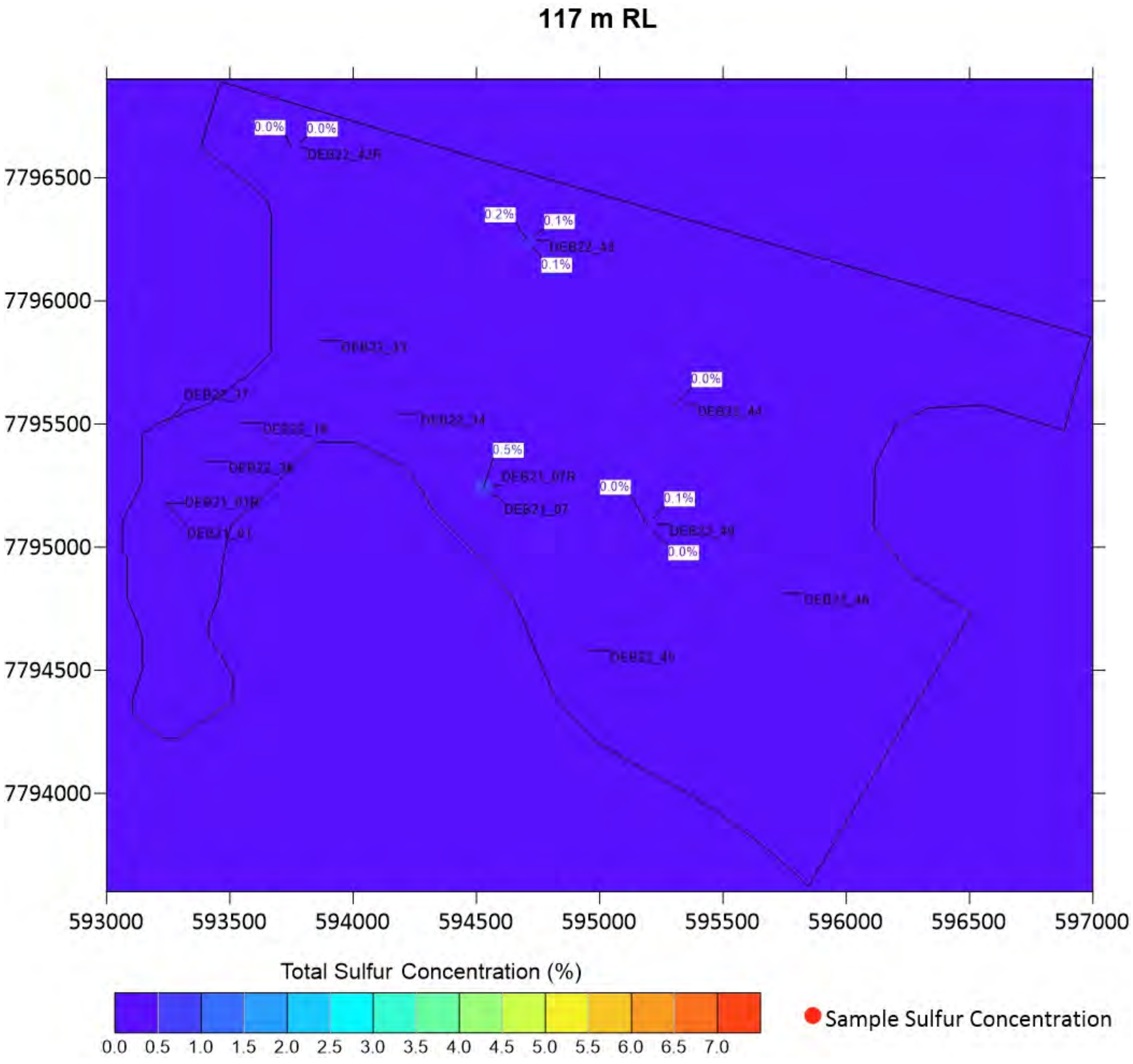

Figure 10-53: TS contour plot at 117 m RL

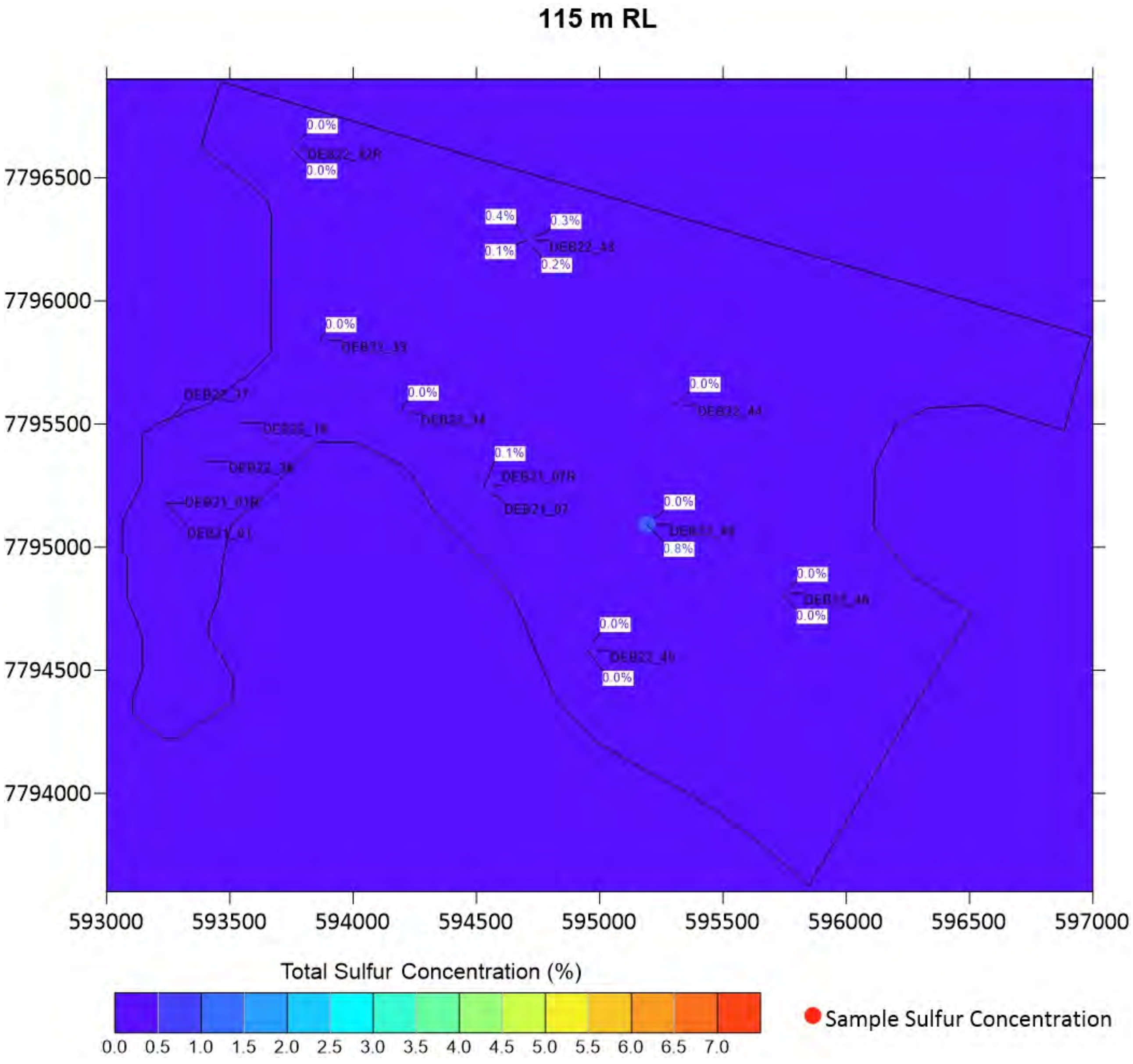

Figure 10-54: TS contour plot at 115 m RL

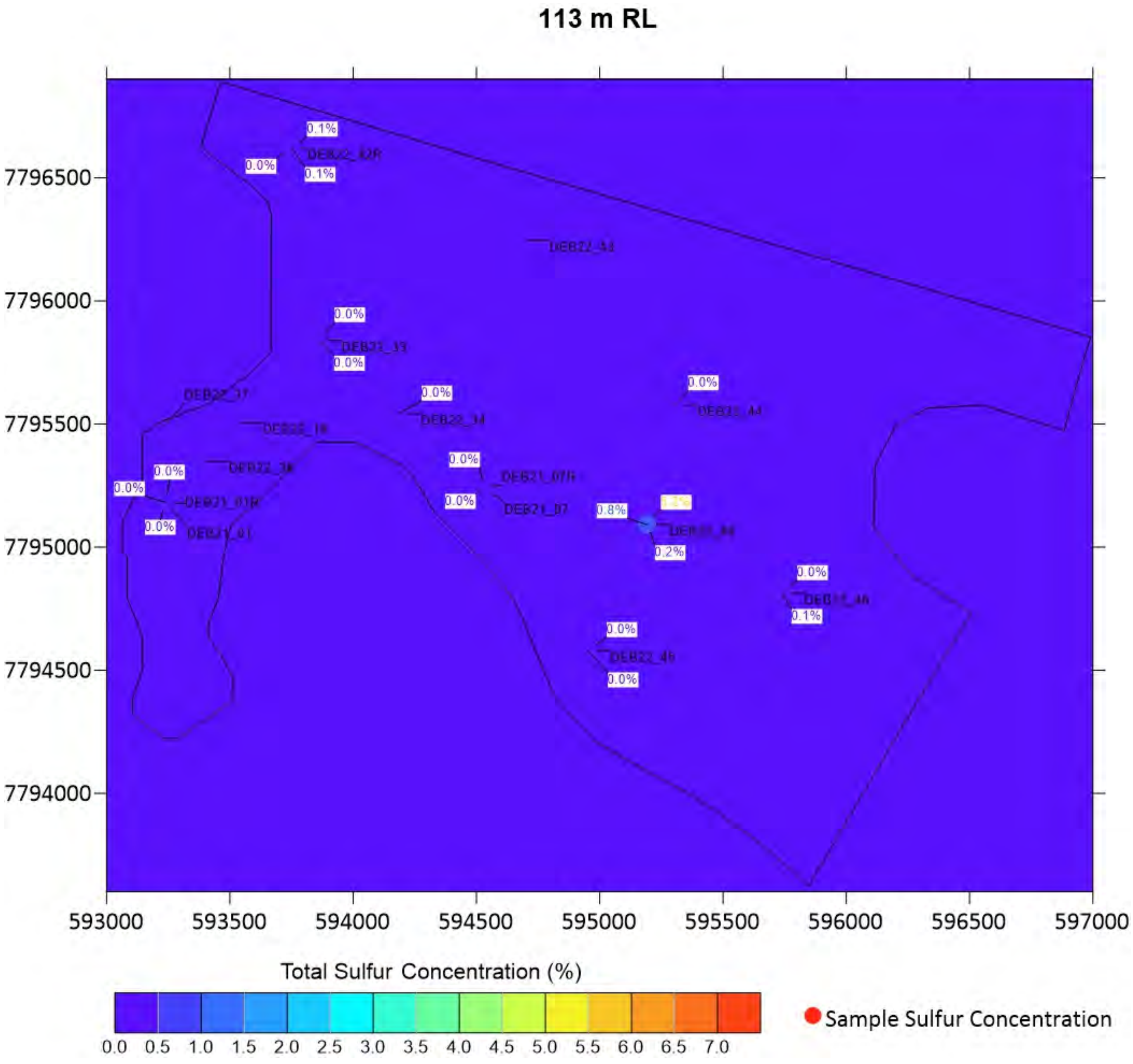

Figure 10-55: TS contour plot at 113 m RL

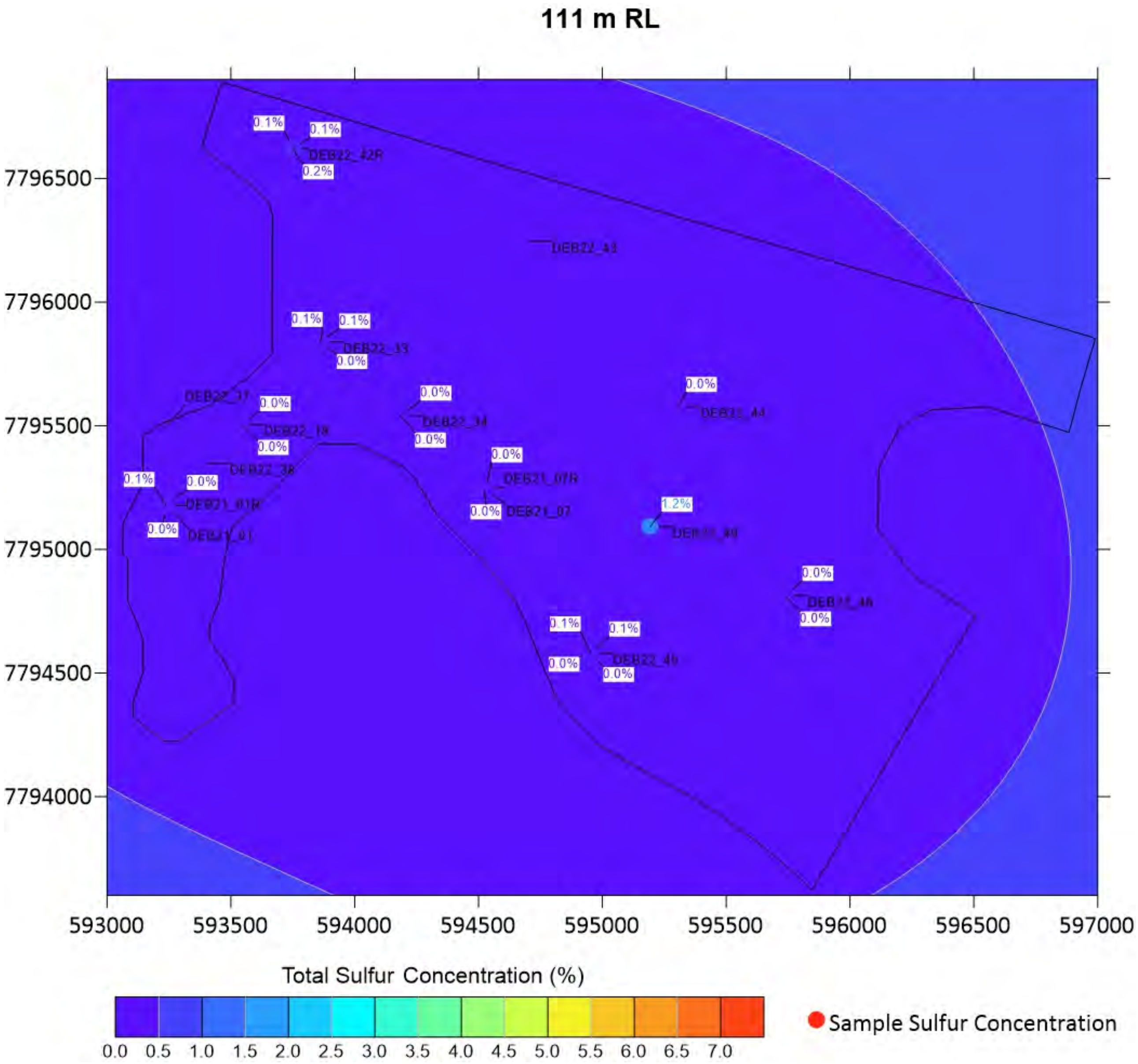

Figure 10-56: TS contour plot at 111 m RL

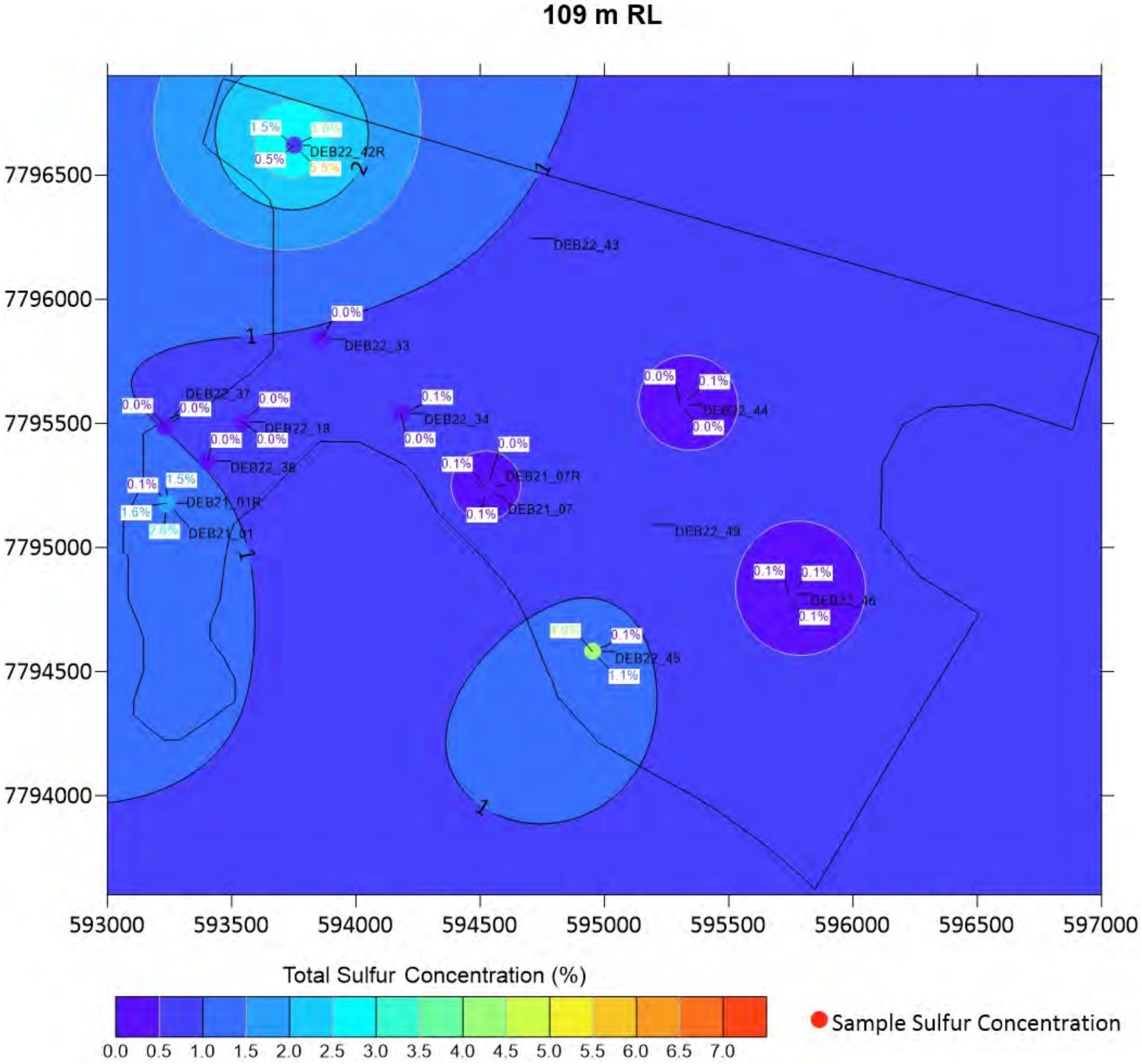

Figure 10-57: TS contour plot at 109 m RL

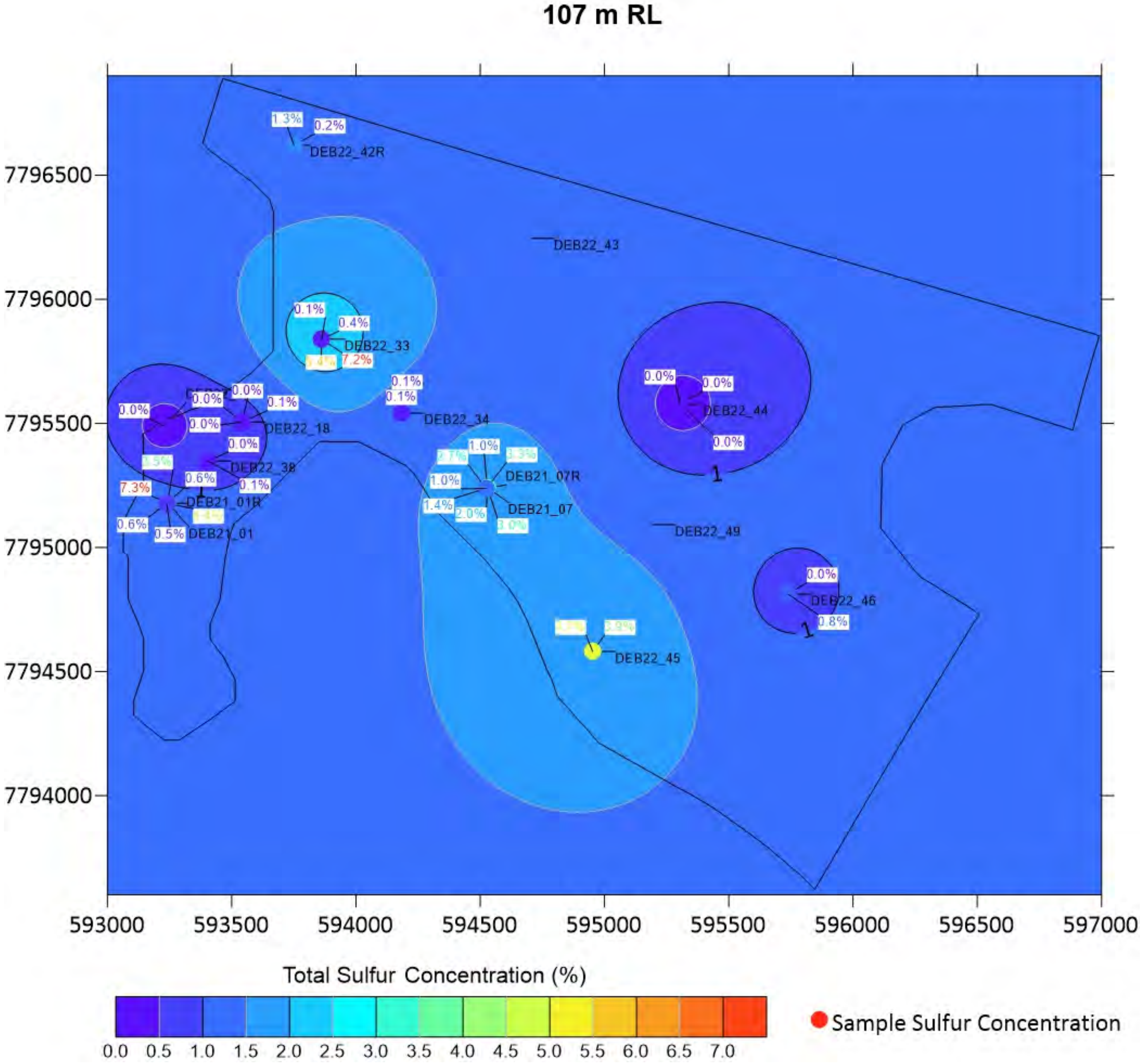

Figure 10-58: TS contour plot at 107 m RL

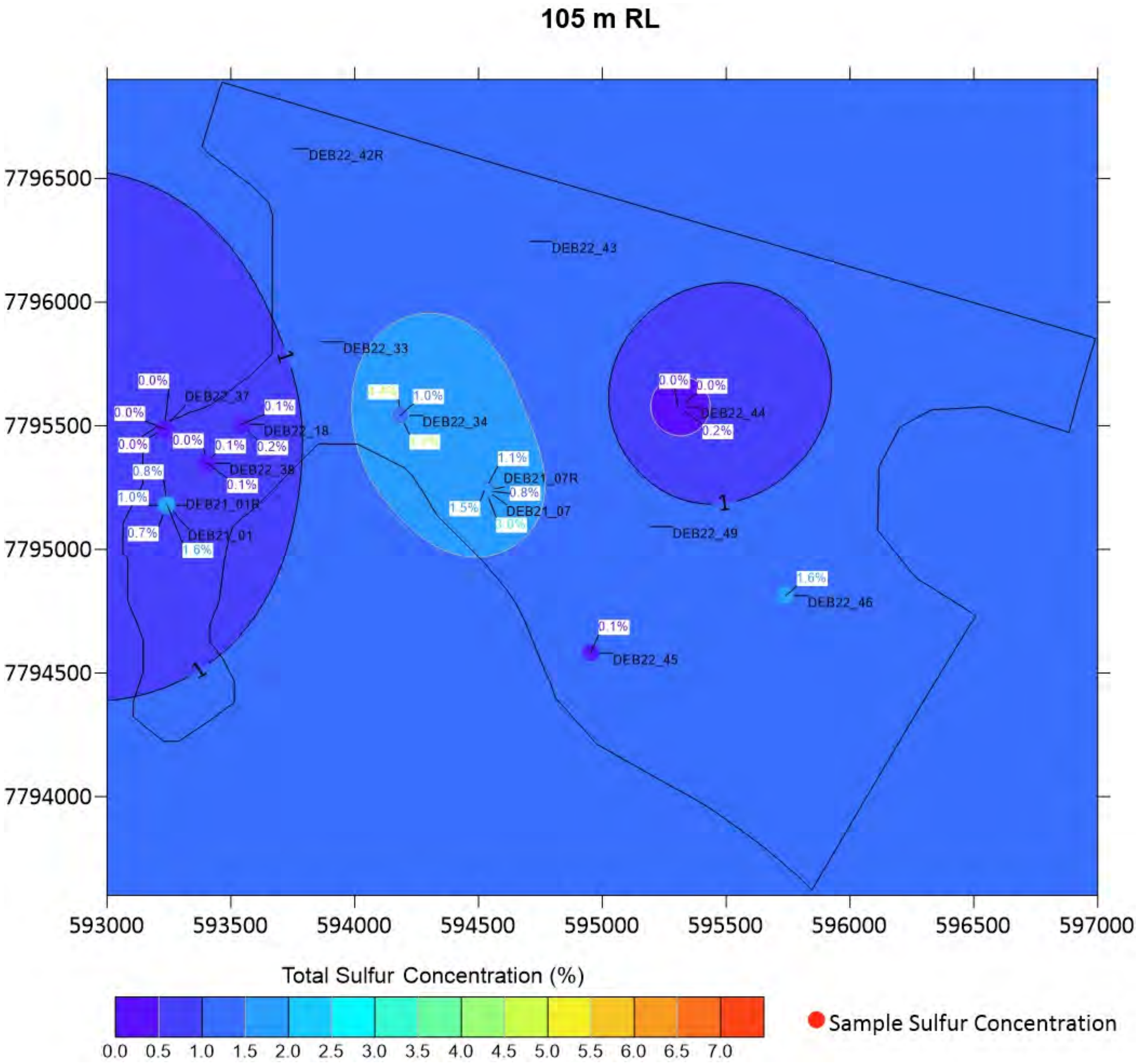

Figure 10-59: TS contour plot at 105 m RL

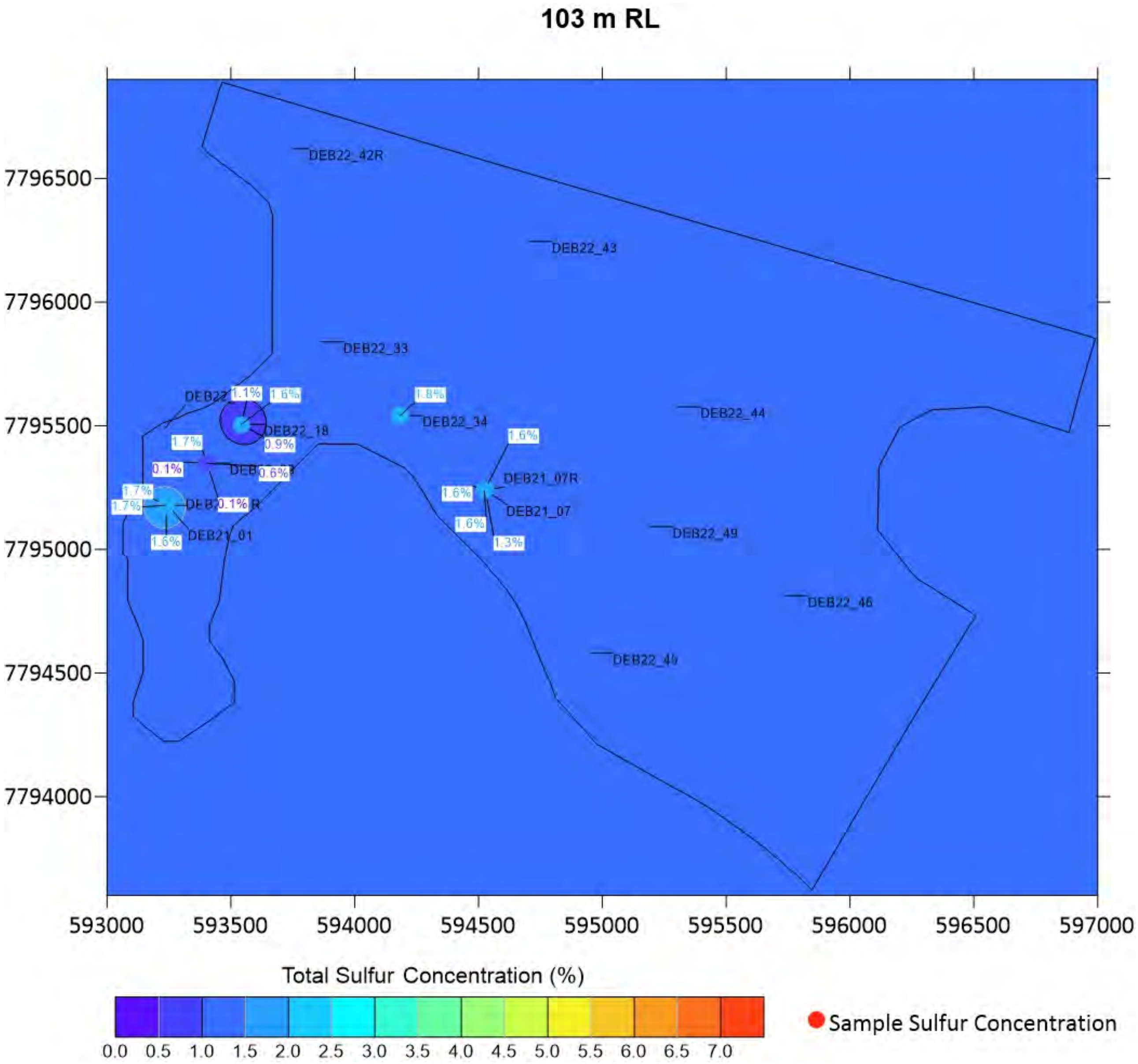

Figure 10-60: TS contour plot at 103 m RL

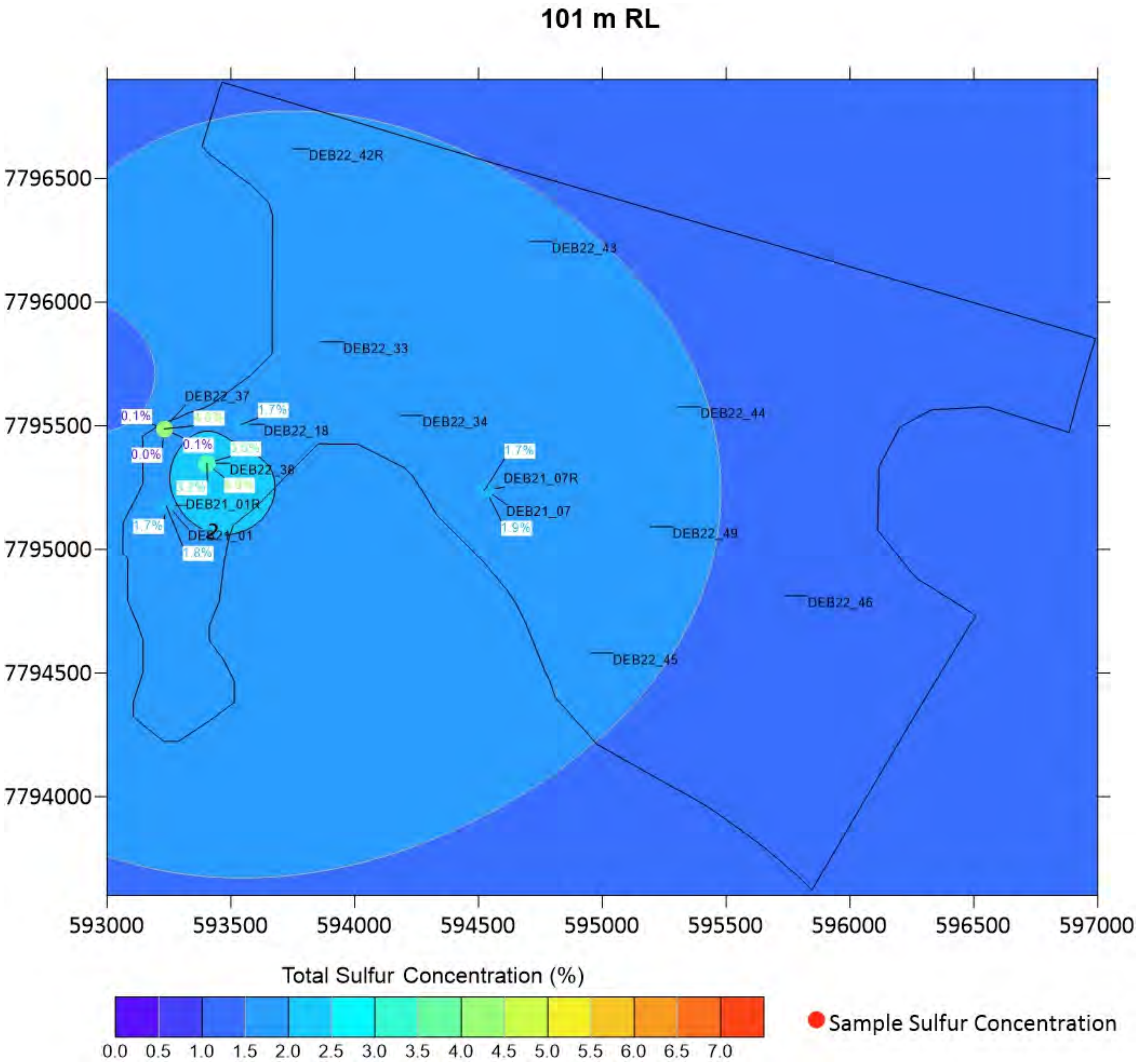

Figure 10-61: TS contour plot at 101 m RL

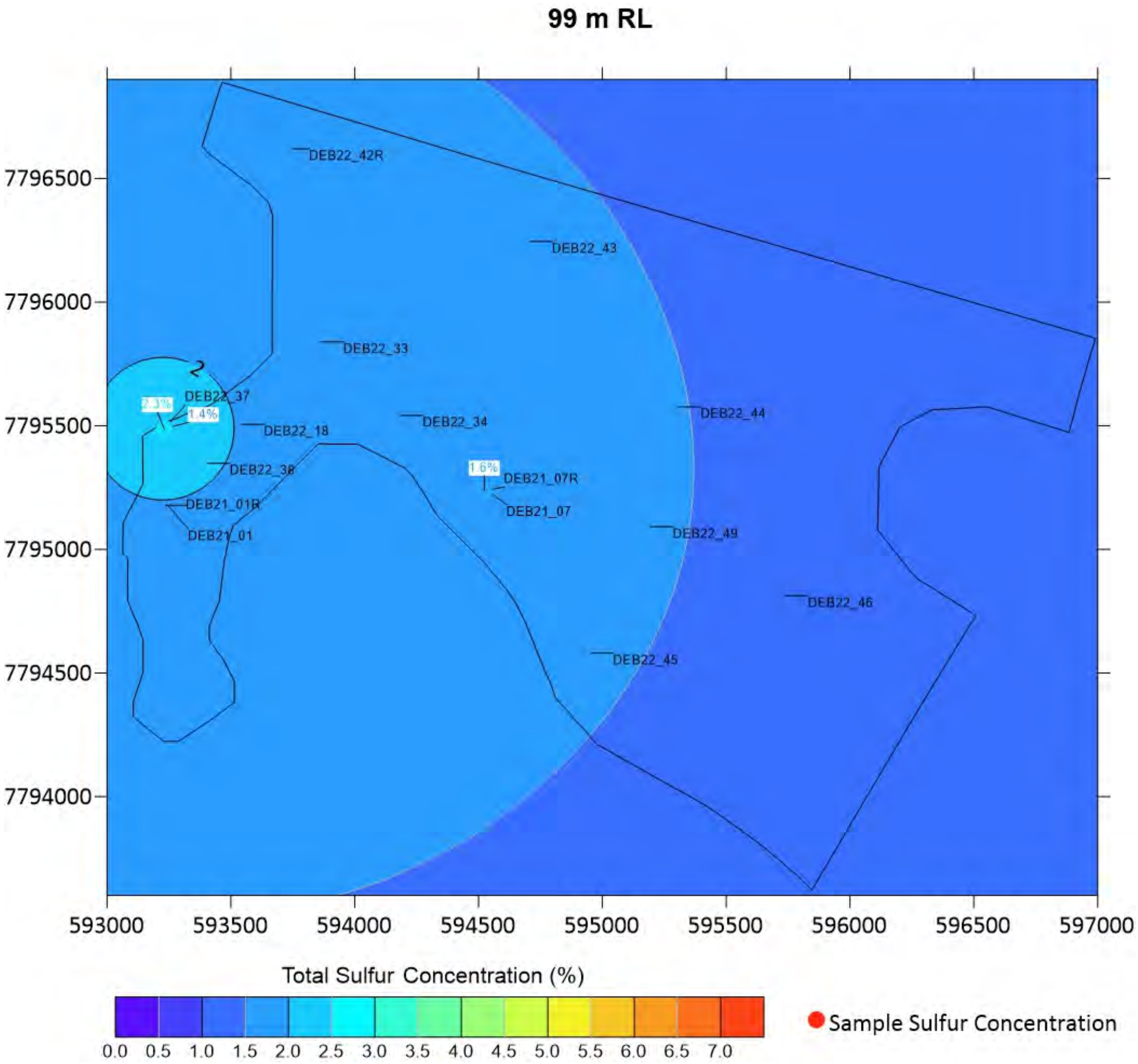

Figure 10-62: TS contour plot at 99 m RL

10.5.2 CRS plots

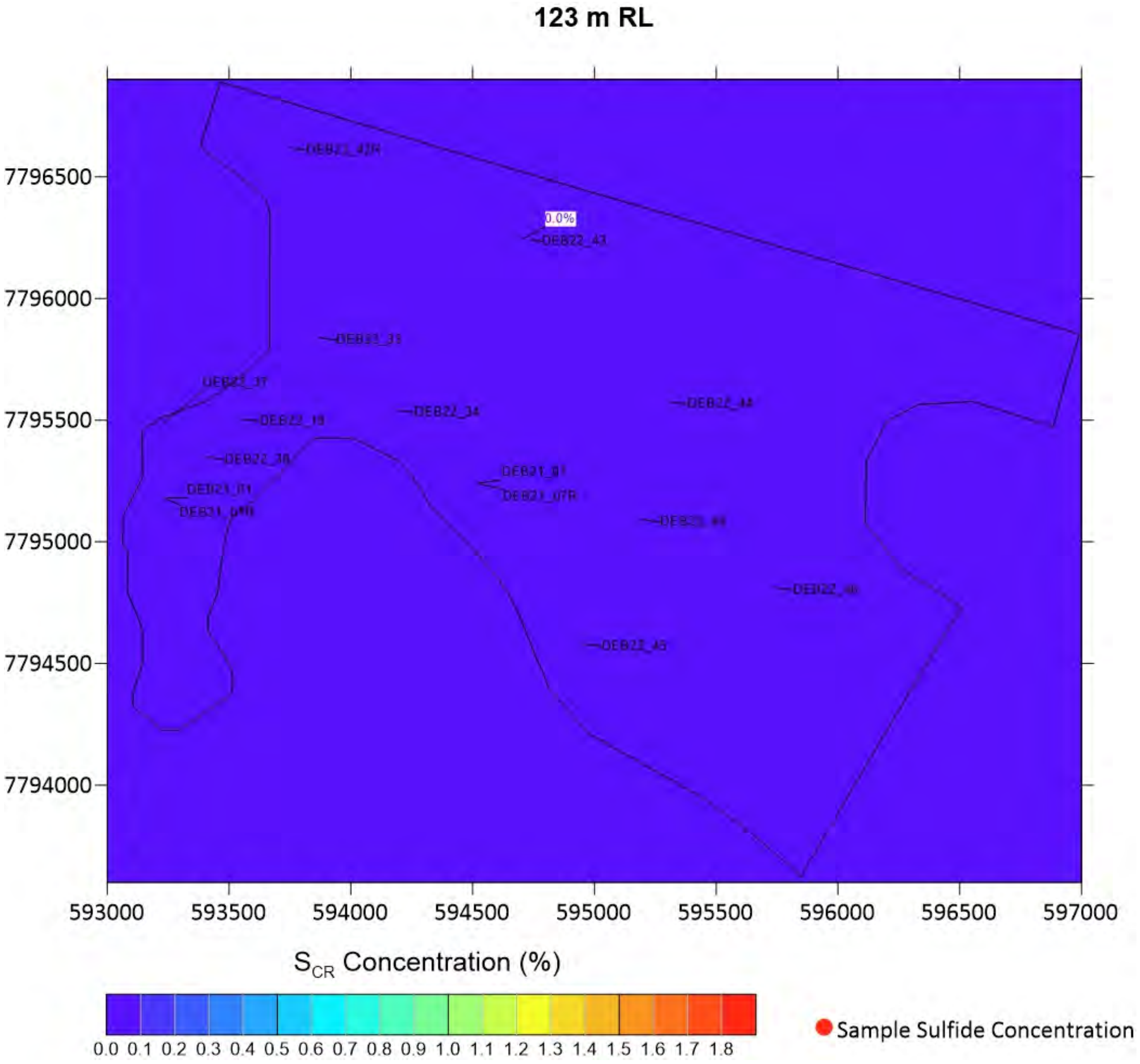

Figure 10-63: CRS contour plot at 123 m RL

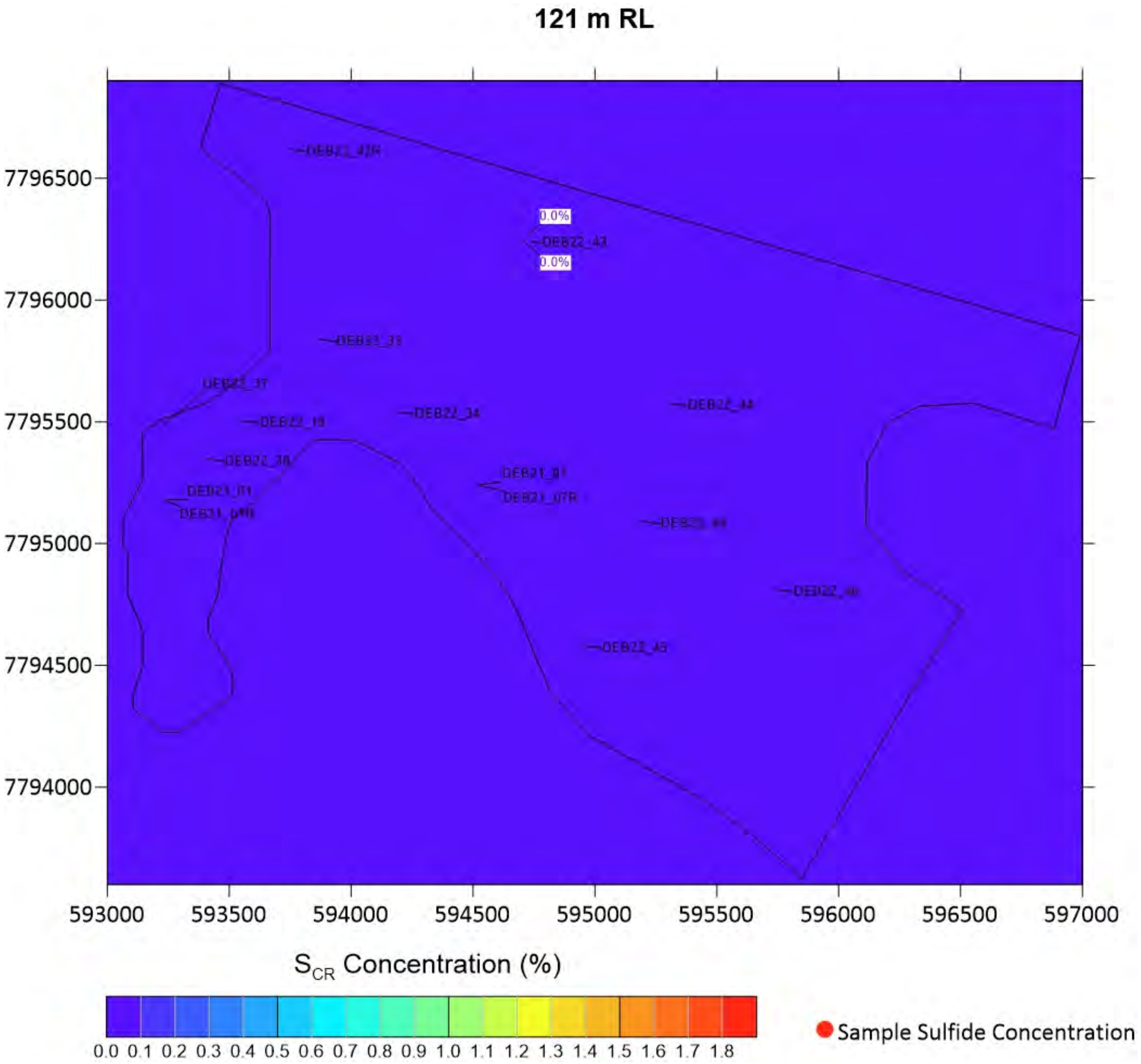

Figure 10-64: CRS contour plot at 121 m RL

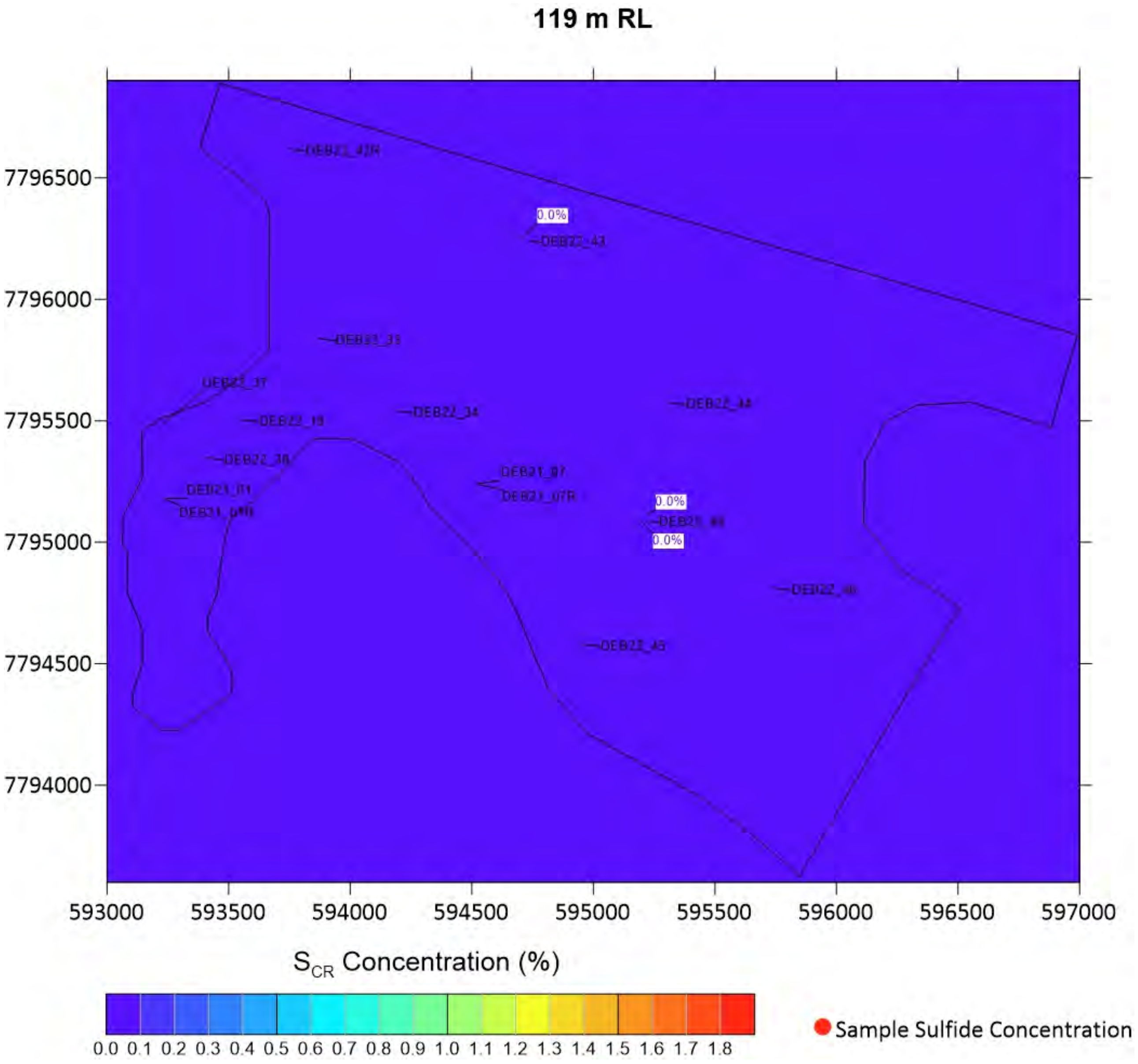

Figure 10-65: CRS contour plot at 119 m RL

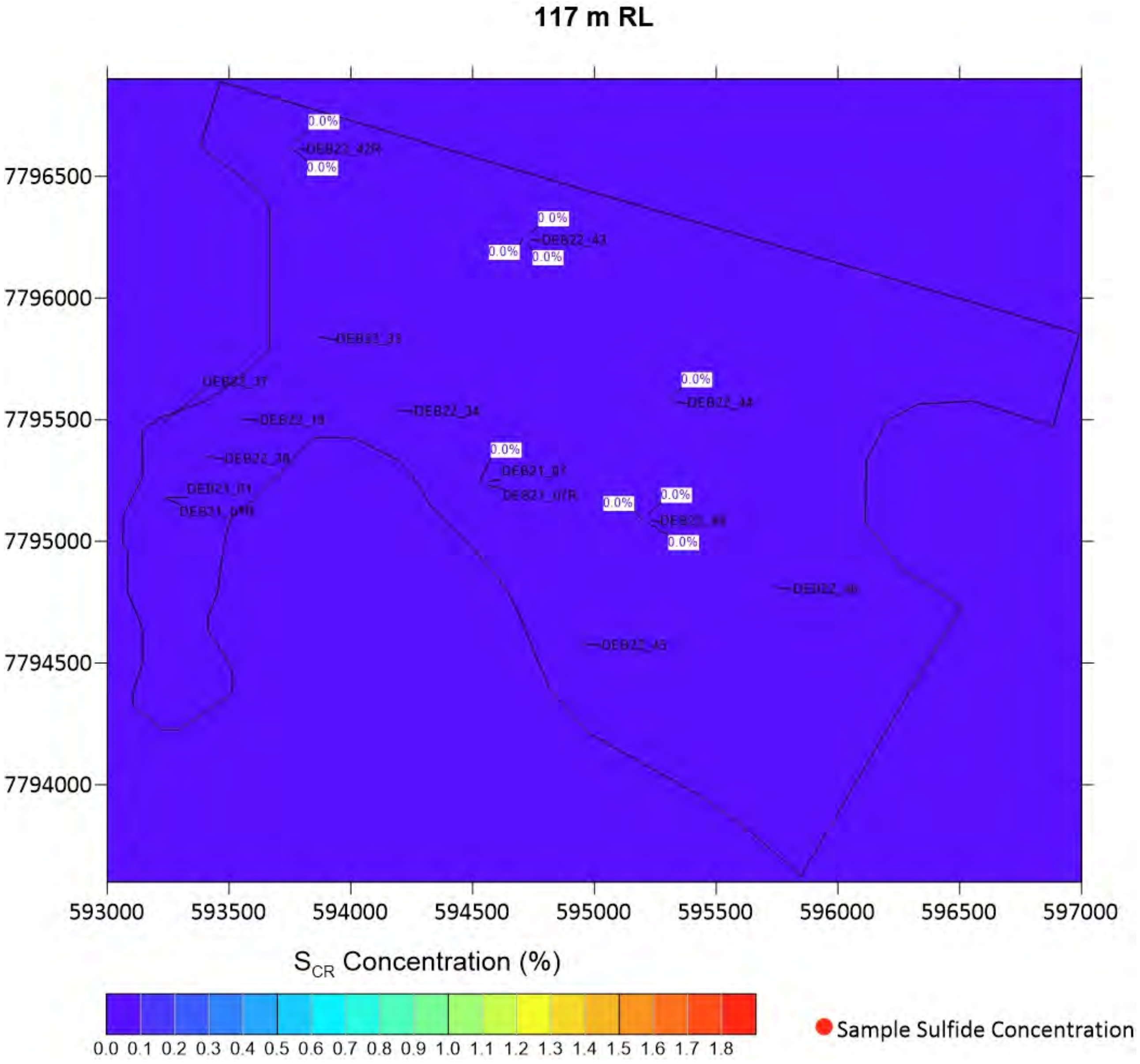

Figure 10-66: CRS contour plot at 117 m RL

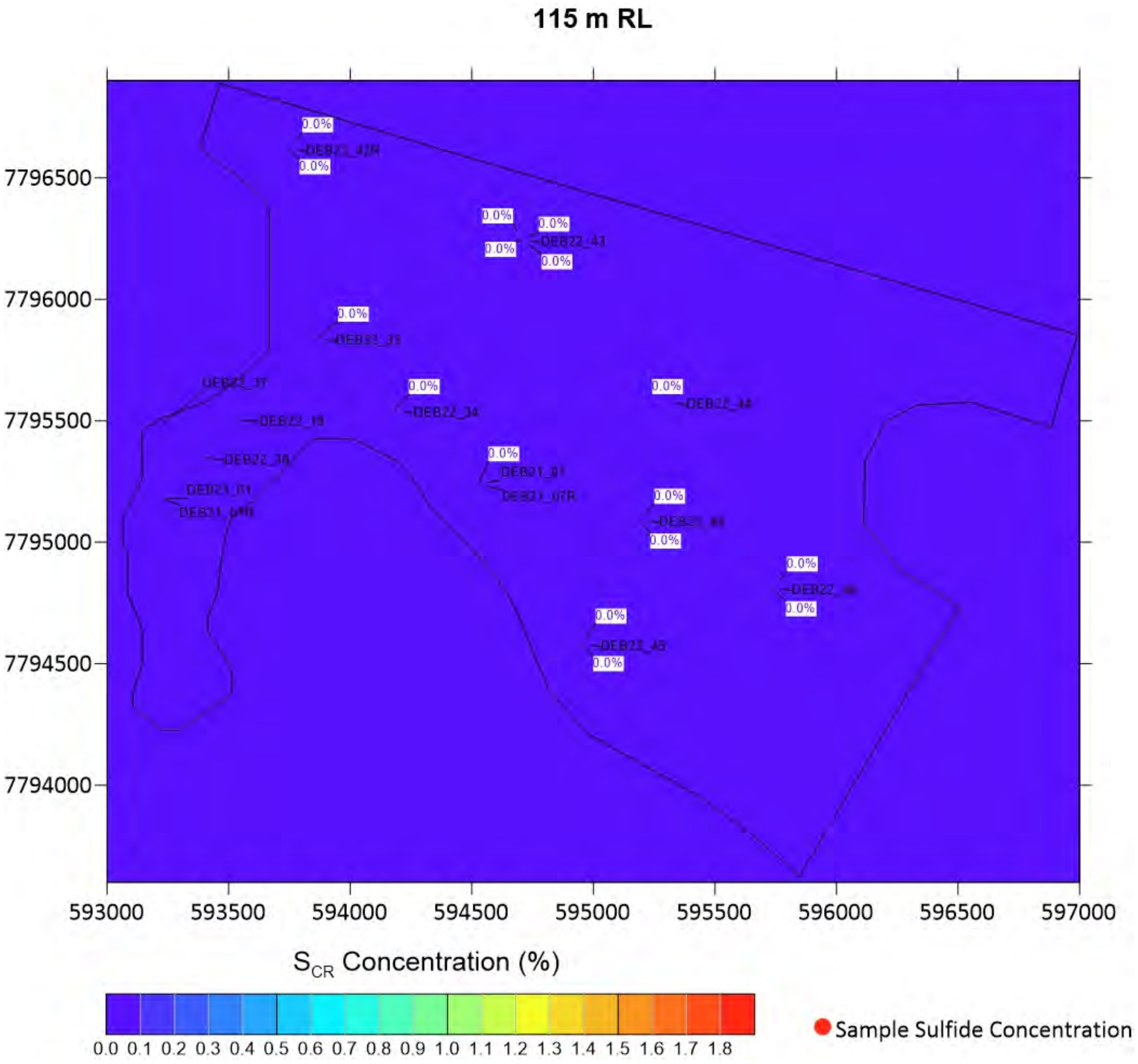

Figure 10-67: CRS contour plot at 115 m RL

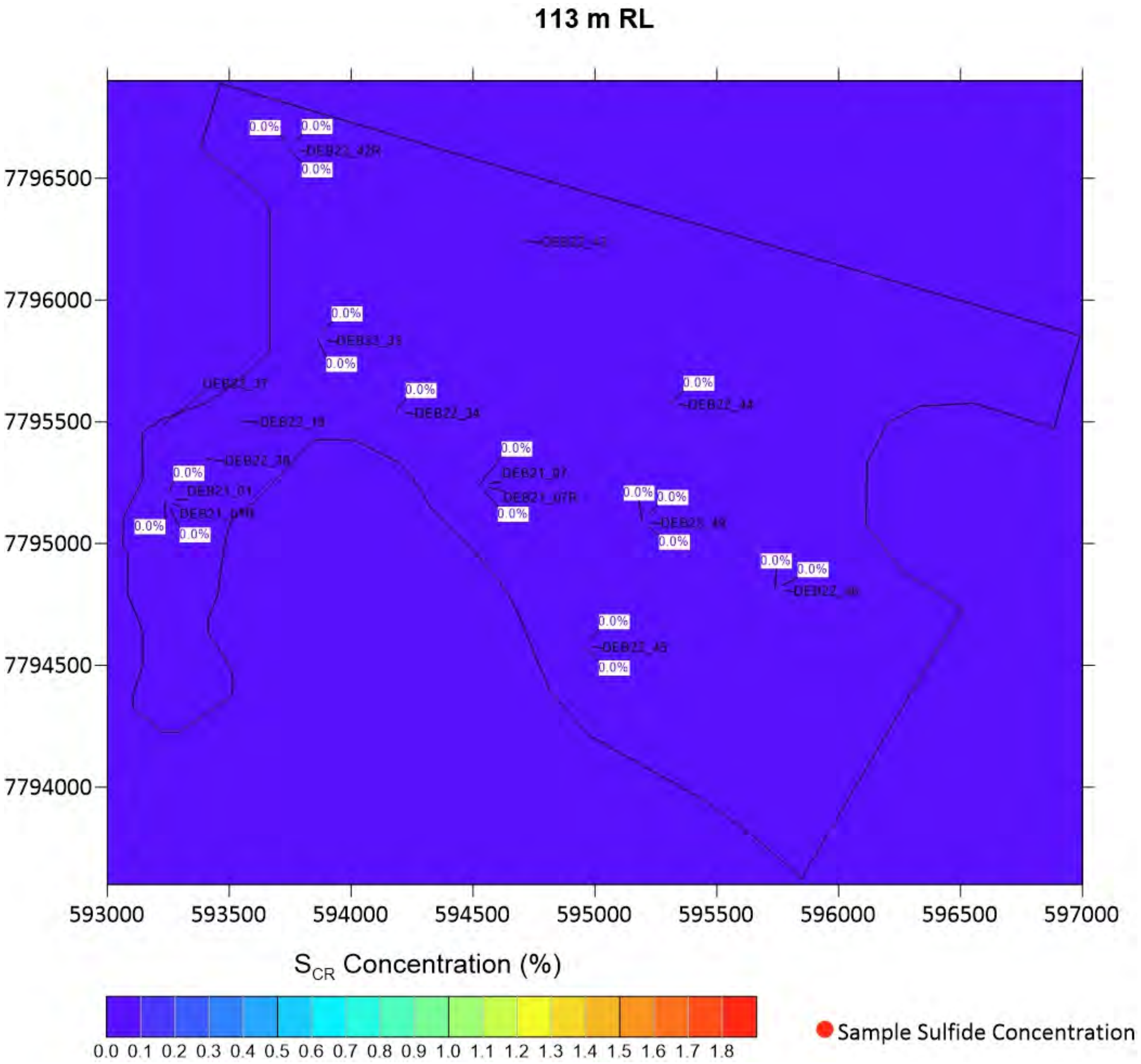

Figure 10-68: CRS contour plot at 113 m RL

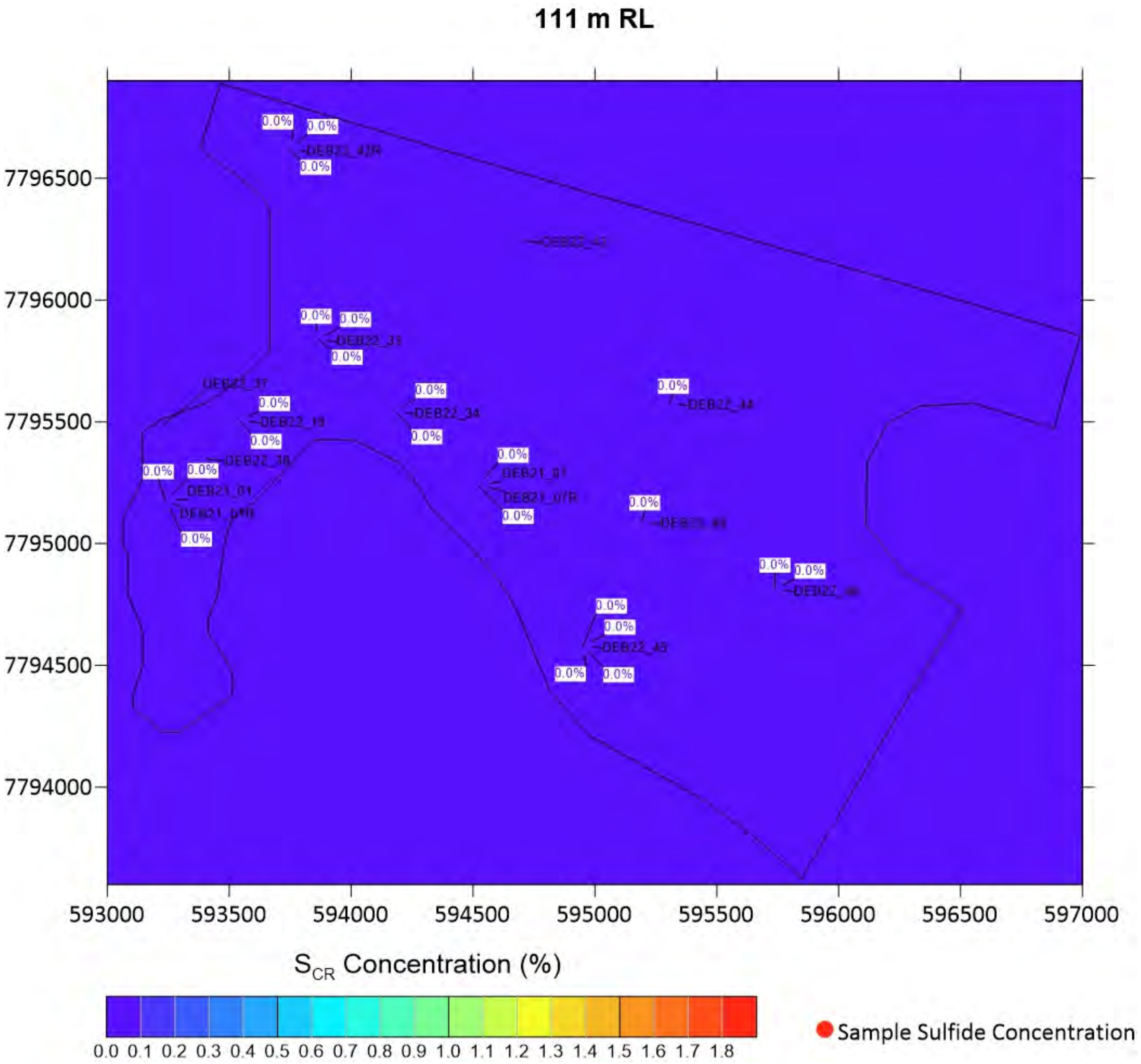

Figure 10-69: CRS contour plot at 111 m RL

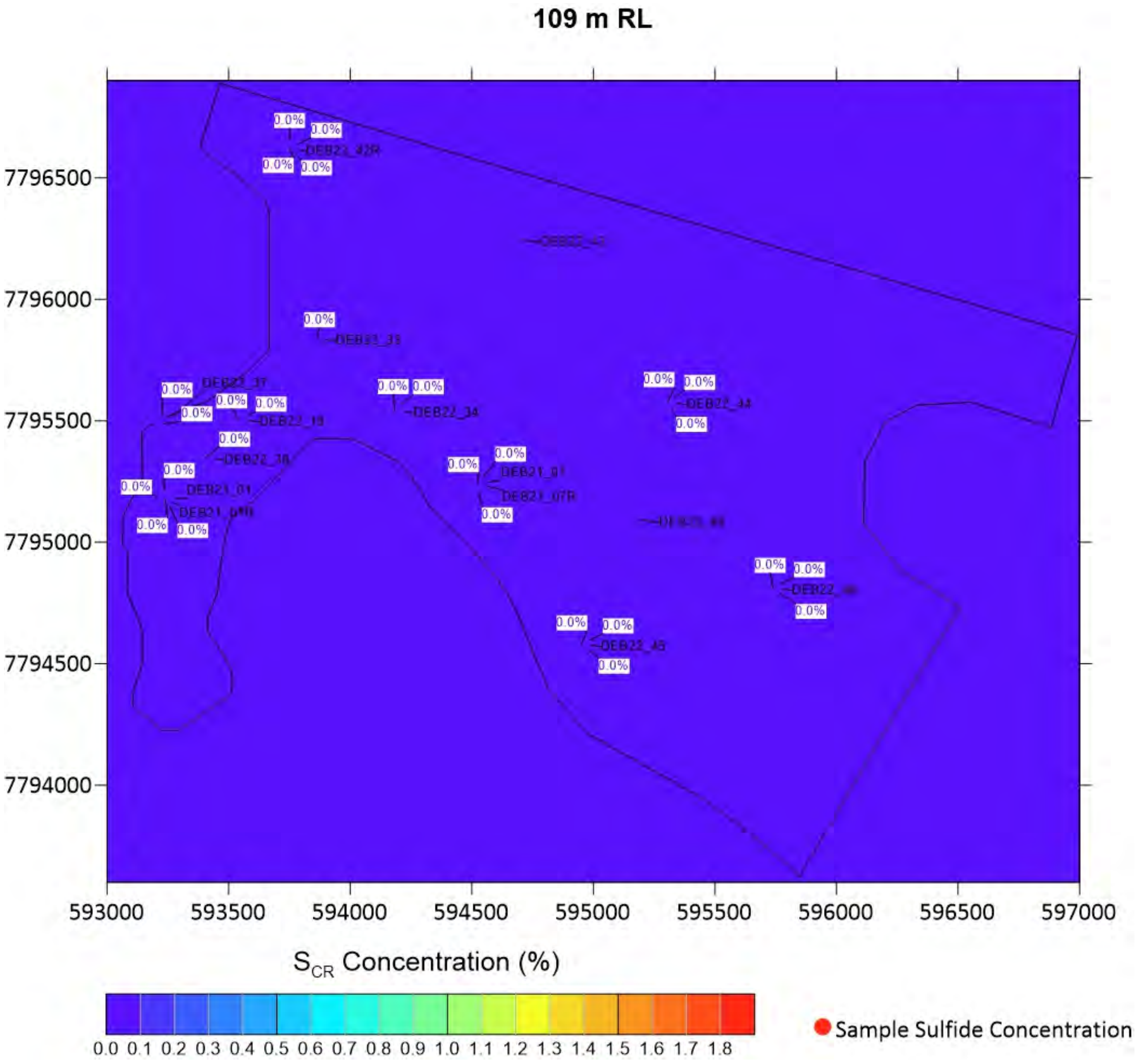

Figure 10-70: CRS contour plot at 109 m RL

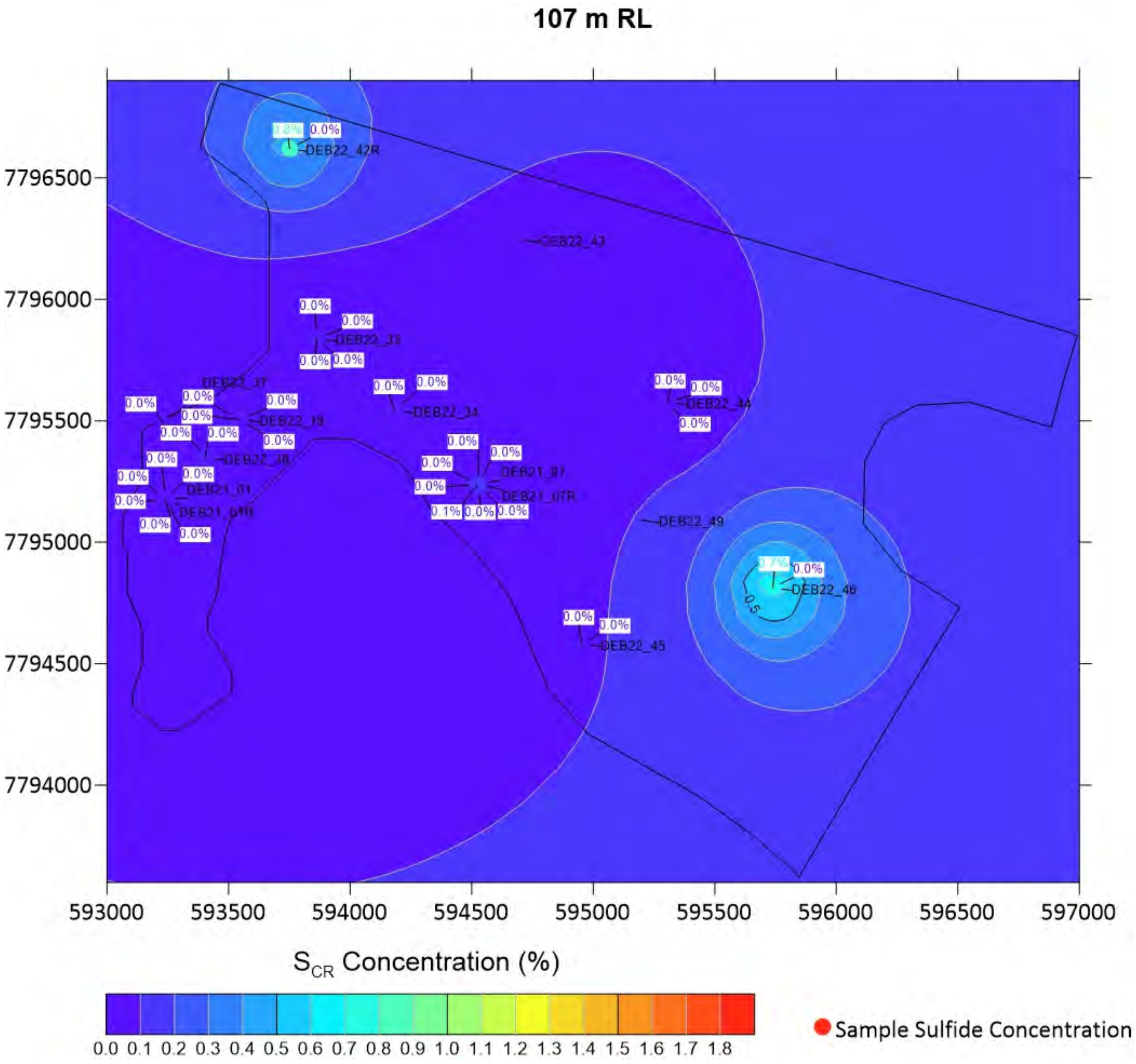

Figure 10-71: CRS contour plot at 107 m RL

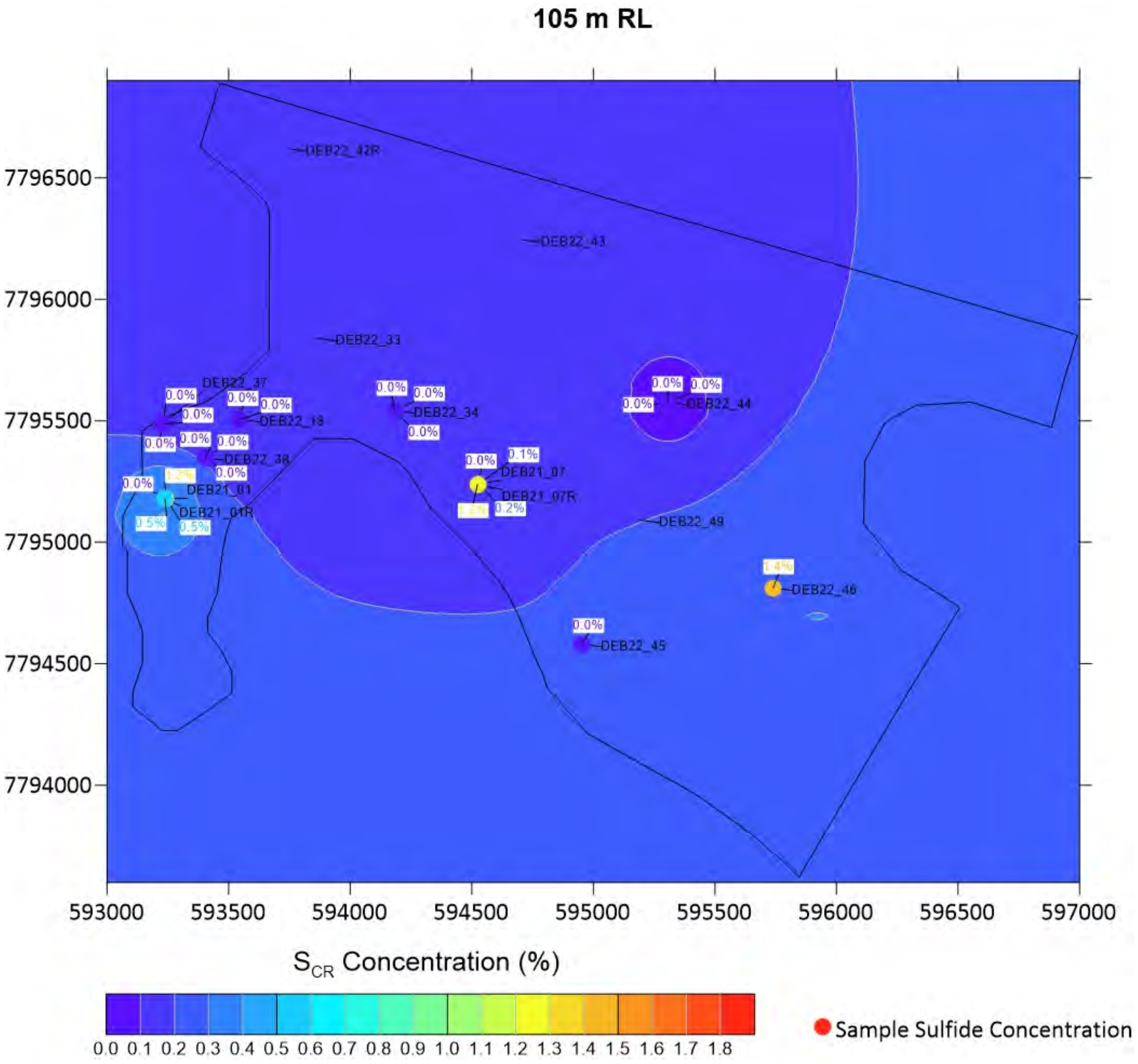

Figure 10-72: CRS contour plot at 105 m RL

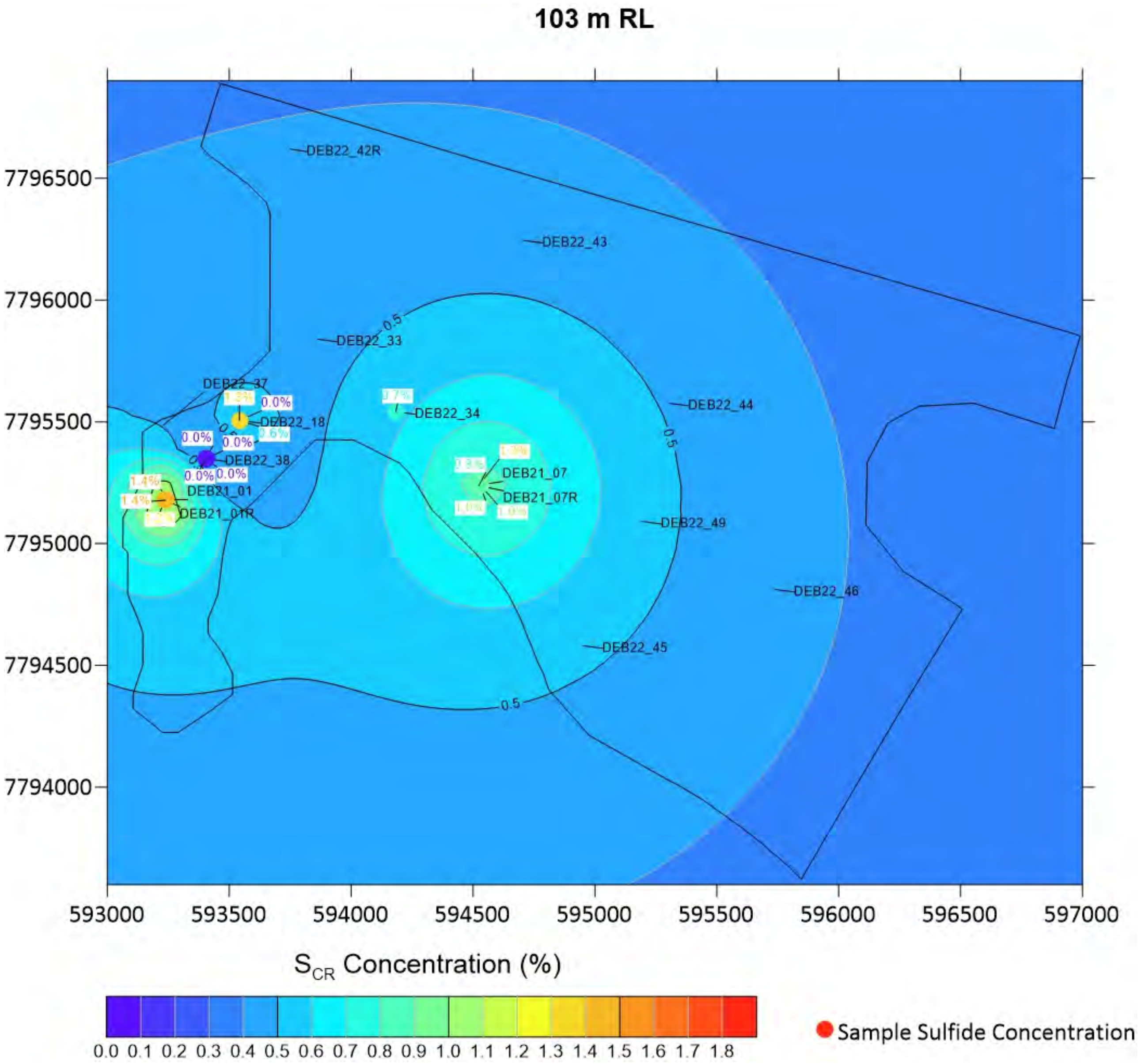

Figure 10-73: CRS contour plot at 103 m RL

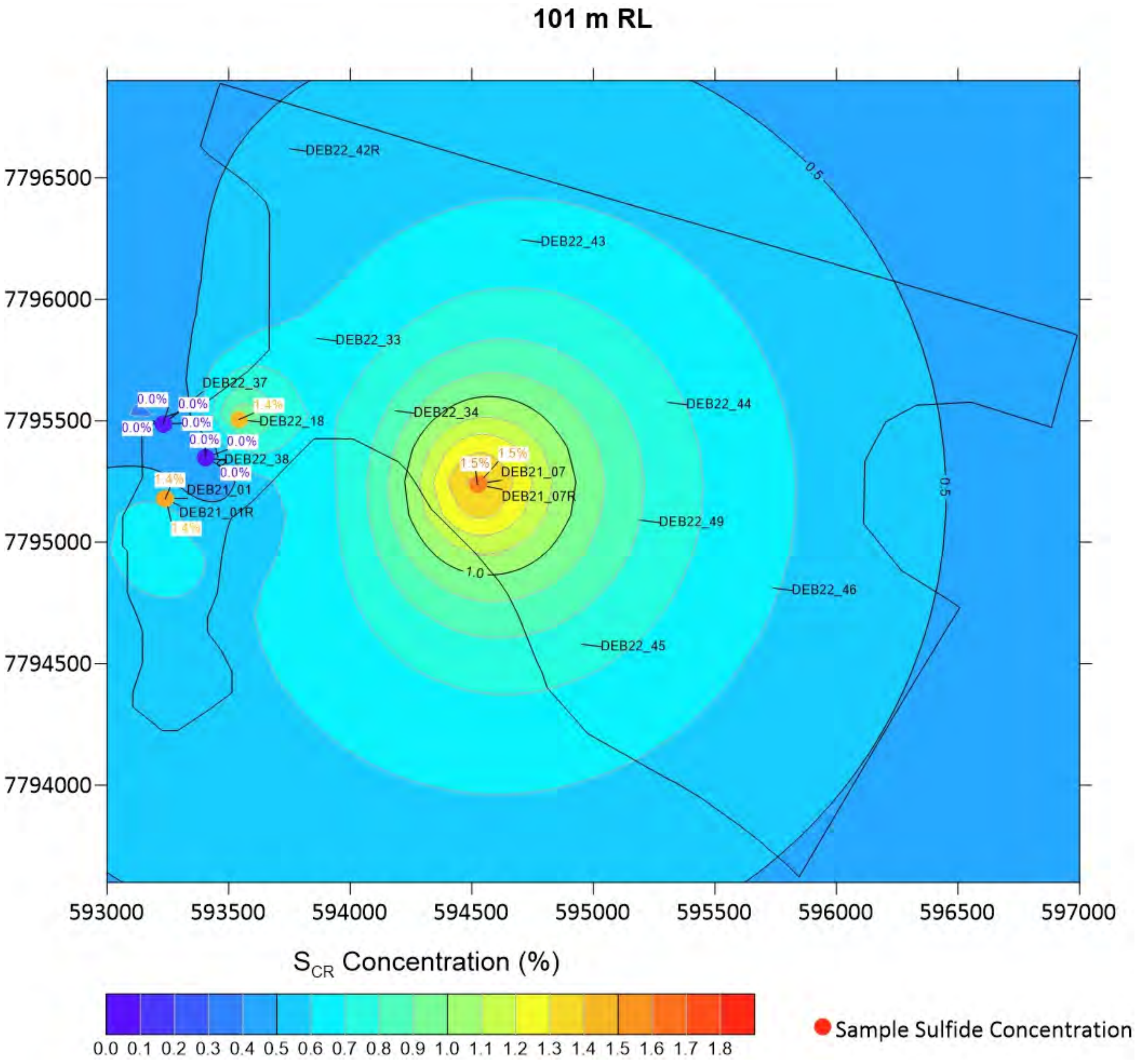

Figure 10-74: CRS contour plot at 101 m RL

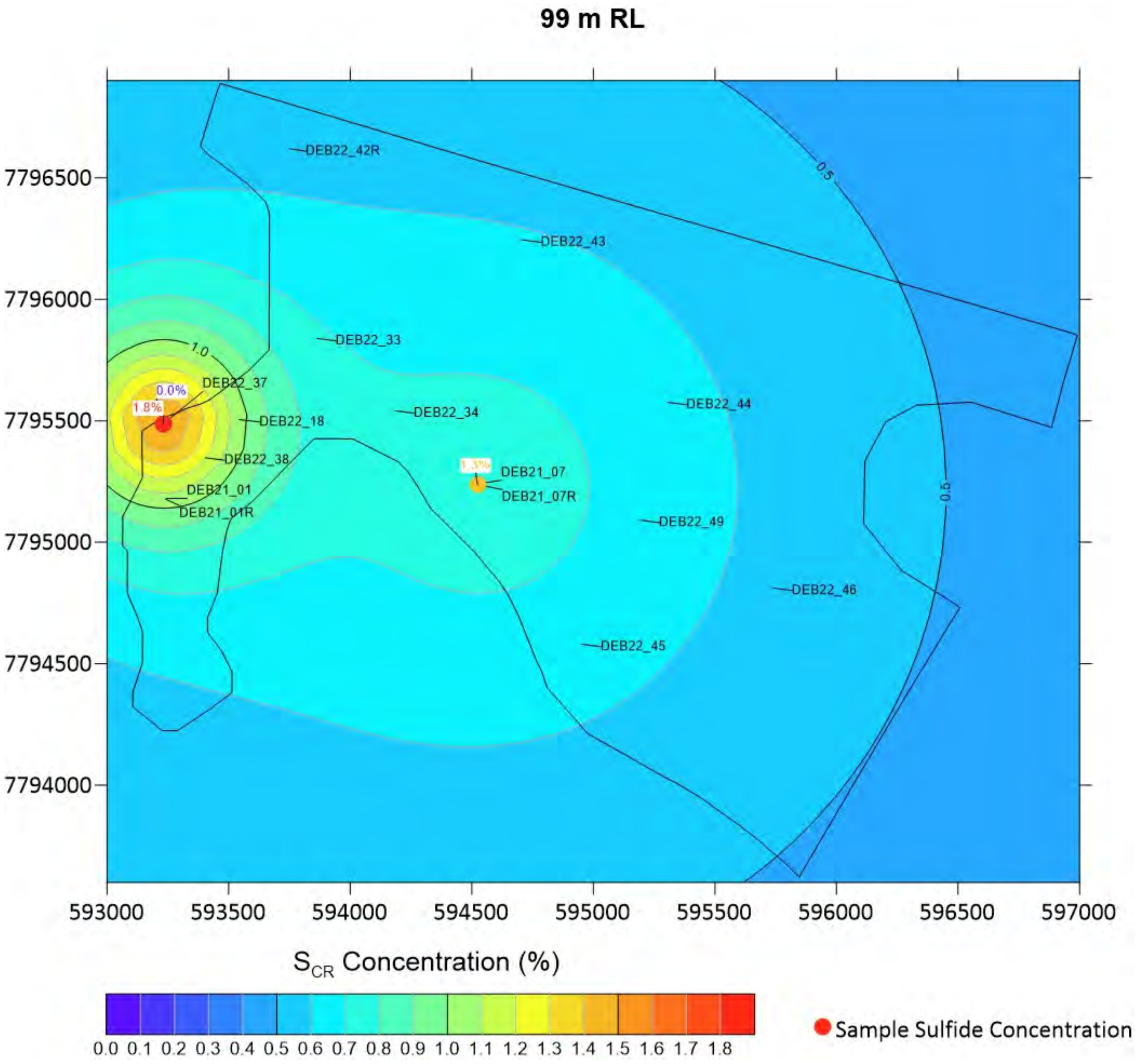

Figure 10-75: CRS contour plot at 99 m RL

10.6 Attachment F: ALS laboratory certificates

10.6.1 Attachment Fi: Acid base account results

10.6.2 Attachment Fii: Multi-element results

10.6.3 Attachment Fiii: KLC results

10.7 Attachment G: Trilab laboratory certificates

10.7.1 Attachment Gi: Particle size distribution results

10.7.2 Attachment Gii:Emerson class, Atterberg limits, and permeability results

10.7.3 Attachment Giii: MDD, CBR, shrink swell index and pinhole dispersion results

10.8 Attachment H: Levay and Co laboratory certificates

10.9 Attachment I: Soil Water Group laboratory certificates

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