Jugari East 8

Subterranean Fauna Habitat Modelling

Report to BHP WA IRON ORE

28 October 2024

Document Status				
Revision No.	Author	Review / Approved for Issue	Approved for Issue to Name	Date
Final	Shae Callan, Tabitha Rudin, Josh Turner, Jenny Abello	Sarah Williamson	Suzi Wild (BHP WAIO)	28/10/2024

Executive summary

BHP Western Australian Iron Ore Pty Ltd (BHP WAIO) are proposing the development of new mine pits at Jugari East 8 (the Proposal), located in the Pilbara region of Western Australia, approximately 90 km northwest of Newman. Subterranean fauna surveys were conducted between 2009-2023 within the Jugari Study Area (the Study Area) surrounding the proposed pits. Surveys found five target troglofauna and two stygofauna species considered to be potentially subject to impacts from the proposed development: a symphylan, *Hanseniella* sp. indet; a centipede, *Cryptops* sp. 'BSCOL091'; a beetle, *Hesperanillus* sp. 'BCO247'; two millipedes, Haplodesmidae 'BDI080' and Trigoniulidae 'BDI079'; and two harpacticoid copepods, *Elaphoidella* sp. 'BHA342' and *Parastenocaris* 'BHA343'.

Biologic Environmental Survey Pty Ltd (Biologic) was engaged to undertake a subterranean fauna habitat assessment (based on 2D information and 3D modelling), within the Study Area with a focus on the target species to support environmental approvals for the Proposal. The 2D and 3D habitat assessments used publicly available spatial data comprising surface geology, geological structures, hydrogeology, and surface drainage, as well as deposit scale geological models created by BHP WAIO. The 3D habitat model was based on a combination of three geological models provided by BHP WAIO (East 8, East 7, and East 3,4,5,6) using Leapfrog® Geo 2022.1.1 software (Leapfrog). Drill core photos and water bore schematics were evaluated to define habitat suitability and assess drill log data.

The 3D habitat modelling showed that suitable troglofauna habitat is hosted within the fractured/weathered CID of the Marillana Formation and alluvial/ colluvial detritals associated with Marillana Creek and floodplains. Groundwater hosted within the CID forms the primary stygofauna habitat, while the fractured/weathered parts of the Weeli Wolli Formation may also provide deeper habitat in some areas within the palaeochannel. Following historic mining and dewatering, the alluvial detritals do not occur below water table but may provide temporary stygofauna habitat following sporadic flood events. Overall, the suitable habitats are well-connected and continuous throughout the East 8 area, with no major habitat barriers.

The proposed mining is predicted to result in a localised reduction of troglofauna habitat and will leave intact a wider extent of high to medium suitability habitat in CID and alluvials. The impacts of the Proposal to the five target troglofauna species listed above are unlikely to be significant, as the East 8 proposed pits are relatively small compared to the wider extent of habitat in the surrounding area. The Proposal is likely to meet the EPA objectives in relation to troglofauna.

The predicted impacts to groundwater habitats are likely to be more substantial, given interconnected aquifers and the effects of historic mining and dewatering. Regional genetic comparisons detected the copepod *Elaphoidella* sp. 'BHA342' beyond the predicted drawdown area, therefore this species is unlikely to be seriously impacted.

Conversely, *Parastenocaris* sp. 'BHA343' is known only from the proposed East 8 pit at the time of writing, and could be subject to a significant reduction of suitable groundwater habitat following the proposed development. There are some residual uncertainties concerning its potential wider occurrence based on regional distribution patterns for the genus, and the possibility of deeper or more extensive suitable habitats beyond the current data. Nevertheless, based on information available to this assessment, the proposed groundwater drawdown could seriously impact *Parastenocaris* `sp. BHA343`, and the Proposal may not be able to meet the EPA objectives in relation to this species.

Table of Contents

Tables

Figures

Appendices

1 Introduction

1.1 Background

BHP Western Australian Iron Ore Pty Ltd (BHP WAIO) operates the Jugari Iron Ore mine (formerly known as Yandi) located in the Pilbara region of Western Australia, approximately 90 km northwest of the town of Newman (Figure 1.1). The Jugari mine has been in operation since the early 1990's and is located immediately west of the Rio Tinto Iron Ore's Jugaricoogina mine (formerly known as Yandicoogina).

BHP WAIO commissioned Biologic Environmental Survey Pty Ltd (Biologic) to develop three-dimensional (3D) habitat modelling for subterranean fauna habitats at the Jugari East 8 Project and immediate surrounds (the Study Area). The Study Area (Figure 1.1) comprises two boundaries covering the East 7/8 area, and the East 3,4,5,6 areas within the Jugari mine lease (ML270SA).

The habitat modelling and assessment will be used to inform environmental approvals for the proposed development of a new mine pit at Jugari East 8. Subterranean fauna surveys of the area have been previously undertaken by Bennelongia (2024) and Subterranean Ecology (data supplied by BHP WAIO). The modelling and habitat assessment work is focused on seven target species that were recorded only within the proposed East 8 area to date, comprising:

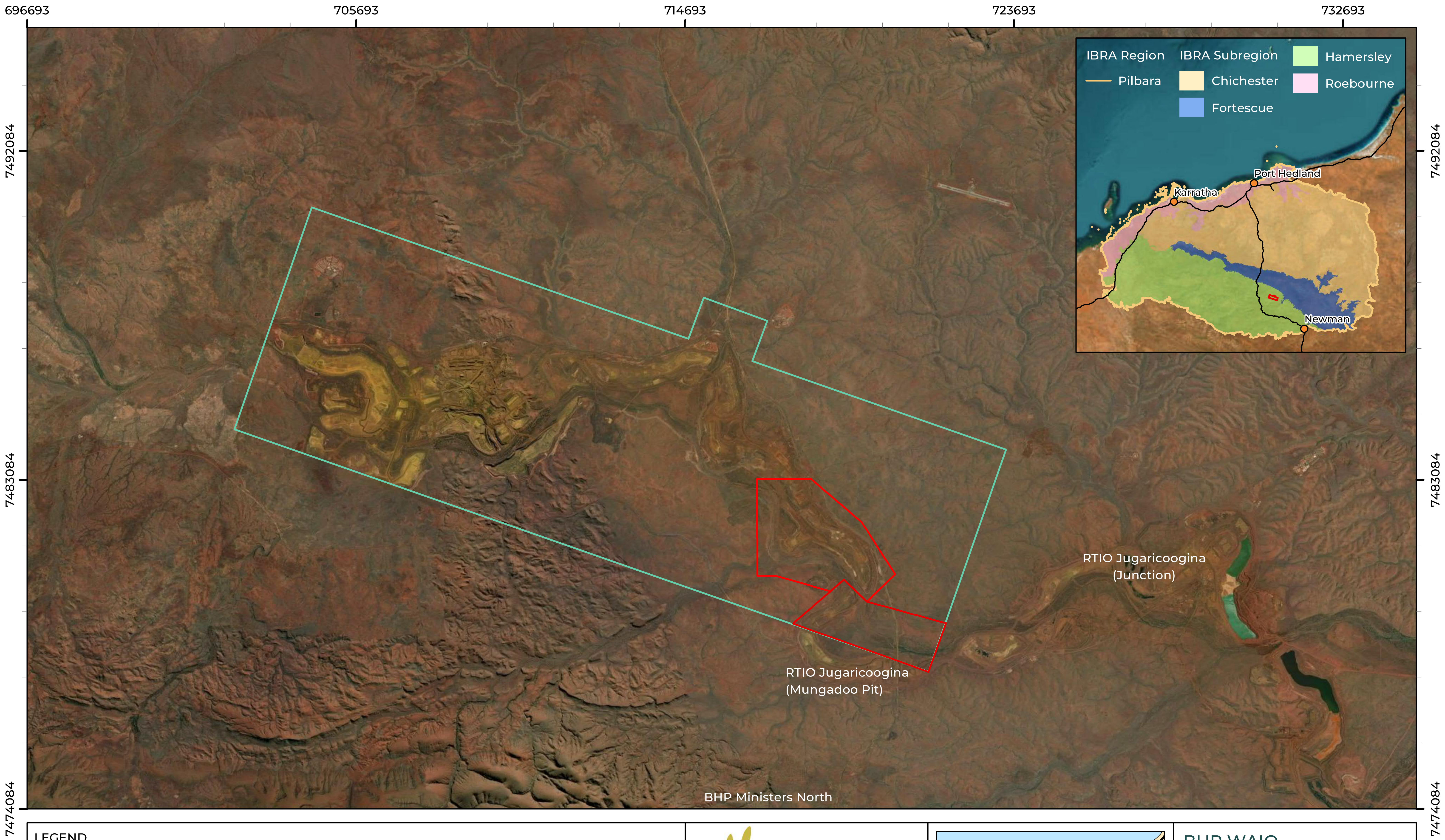
Troglofauna:

- a symphylan, *Hanseniella* sp. indet.
- a centipede, *Cryptops* sp. 'BSCOL091'
- a beetle, *Hesperanillus* sp. 'BCO247'
- two millipedes, Haplodesmidae 'BDI080' and Trigoniulidae 'BDI079'

Stygofauna:

- two harpacticoid copepods, *Elaphoidella* sp. 'BHA342' and *Parastenocaris* 'BHA343'

The aim of the modelling and habitat assessment work was to determine the suitability, extent, and connectivity of subterranean habitats within the Study Area relevant to these target subterranean fauna species. The extent of suitable habitats for these target taxa in relation to the proposed impact areas (i.e. the East 8 proposed pits and proposed groundwater drawdown) has been assessed using available two-dimensional (2D) spatial information and three-dimensional (3D) habitat modelling.



LEGEND

Study Area

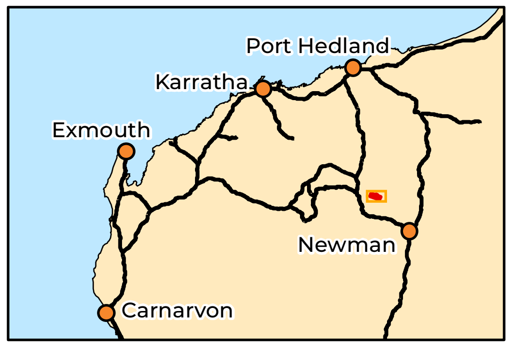
Jugari Lease

Biologic

Scale 1:95,000

0 1 2 3 4 Km

Coordinate System: GDA2020 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA2020 Created 28/10/2024



BHP WAIO

Jugari East 8 Subterranean Fauna Habitat Modelling

Figure 1.1: Study Area and regional context

1.2 Project background

The Jugari mine is situated within mining lease ML270SA and is operated in accordance with the *Iron Ore (Marillana Creek) Agreement Act, 1991*. BHP WAIO are seeking approval for expansion into a new mining area at East 8 (E8), which consists predominately of Channel Iron Deposit (CID). The E8 area is located in the southeast corner of the current Jugari mining lease ML270SA. Mining will occur above and below the current groundwater level and therefore additional groundwater abstraction will be required for mine dewatering at E8.

1.3 Scope and objectives

The habitat assessment and modelling work comprises a desktop assessment based on data and information provided by BHP WAIO (as outlined in section 2.1), and publicly available sources, with no new field data collected.

The assessment of habitat suitability, extent and connectivity for subterranean fauna used available geological information and the 3D habitat model developed by Biologic to determine:

- The most likely geological/ hydrogeological habitat that each target species was collected from, particularly in relation to weathered, fractured, vuggy, or porous lithologies occurring at the known collection locations for each species;
- The modelled or inferred extent of suitable habitat (as described above) throughout the immediate local area, particularly in relation to areas of potential impact – i.e. the proposed East 8 pits and proposed groundwater drawdown;
- The presence and extent of any geological structures, barriers or features that may limit species dispersal (i.e. dykes/ sills, fresh rock, clay, shale, dolerite or other lithologies lacking suitable void spaces); and
- The connectivity of suitable habitat (as described above) in relation to known collection locations for each target species and any areas of habitat beyond potential impact areas (proposed and current/ approved pits and groundwater drawdown).

Habitat suitability for troglofauna relates directly to the occurrence, prevalence, and interconnectedness of subterranean voids, cavities, caves, fractures, and pore spaces above the water table (AWT), formed by weathering in certain types of rock. Rock type alone (as classed by geological formation, member, unit, or subunit) is not an adequate predictor of subterranean fauna habitat suitability. Nevertheless, certain rock types and detrital formations in the Hamersley region, when sufficiently weathered and fractured, are well-known to host networks of suitable void spaces AWT that provide habitat for troglofauna (Bell *et al* 2010, Halse 2018, EPA 2021).

Habitat suitability for stygofauna also relates to the occurrence, prevalence, and interconnectedness of subterranean voids as above, but below the water table (BWT) wherever suitable groundwater occurs.

3D habitat modelling was undertaken AWT and BWT using Leapfrog® Geo 2022.1.1 software (Leapfrog), based on drill-hole logging (i.e. down-hole lithological data), geophysics data, structural information, weathering profiles, and hydrogeological data provided by BHP WAIO. 3D modelling in Leapfrog provides a rich visual platform for creating realistic models and detailed conceptualisations of the extent and connectivity of subterranean fauna habitats.

1.4 Compliance

This assessment was carried out in acknowledgement of the following guidelines and recommendations developed by the relevant state and federal regulatory bodies:

- EPA (2023) Statement of Environmental Principles, Factors, Objectives and Aims of EIA;
- EPA (2021) Technical Guidance – Subterranean Fauna Surveys for Environmental Impact Assessment; and
- EPA (2016) Environmental Factor Guideline – Subterranean Fauna.

At the time of writing there was no formal regulatory guideline for subterranean fauna habitat modelling in Western Australia. Biologic has developed a 3D modelling approach that aims to provide a rigorous and realistic characterisation of the extent, connectivity, and suitability of subterranean habitats. Biologic's 3D modelling approach has been used in support of Environmental Impact Assessment (EIA) for projects such as Rio Tinto's Greater Paraburdoo Iron Ore Project (Biologic 2021a), Atlas Iron's McPhee Creek Iron Ore Project (Biologic 2021b), and BHP WAIO's Jimblebar Hub Iron Ore Mining Operations Significant Amendment (Biologic 2023).

2 Methods

2.1 Spatial information and data

2.1.1 Geology, topography, drainage

The habitat assessment used publicly available spatial data comprising surface geology, geological structures, and regolith (GSWA 1:500K regional regolith data), as well as local 20K and 5K geological data provided by BHP WAIO (refer section 2.3). Two-dimensional (2D) habitat assessment was undertaken based on the attributes of geological units occurring in the Study Area and immediate surrounds.

Local topographic data (2 m interval contours for the Jugari Mining Lease, and 3D meshes from BHP WAIO models) were used to show pre-mining landforms and land surface elevations within and surrounding the Study Area.

Publicly available drainage spatial data was clipped for the Study Area and surrounds to show the occurrence of major and minor drainage lines.

2.1.2 Subterranean fauna data

Environmental approvals for the existing Jugari operations pre-date consideration of subterranean fauna in environmental impact assessment, therefore no baseline/ detailed subterranean fauna surveys to relevant EPA guidelines were undertaken before mining commenced.

Subterranean fauna sampling data and species records from studies undertaken between 2009 and 2022 (Bennelongia in 2009, 2020, and 2022 and Subterranean Ecology in 2010) was provided by BHP WAIO from internal databases. Reconciliation of historic data and taxonomic alignment of species-level Operational Taxonomic Units (OTU's) was beyond the scope of this study. Nevertheless, a separate study was commissioned to align the available genetic information (sourced from third party molecular genetic analysis) to regional sequence records available to Biologic; the results of which are described in Appendix B. Sampling data and troglofauna and stygofauna records were cross referenced in the 3D model to provide validation for potential habitat suitability, and to show the recorded locations of the target species for this assessment.

Although available sampling data and troglofauna and stygofauna occurrence records were used in the modelling as above, the impact assessment focused solely on the seven target subterranean fauna species as identified by Bennelongia (2024) (Table 2.1). Subterranean fauna species already considered not to be at risk from the proposal were not reassessed.

Table 2.1: Target subterranean fauna species.

Species	Drill hole	Current knowledge
Troglofauna		
Hanseniella sp. indet.	YE2061R	Singleton record from a scrape and only identified to genus level. This is the only record of *Hanseniella* at Jugari, so it can be inferred to represent a new species. DNA sequencing of the specimen was unsuccessful.
Hesperanillus `BCO247`	YE2045R	Singleton record from a scrape. DNA sequencing unsuccessful so relying on morphological ID.
Haplodesmidae `BDI080`	YE2020R	Singleton record identified from a trap. DNA sequencing unsuccessful so relying on morphological ID.
Cryptops `BSCOL091`	YE2029R YE2033R	Collected from two drillholes 300 m apart. Sequencing established that the records were the same species and did not match any previously recorded species. Both records were from nets. There was a record of *Cryptops* sp. indet. from W4. Unfortunately, this specimen could not be sequenced. It is possible that this is the same species but unable to currently confirm.
Trigoniulidae `BDI079`	YE2033R	Singleton record identified from a net (bycatch of stygofauna sampling). Genetic sequencing successful and designated as a new species.
Stygofauna		
Elaphoidella `BHA342`	YE2070R HYE1511	Three records collected from two bores in the E8 pit and additional drawdown area. Molecular analysis suggested this is a new species.
Parastenocaris `BHA343`	YE2070R	Singleton record collected from a bore in the E8 Pit. Molecular analysis suggested this is a new species.

2.1.3 Project information

BHP WAIO provided spatial information regarding the proposed pits at Jugari East 8 and current/ approved pits within the Study Area. Spatial data in local grid Jugari Grid YAN94 was transformed to GDA94 MGA zone 50 for use in ArcGIS.

2.2 2D Habitat assessment

Assessment and categorisation of geological mapping is the first step in subterranean fauna habitat assessment (EPA, 2021). Although the information available for 2D habitat assessment can be broad scaled and limited spatially (especially in the third dimension, vertically below surface), it provides a necessary context for more detailed interpretations of habitat suitability. Geological mapping typically forms the initial basis for habitat assessment as it is regionally standardised and widely available beyond the boundaries that limit 3D modelling.

The 2D habitat assessment was based on bedrock and regolith mapping, but also integrated linear structural mapping, geological cross sections, diamond cores and water bore schematics, and subterranean fauna sampling results, where available (refer sections 3 and 4). This information also contributed to the 3D modelling as discussed further below.

Habitat for troglofauna is mainly contingent upon the occurrence sufficient underground void spaces. Subterranean void spaces are related to rock type and the degree of weathering or fracturing within the local geological context. Suitable interstitial voids may also occur within coarse textured detritals (i.e. gravels, pebbles, and scree), and secondarily weathered regolith deposits (e.g. calcrete, pisolitic hardcap, and channel iron deposits - CID). However, assessment of 2D geological spatial information is in most cases limited to rock and regolith types, and their descriptions.

Habitat for stygofauna depends on groundwater within subterranean voids. Geological formations that provide suitable habitat for troglofauna AWT are often found to provide suitable habitat for stygofauna BWT where weathering characteristics and groundwater quality is suitable. However, even when groundwater data (such as water level contours or water quality measurements from bores) is available to cross reference against geological mapping, 2D habitat assessment does not account for changes that may occur with depth from the surface.

2.3 3D Habitat modelling

Assessing and modelling subterranean habitats in 3D facilitates a more realistic representation of suitable habitats within the modelled boundaries, subject to the availability and density of various types of data.

The 3D models developed by Biologic utilised available geological models developed in Maptek Vulcan Software, converted into in Leapfrog® Geo 2022.1.1 (Leapfrog), and combined to form a single modelling area. The final 3D habitat model was a combination of three smaller deposit scale models provided by BHP WAIO (East 3456, East 7, and East 8), and was updated and refined using the following information sources and parameters to specifically investigate the suitability, extent, and connectivity of habitats for subterranean fauna.

2.3.1 Boundaries

Spatial boundaries are required in 3D modelling to determine the limit of extrapolation of geological and hydrogeological trends. Subterranean fauna habitats were modelled using lateral and vertical boundaries that represented the Study Area (external boundary of modelling), the land-surface (topography), the water table (water table levels for different groundwater drawdown scenarios), pit shells (current/ approved and proposed pits), system basement and fault structures, as described in further detail below.

2.3.1.1 Study Area

A boundary box is established for all modelling, to encompass the Study Area. The boundary box for the habitat model extended across the boundaries of the combined models and the water table mesh data provided, between the data points shown in Table 2.2. Note: the BHP WAIO deposit models were provided in local YAN94 grid and all references to the habitat model will display this co-ordinate system.

Table 2.2: Parameters for 3D habitat model in Jugari Grid (YAN94).

Data point	Easting	Northing
North-west	9469.33	89296.64
South-east	23393.61	77263.67

2.3.1.2 Topography

Topographic information provided by BHP WAIO (based on LiDAR data within the deposit models, and 2 m contour data outside the existing model boundaries), formed the vertical boundary of the habitat modelling (i.e. separating the geology from the air). The proposed and approved pit shells were extracted from the topography as additional vertical boundaries for impact evaluation, as per section 2.3.1.4.

2.3.1.3 Water table

Water level data provided by BHP WAIO hydrogeologists was used to indicate water tables for the Study Area and surrounds, under various scenarios. The three scenarios of water levels provided corresponded to:

1. Water levels with no mining (approximation of pre-impact water levels across the Jugari mine lease);
2. Water levels with mining, excluding East 8 Pits (approximation of water levels under 'current' impact scenario);
3. Water levels with mining, including proposed East 8 Pits (approximation of water levels under 'maximum' impact scenario).

Owing to different hydrogeological characteristics measured on-site, water levels within the basement rocks (such as weathered Weeli Wolli) were provided separately for each scenario, compared to water levels within the CID/ upper aquifer. In total, this resulted in six groundwater level scenarios being modelled, with pre-impact, current and maximum impact scenarios for the basement aquifer and for the CID aquifer.

The water levels were combined in Leapfrog Geo to provide a single mesh that represented both basement and CID aquifers within their respective spatial extents. In areas where the provided CID aquifer mesh extended beyond the geological boundary of the CID, the water levels provided for the basement aquifer replaced it, and visa-versa in areas where the basement aquifer extended through CID geologies as modelled.

2.3.1.4 Pit shells

Proposed pit shells were provided by BHP WAIO for Jugari East 8. The pit meshes were clipped, merged, and then extracted from the topography to show the remaining habitat post-disturbance.

Current/ approved pit shells were provided by BHP WAIO as a revised topography for the 'As mined' surface. The 'As mined' surface represents the maximum extent of mining within each existing pit, prior to any backfilling that may occur pre-development of the E8 pit.

2.3.1.5 Structures

Regional geological mapping identified one regional dyke occurring in the Study Area (Figure 3.2). This regional dyke extends along the length of Jugaricoogina Creek to the south of the Jugari mine lease, from the WSW to ENE. The dyke crosscuts the East 3,4,5,6 section of the Study Area and continues throughout the Jugari mine lease and the wider region beyond. Geological and hydrogeological investigations do not interpret this dyke to be a significant barrier for groundwater flows and it does not appear to correspond to any significant change in the geology or water levels modelled on either side of the dyke.

2.3.2 Geology modelling

A combined Leapfrog geological model was created by merging exported mesh layers from Vulcan models provided by BHP WAIO at East 3456, East 7, and East 8. Interpretations of drill hole logging, diamond core photos, hydrological bore schematics and downhole geophysical data were used to categorize the geological members and sub-units for potential habitat suitability. Pre-impact, Current and Maximum impact groundwater contours were imported as per section 2.3.1.3 above, and used to divide AWT from BWT habitat zones, as per section 2.3.2.5.

2.3.2.1 Merging and extrapolation

The scope of habitat modelling for the current assessment was limited to the Bio 1 and Bio 2 areas at the time of writing. To better understand the continuity of potential habitat across the Study Area, the bedrock stratigraphic geology from E7 and E8 was merged into a single

3D model area (Bio 1). The E7 model was able to be combined with the East 3,4,5,6 model (Bio 2) (Figure 1.1) at the section where their boundaries meet, but the boundaries of the E7 and E8 models did not meet completely, and some extrapolation was required to combine them. The bedrock stratigraphic model provided the geological setting to enable extrapolation.

Densely spaced drilling over each deposit was used to extrapolate lithologies between the E7 and E8 model areas. Although more sparsely drilled, several drill holes were present within the extrapolation area, providing reasonable confidence in the continuation of lithologies as modelled. The interpolation and extrapolation abilities of Leapfrog Geo 'infilled' the remaining area. The modelling throughout the extrapolation area is based on the best available information, but remains conceptual until confirmed by further drilling. Using landform information, palaeochannel mapping, and geological mapping, finer scaled extrapolation boundaries were established for the CID units to prevent the extension of these units into the surrounding geological context.

2.3.2.2 Drilling log data

Each depth interval for each drill hole was logged for lithology and mineralisation characteristics (amongst other metrics) by BHP WAIO geologists. The resulting drill logging data is the foundation of all geological modelling and provides the basis for interpretations of lithology, trends and structures. The merged 3D model incorporates drill logging data from 3,685 drill holes and over 149,054 metres of rock modelled throughout the Study Area.

Collated drill log data was reviewed for suitable subterranean fauna habitat attributes, including the presence and abundance of subterranean void spaces, fracturing, and geophysical attributes such as Gamma API units (American Petroleum Institute units).

2.3.2.3 Diamond core images

Diamond drill core images were visually examined to confirm physical habitat suitability at key depth intervals within the rock. Thirty-two drill holes were selected, comprising fifteen from East 3456, four from East 7, and twelve from East 8, chosen to provide spatial coverage of the Study Area and key stratigraphic intercepts. The visual assessment of habitat suitability was based on the following rating framework:

- High potential habitat – observed cavity; obvious/ well-defined/ interconnected voids, vugs and microcavities; open fractures (penetrated by water); obvious signs of secondary/ hydrated weathering.
- Medium potential habitat – partially weathered rock, calcareous detritals, or pisolite without well-developed cavities; smaller, less obvious or partly open fractures; singular or poorly developed voids/ vugs; gravels and gravelly detritals; cavity fill; fault contacts.

- Low potential habitat – fresh rock lacking cavities, fractures, vugs, evidence of weathering; rock freshly fractured during drilling (no signs of weathering/ water penetration); fresh clay, silt, and fine textured detritals; fresh or crumbly shale, black shale, dolerite.
- Uncertain – rock intervals that cannot be confidently placed in the above categories.

Results per interval were catalogued and uploaded into the 3D models for display using colour coding of the above categories.

2.3.2.4 Geophysics

Geophysical information can often provide a specific insight into subsurface conditions. Available downhole Gamma API logs were reviewed in conjunction with the diamond core photo logging to provide a basis for interpreting weathering status within the Weeli Wolli Formation and Alluvial deposits. Gamma API data wasn't used to interpret CID units and clays units, these were visually confirmed to be either high (CID) or low (clay units) for subterranean habitat fauna suitability.

Downhole Gamma data was received for the whole Jugari region and was subsequently reduced to 3685 holes within the Study Area, of which only 290 holes were selected for subterranean fauna habitat analysis based on spatial occurrence and intercepts of representative lithologies.

Gamma API data was also used to identify subterranean habitat fauna suitability within the Basal clay (BK) and Basal conglomerate (BG) lithologies. Photo analysis showed the BK as predominantly a clay unit with some well fractured areas resulting in medium habitat classification, contracting the assumed low habitat classification. The gamma API helped identify parts of the BK unit which could host fractures and cavities that could be suitable for subterranean fauna.

The BG unit was visually assed to contain areas of vugs, fractures as well as clay and cementation. The gamma API helped identify the low, medium and high occurrence of subterranean voids that could provide suitable habitat within the BK unit.

Generally, the range of gamma signatures observed are unique to single lithological units; i.e. there is no universally applicable set of criteria to interpret gamma signatures between lithologies. In this study, a gamma API range was identified from data analysis and comparison with drill cores that was reasonably indicative of the occurrence of subterranean voids in alluvium (A), Weeli Wolli (HJ) and BK/ BG units for both Bio 1 & Bio 2 model areas. Two separate ranges for each project area were chosen to delineate the 'higher' gamma API readings which corresponded to lower porosity and reduced cavities. The gamma API units were then given a range that ranked the data into low, medium and high classifications for porosity and cavities, which thus enabled a basis for interpretations of the likely characteristics of A, BK, BG and HJ units where drill core data was sparse. These interpretations were applied to the habitat model in data poor areas (e.g. model extrapolation and areas peripheral to CID), with acknowledgement that this method is conceptual only.

2.3.2.5 Combined Models

After the merged stratigraphic model was created, Leapfrog's 'combine models' function was used to identify areas of stratigraphy/ habitat occurring inside and outside of boundaries relevant to the impact assessment, namely the layers derived from the groundwater contours and the pit shells (refer section 2.3.1). Up to four different modelling sets at a time can be combined in this way, and the resulting volumes of rock are modelled independently. For example, combining the stratigraphic layers with proposed pit shells and the pre-impact groundwater level for CID allows modelling of each stratigraphic layer inside and outside of the East 8 pit, as well as AWT vs BWT. Combining this model with a third layer representing the CID water level at maximum impact then allows separate calculation of the volume of each stratigraphic layer remaining BWT after maximum groundwater drawdown, and the predicted change in volume after drawdown and pit impacts have occurred, within each layer of rock.

Table 2.3: Combined model outputs.

Combined Modelling	Habitat model	Existing Pits	E8 Pits	Water scenarios	Scenarios/ components	Input description	Output description
Habitat model		✓	✓	✓	Bio 1, Bio 2 merged	Stratigraphic units, potential habitat zones	Habitat extent, impact assessment AWT and BWT
Existing Pits	✓		✓	✓	As mined surface, no pre-mining available	As-mined Topography with all existing pits, no backfill	Impact assessment AWT
E8 Pits	✓	✓		✓	Current surface, proposed E8 surface	Proposed E8 pit shells	Impact assessment AWT/ BWT
Water scenarios	✓	✓	✓		1. Pre-impact 2. Current WL 3. Proposed WL	Combined CID and basement aquifer WL	Delineation AWT vs BWT. Impact assessment BWT

2.4 Constraints and limitations

2.4.1 Inherent constraints

The modelling and habitat assessment is limited to the extent and density of information available at the time of assessment (from BHP WAIO and public sources as described in section 2).

The spatial layout of drill holes is the limit of granularity/ density of data within the model. It is not possible to precisely model the extent and connectivity of individual subterranean voids, caves, or fractures that may provide habitat. Localised variability is likely to occur within every modelled stratigraphic unit, which could affect the likelihood of suitable habitat occurring, or being connected, at scales beyond the ability to model.

Nevertheless, the use of down hole data (e.g. diamond cores, gamma) to evaluate porosity provides a representative basis for interpretation of the likely presence and abundance of cavities, voids, fractures, and weathered/ porous rock zones within and between stratigraphic units.

The 3D models primarily focus on the occurrence and frequency of subterranean voids within rock, because without this fundamental factor (i.e. where rocks is fresh/ unaltered, or where compact fine sediments and clays occur), there is no physical space available for subterranean fauna to inhabit.

There are other habitat quality factors that may influence the relative suitability of some areas of habitat over others that are beyond the scope of the current modelling. Habitat quality data (such as humidity or air quality monitoring from subterranean voids, or comprehensive water quality data of the groundwater) is not routinely collected for during sampling, and there is no such data available for the current assessment.

The modelling provides the best available representation of the extent and connectivity of the most likely suitable habitat strata for subterranean fauna throughout the modelling boundary; however, it is not a precise predictor of subterranean fauna occurrence or distribution. Other potentially important variables beyond the scope of modelling that could affect this may include (but are not limited to):

- infiltration rates and variability in inputs (water nutrients and oxygen) from the surface;
- groundwater quality (i.e. salinity, oxygen);
- geochemical characteristics of the rock (e.g. pyritic shales, acid forming material);
- biological interactions with surface such as roots of vegetation providing nutrient sources and flow pathways;

- ecological influences on species occurrence, such as competition for resources and habitat niches, trophic interactions,
- behavioural and physiological dispersal limitations; and
- complexities of the evolutionary history of the assemblages (e.g. differential colonisation of subterranean habitats by various taxa over time, influences on present day species turnover patterns).

The incorporation of subterranean fauna sampling data and specimen records into the modelling is important to provide biological context for the habitat modelling results; however, subterranean fauna surveys have their own well-documented limitations (Halse & Pearson, 2014), and results of historical surveys are often subject to the limitations of knowledge available at the time of survey. Prior to the current technical guidelines released in 2021, subterranean fauna surveys conducted for EIA in WA were not required to undertake more than two phases of sampling, and sampling was often limited to fewer sites. The use of DNA to identify species has become more prevalent in the last decade, which has begun to resolve taxonomic impediments and reveal more reliable species distributions regionally, but this has reduced the utility of much of the legacy survey data at the morpho-species level.

In the local context, there are major gaps in the baseline knowledge of subterranean fauna and extent of habitats prior to mining and groundwater drawdown, as the environmental approvals for the existing operations, and the adjacent Jugaricoogina operations (RTIO) were already in place before subterranean fauna were routinely considered as a factor in EIA.

2.4.2 Limitations

The scope of this assessment was to focus on the local E8 area. No previous mining has taken place within this area, and the natural extent of CID remains intact within the Jugari mine lease. Beyond the East 8 area, the Marillana Formation CID has been subject to extensive mining throughout the Jugari mining lease to the west and throughout the adjacent Jugaricoogina mining area to the east. As per section 2.1.2, the historic mining pre-dates consideration of subterranean fauna values as a factor in EIA; therefore, no detailed or baseline survey information was available prior to mining or dewatering impacts.

Extrapolation of the habitat modelling in the area between E7 and E8 as per section 2.3.2.1 was based on best available data but remains conceptual in areas where drilling has not been undertaken to date.

The groundwater impact information provided by BHP WAIO is accurate to groundwater data measured within the Jugari mining lease and BHP WAIO regional bores. No groundwater impact scenario related to closure or potential evaporative losses was modelled.

No geological information, 3D pit data, or groundwater impact data is available from Rio Tinto's Jugaricoogina mine immediately adjacent the East 8 area. Assessment of cumulative or combined impacts to potential AWT and BWT habitats beyond the East 8 area and/or beyond the Jugari mine lease was outside of the scope of this assessment.

3 2D habitat assessment

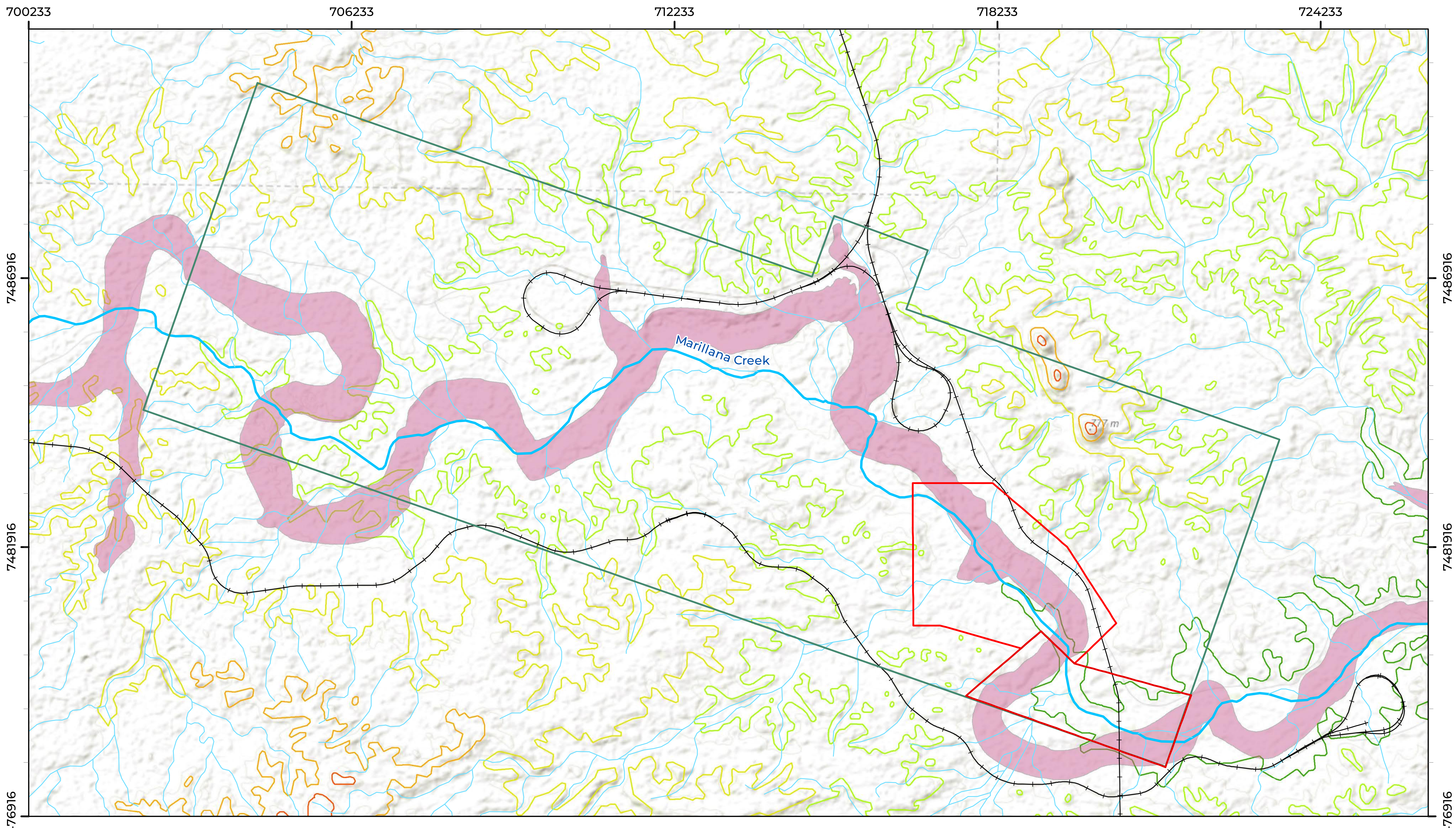
3.1 Geological context

In the Pilbara region, many different geologies (and detrital formations) have been found to provide suitable voids, cavities, fractures, and pore spaces for subterranean fauna; including (but not limited to):

- Weathered and fractured BIF (e.g. Brockman and Marra Mamba Iron Formations);
- Weathered hardcap and duricrust (typically occurring atop BIF);
- Weathered and karstic limestone, calcrete, and dolomite (e.g. Cape Range limestone, Wittenoom Dolomite);
- Weathered and vuggy pisolitic channel iron deposits (i.e. CID, Robe Pisolite); and
- Unconsolidated and partly consolidated detritals (colluvium, alluvium, particularly coarse sediment textures such as gravel, talus, scree).

The geological setting of the Study Area and surrounds is dominated by Hamersley Group lithologies, featuring the Weeli Wolli Iron Formation, Marillana Formation CID and superficial detritals (Figure 3.1, Figure 3.2, Figure 3.3 and Figure 3.4). The Marillana Formation is confined to the meandering central palaeochannel of Marillana Creek (Figure 3.1), while the alluvial and colluvial detritals follow the present-day drainage line and floodplains (Figure 3.2 and Figure 3.3). At the basement of the Marillana Formation is the Weeli Wolli Formation comprised of weathered shaly BIF and dolerite.

The potential for subterranean fauna habitat within the CID and alluvial/ colluvial detritals has been well established by subterranean fauna sampling locally at Jugari/ Jugaricoogina, and similar examples exist regionally at the Robe Valley (Rio Tinto) and Solomon (Fortescue). In contrast, the Weeli Wolli Iron Formation is typically unmineralised, variable in permeability and has received less sampling attention for subterranean fauna than other economically important lithologies such as the Brockman and Marra Mamba Iron Formations. The Weeli Wolli Iron Formation has considerably less regional precedent as a suitable habitat for subterranean fauna, but this does not exclude the possibility that it may provide suitable habitat in some geological settings.



LEGEND

Study Area

Jugari Lease

Rail

Palaeochannel supporting the CID (Approximate)

Surface Drainage

Major

Minor

Elevation (m AHD)

500 - 550

550 - 600

600 - 650

650 - 700

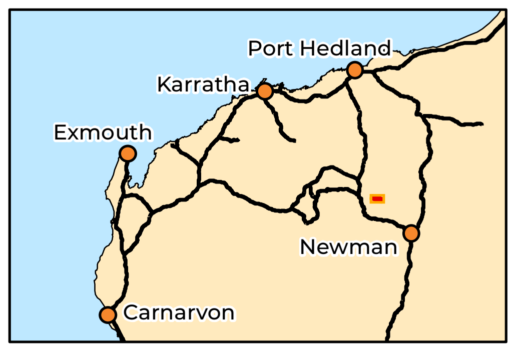
700 - 750

Biologic

Scale 1:65,000

0 0.6 1.2 1.8 2.4 Km

Coordinate System: GDA2020 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA2020 Created 22/10/2024



BHP WAIO

Jugari East 8 Subterranean Fauna Habitat Modelling

Figure 3.1: Palaeochannel, topography, and drainage

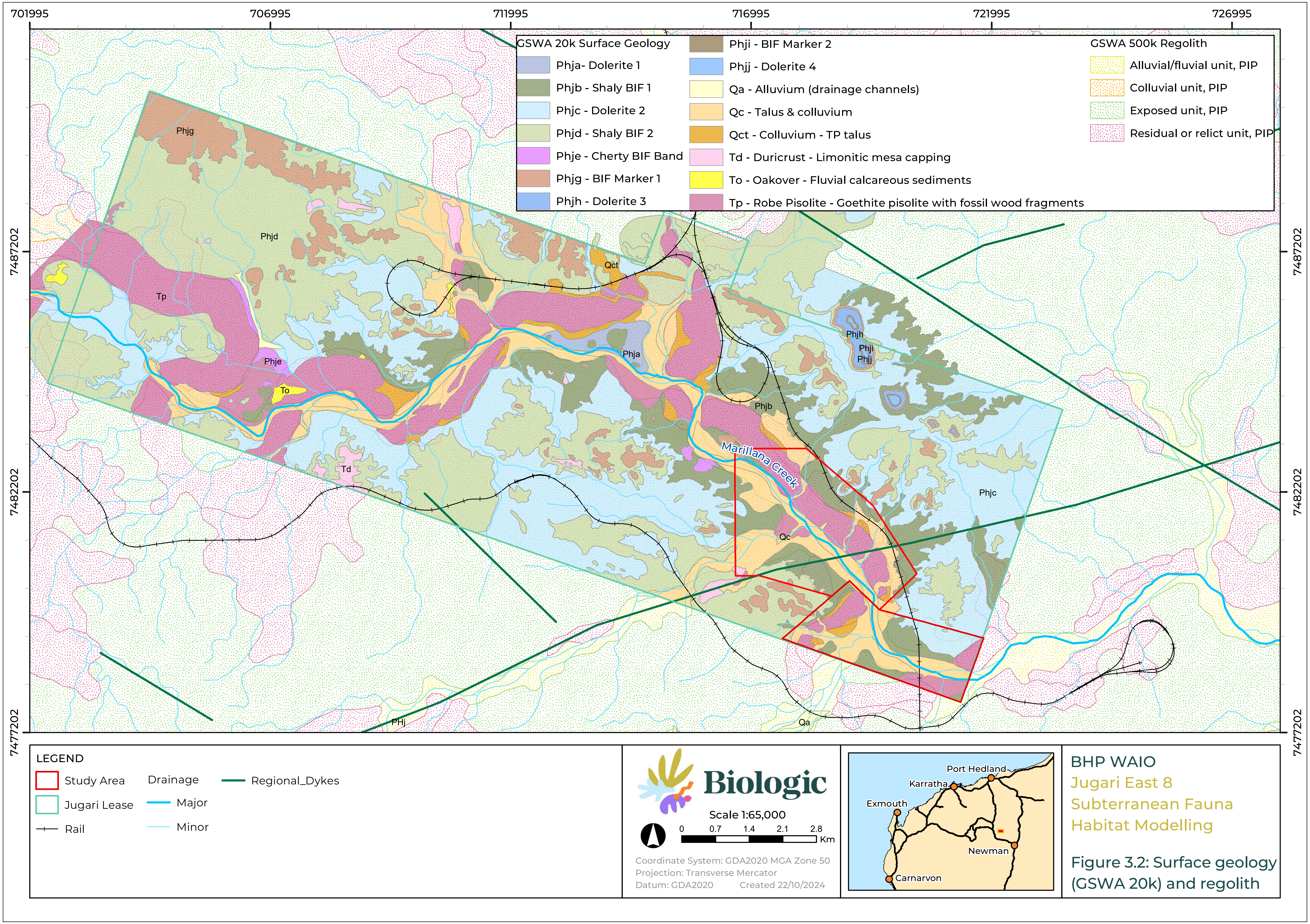
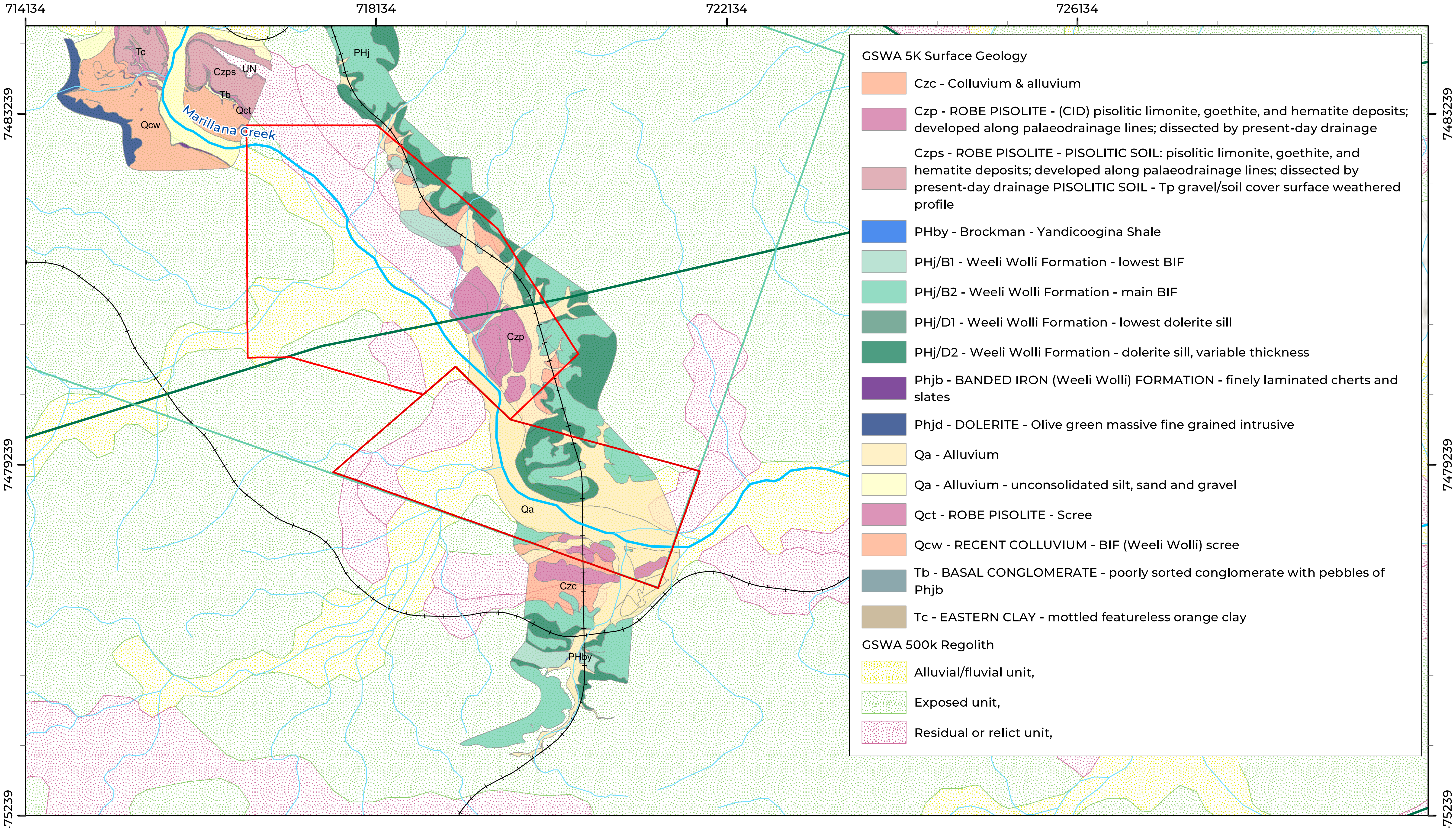


Figure 3.2: Surface geology (GSWA 20k) and regolith



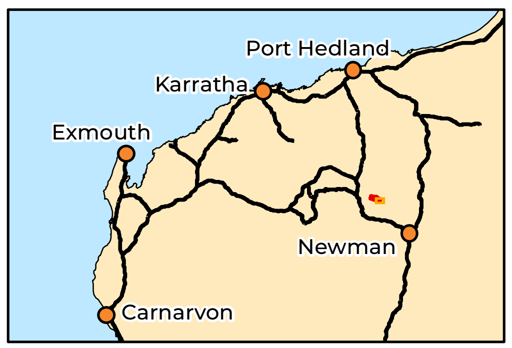
LEGEND
Study Area
Jugari Lease
Rail
Drainage
Major
Minor
Regional_Dykes

Biologic

Scale 1:40,000

0 0.5 1 1.5 Km

Coordinate System: GDA2020 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA2020 Created 22/10/2024



BHP WAIO
Jugari East 8
Subterranean Fauna
Habitat Modelling

Figure 3.3: Surface geology (GSWA 5k)

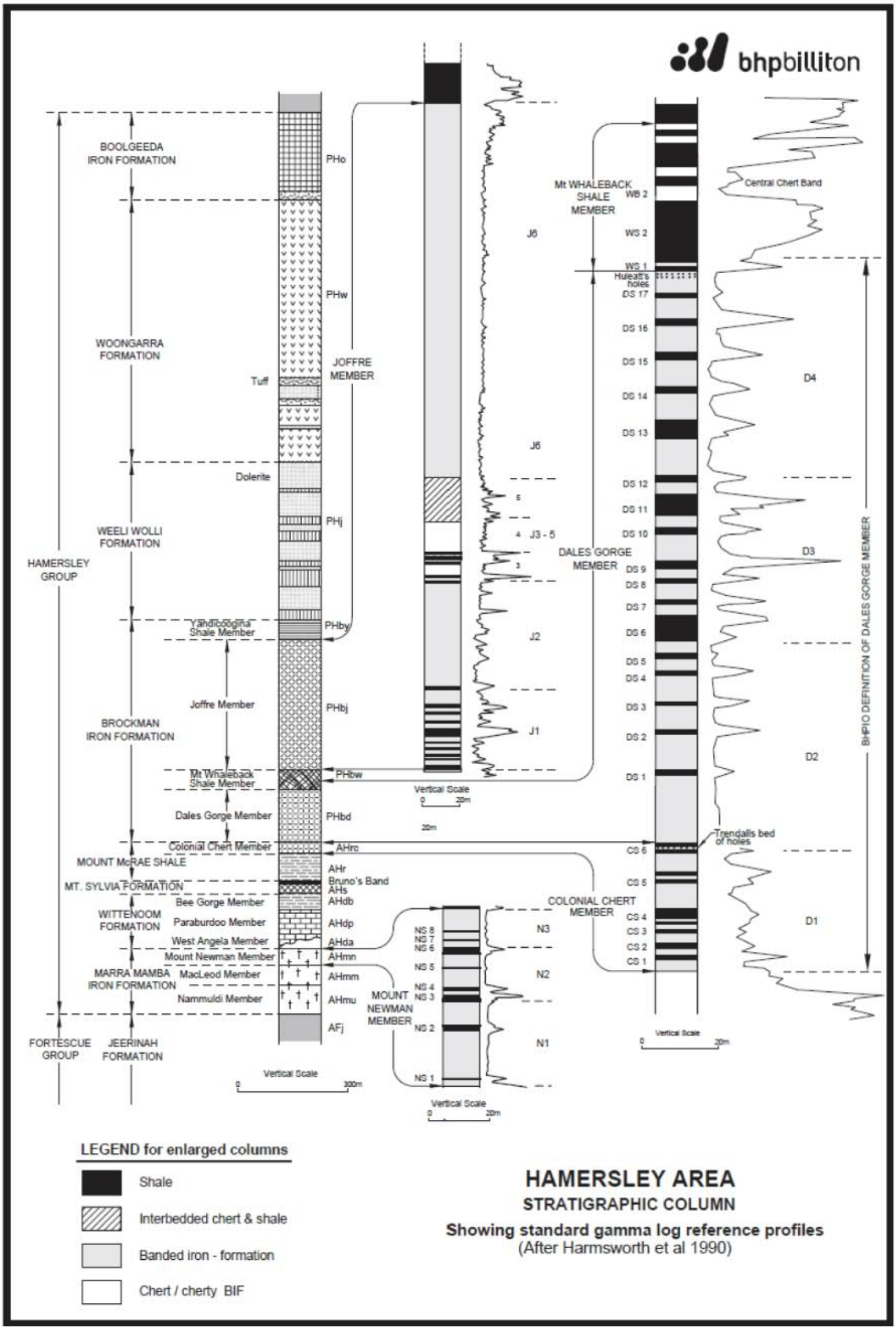


Figure 3.4. Hamersley Group stratigraphic profile. Image provided by BHP WAIO (Perring & Hronsky, 2019).

Surface geology information within the Study Area and immediate surrounds was available at two different scales. GSWA 1:20,000 mapping (Figure 3.2) provided information on both bedrock and surface geology across the whole Jugari Lease and was primarily used in the assessment of habitat extent and suitability for subterranean fauna (Table 3.1). GSWA 1:5,000 mapping, as shown in Figure 3.3, provided information on surface detritals at a more localised scale within the Study Area and was used to complement the more large-scale habitat patterns where needed.

3.1.1 Bedrock geology

Based on the surface geology mapping (Figure 3.2 and Figure 3.3) the bedrock geology within the Study Area comprises the Weeli Wolli Formation (Fm) (Table 3.1). The Weeli Wolli underlies the Marillana Formation CID and ranges between 180 and 600 m in thickness. It is comprised of alternating sequences of shale, tuffaceous sedimentary rocks, basalt and dolerite (Table 3.1)(Barley *et al.*, 1997). This formation is not well known regionally as a potential habitat for subterranean fauna, but this may be influenced by a lack of thorough sampling. In some areas of the region, outcropping Weeli Wolli BIF has been observed to be jaspilitic and weathered and can even be enriched to high grade ore (e.g. at Paraburdoo) (Perring & Hronsky, 2019). Where fresh/ unweathered or in units featuring shale and dolerite, the Weeli Wolli is likely to be relatively impermeable, and probably low suitability for subterranean fauna.

3.1.2 Detritals and CID

Based on the known regional patterns from extensive sampling, CID and detritals are expected to form highly suitable subterranean fauna habitats within the Study Area (Table 3.1). Secondary weathering and fracturing of CID provide frequent and well-developed cavities, vugs, and pore spaces. The CID is confined to the central palaeochannel of Marillana Creek where it forms a series of low mesas (Perring & Hronsky, 2019). Beyond the Study Area to the west, the CID is overlain by calcrete of the Oakover Formation, which is also likely to be highly weathered and provide wider suitable habitats in the surrounding local area.

Quaternary detrital deposits associated with the present-day drainage lines and floodplains of Marillana Creek overlie the CID and infill the paleochannel beside the mesas (Figure 3.2, Figure 3.3). These deposits are likely to provide further suitable habitats for subterranean habitat where sufficient pore spaces occur between variably textured material.

Table 3.1: Subterranean fauna habitat potential of local regolith and bedrock geological units.

Stratigraphic unit	Map Code/s	Description	Habitat potential	Subterranean fauna habitat suitability assessment
DETRITALS & CID				
Quaternary detritals	Qa	Alluvium in drainage channels	Likely	Occurs in Study Area as detrital cover associated with the palaeochannel and drainage lines. May provide some subterranean fauna habitat, but habitat suitability is locally variable based on texture.
	Qc and Qct	Colluvial talus derived from different rock types	Possible	Occurs along the edge of the palaeochannel. May represent potential habitat in pore spaces between gravels/pebbles.
Tertiary detritals	Td	Duricrust, Limonitic mesa capping	Possible	Three small patches occur in the Study Area. Forms a hardcap on top of several mesas. Suitable void spaces may occur if sufficiently weathered, fractured, vuggy.
	To	Oakover - Fluvial calcareous sediments	Highly Likely	Several small patches of this calcrete formation occur along the palaeochannel. Likely to provide highly suitable habitat for subterranean fauna due to frequent occurrence of well-developed void spaces.
	Tp	Robe Pisolite - Goethite pisolite with fossil wood fragments	Highly Likely	Vast deposits of fluvial goethite–hematite channel iron deposits (CID) (also known as Robe Pisolite) that are confined to the meandering central palaeochannel of Marillana Creek. Void spaces expected to occur frequently throughout the CID (e.g. secondary weathering, vugs, fractures, porosity). Typically forms highly suitable subterranean fauna habitat.
BEDROCK				
Weeli Wolli Formation – Unit 1	Phja	Dolerite 1	Unlikely	Belongs to Unit 1 of the Weeli Wolli Formation, a dolerite dominant sequence which intrudes into a "weak" shaly BIF sequence. Phja represents a medium to coarse dolerite sill and is unlikely to represent suitable subterranean fauna habitat (assumed insufficient void spaces).
	Phjb	Shaly BIF 1	Possible	Belongs to Unit 1 of the Weeli Wolli Formation, a dolerite dominant sequence which intrudes into a "weak" shaly BIF sequence. Phjb represents a shaly, flaggy, more easily eroded BIF sequence which may represent some subterranean fauna habitat if sufficiently weathered/fractured.

Stratigraphic unit	Map Code/s	Description	Habitat potential	Subterranean fauna habitat suitability assessment
	Phjc	Dolerite 2	Unlikely	Belongs to Unit 1 of the Weeli Wolli Formation, a dolerite dominant sequence which intrudes into a “weak” shaly BIF sequence. Phjc represents a medium to coarse dolerite sill and is unlikely to represent suitable subterranean fauna habitat (assumed insufficient void spaces).
Weeli Wolli Formation – Unit 2	Phjd	Shaly BIF 2	Possible	Belongs to Unit 2 of the Weeli Wolli Formation which consists of several BIF sequences. Phjd represents a shaly, flaggy BIF sequence which may represent some subterranean fauna habitat if sufficiently weathered/fractured.
	Phje	Cherty BIF Band	Possible	Belongs to Unit 2 of the Weeli Wolli Formation which consists of several BIF sequences. Phje represents a cherty BIF sequence which is commonly silicified. May represent some subterranean fauna habitat if sufficiently weathered/fractured.
	Phjg	BIF Marker 1	Possible	Belongs to Unit 2 of the Weeli Wolli Formation which consists of several BIF sequences. Phjg represents a resistate BIF sequence. May represent some subterranean fauna habitat if sufficiently weathered/fractured.
Weeli Wolli Formation – Unit 3	Phjh	Dolerite 3	Unlikely	Belongs to Unit 3 of the Weeli Wolli Formation, a dolerite dominant sequence. Phjh represents a medium to coarse dolerite sill and is unlikely to represent suitable subterranean fauna habitat (assumed insufficient void spaces).
	Phji	BIF Marker 2	Possible	Belongs to Unit 3 of the Weeli Wolli Formation, a dolerite dominant sequence. Phji represents the second BIF Marker, a resistate BIF sequence. May represent some subterranean fauna habitat if sufficiently weathered/fractured.
	Phjj	Dolerite 4	Unlikely	Belongs to Unit 3 of the Weeli Wolli Formation, a dolerite dominant sequence. Phjj represents a medium to coarse dolerite sill and is unlikely to represent suitable subterranean fauna habitat (assumed insufficient void spaces).

3.2 Hydrogeology

The hydrogeology of the Study Area is dominated by the Marillana Creek palaeochannel which hosts extensive fractured/weathered rock aquifers within the Barimunya Member (CID) of the Marillana Formation (Figure 3.5). The CID aquifers are comprised of an upper CID unit (UCID) which has a high hydraulic conductivity, and a Lower CID unit (LCID) which is assumed to have a comparatively lower hydraulic conductivity (BHP, 2023; Figure 3.5). Nevertheless, based on relatively high storage and transmissivity, both UCID and LCID are likely to provide habitat for stygofauna. The UCID increases in thickness from west to east of the Jugari Lease (downstream) and is approximately 50 to 70 m thick at the location of the proposed pits at East 8 (BHP, 2023). The two CID units are occasionally separated by a thin clay layer (OK- Ochreous Clay unit) while other local clay pods and lenses also occur within the CID sequence. It is uncertain what effect these clay layers may have on localised fauna distributions, but the overall interconnectivity of the local groundwater system is high, with no known barriers to groundwater flow or changes in groundwater levels indicative of compartmentalisation (Figure 3.5).

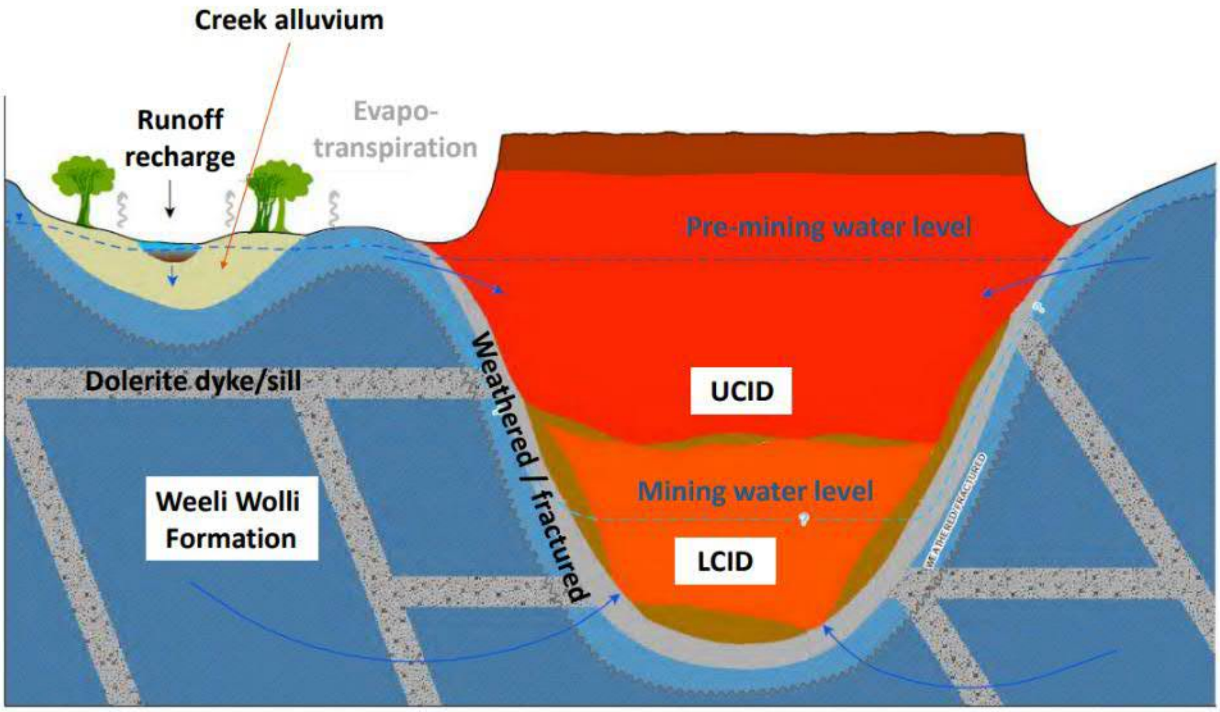


Figure 3.5. Jugari east conceptual hydrogeological cross-section (provided by BHP WAIO)

An indurated basal conglomerate (Munjina Member, BG) is located underneath the CID at the base of the palaeochannel (BHP, 2023; Figure 3.5). This unit seems to occur throughout the palaeochannel length and along the palaeochannel sides (BHP, 2023). Basal clays (BK) also occur sporadically along the base of the palaeochannel (Figure 3.5).

The Weeli Wolli Formation surrounds the CID and has variable hydraulic characteristics. Immediately beneath and adjacent to drainage lines and CID, the Weeli Wolli Formation has shown elevated hydraulic conductivity due to weathering (BHP, 2023; Figure 3.5). However, beyond this zone, transmissivity ranges from very low to moderate, with low storage (BHP, 2023). Some subterranean fauna habitat may be possible within the Weeli Wolli Formation in weathered areas, while deeper and fresher units are unlikely to provide habitat for subterranean fauna.

Although Marillana Creek and other drainage lines in the Study Area are ephemeral, superficial aquifers (including hyporheic aquifers) within the Study Area used to be hosted in detrital alluvium and other Quaternary detritals associated with Marillana Creek and other drainage channels. Marillana Creek follows the same valley in which the CID palaeochannel developed and has an ephemeral flow, flowing to the east after heavy rainfall events in summer. The thickness of the alluvium cover increases from west to east in the Jugari Lease, approaching 20 m thick on average in the East 7/8 area (BHP, 2023). However, following dewatering throughout the wider local area, the detritals now occur mostly above the water table, and may only become temporarily saturated following flood events (BHP, 2023).

Hydraulic data suggests that there are no major flow barriers perpendicular to the palaeochannel, indicating that the potential groundwater habitats for stygofauna throughout the Study Area and beyond are well-connected, and that there is no compartmentalisation affecting groundwater flows.

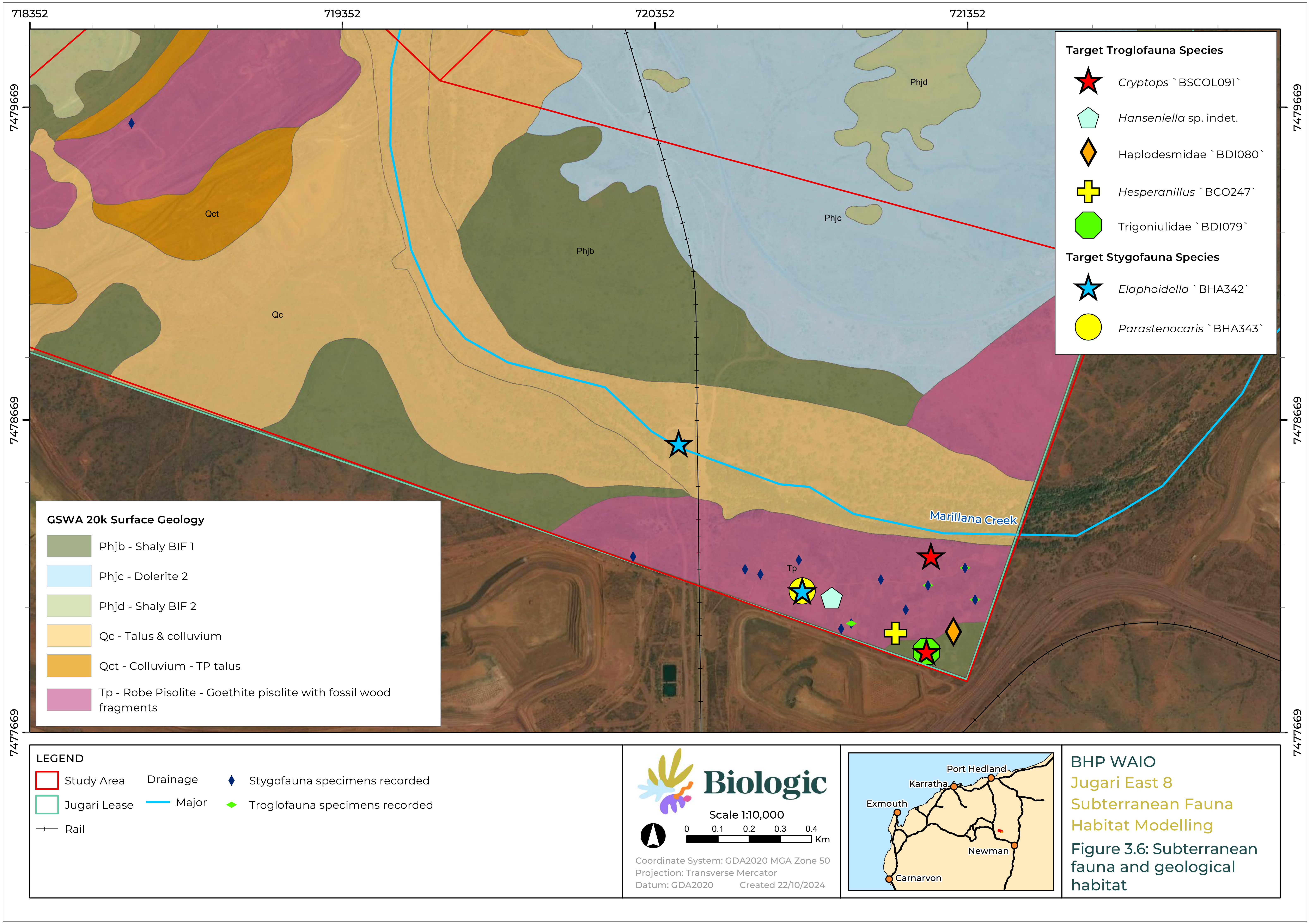


Figure 3.6: Subterranean fauna and geological habitat

4 3D modelling habitat assessment

4.1 Stratigraphic modelling

Habitat assessment was conducted across two 3D model areas, Bio 1 and Bio 2 (Figure 4.1). The Bio 1 model covers the area surrounding East 7 and East 8, while the Bio 2 model covers the area surrounding the historic East 3,4,5,6 pits.

Figure 4.1 and Figure 4.2 provide a plan and oblique view of the stratigraphic model, showing the 3D extent of lithologies within the model areas, while Figure 4.3 provides an example 2D cross-section through the stratigraphy at East 8. Table 4.1 below describes each stratigraphic unit and provides a key to codes used in the figure legends.

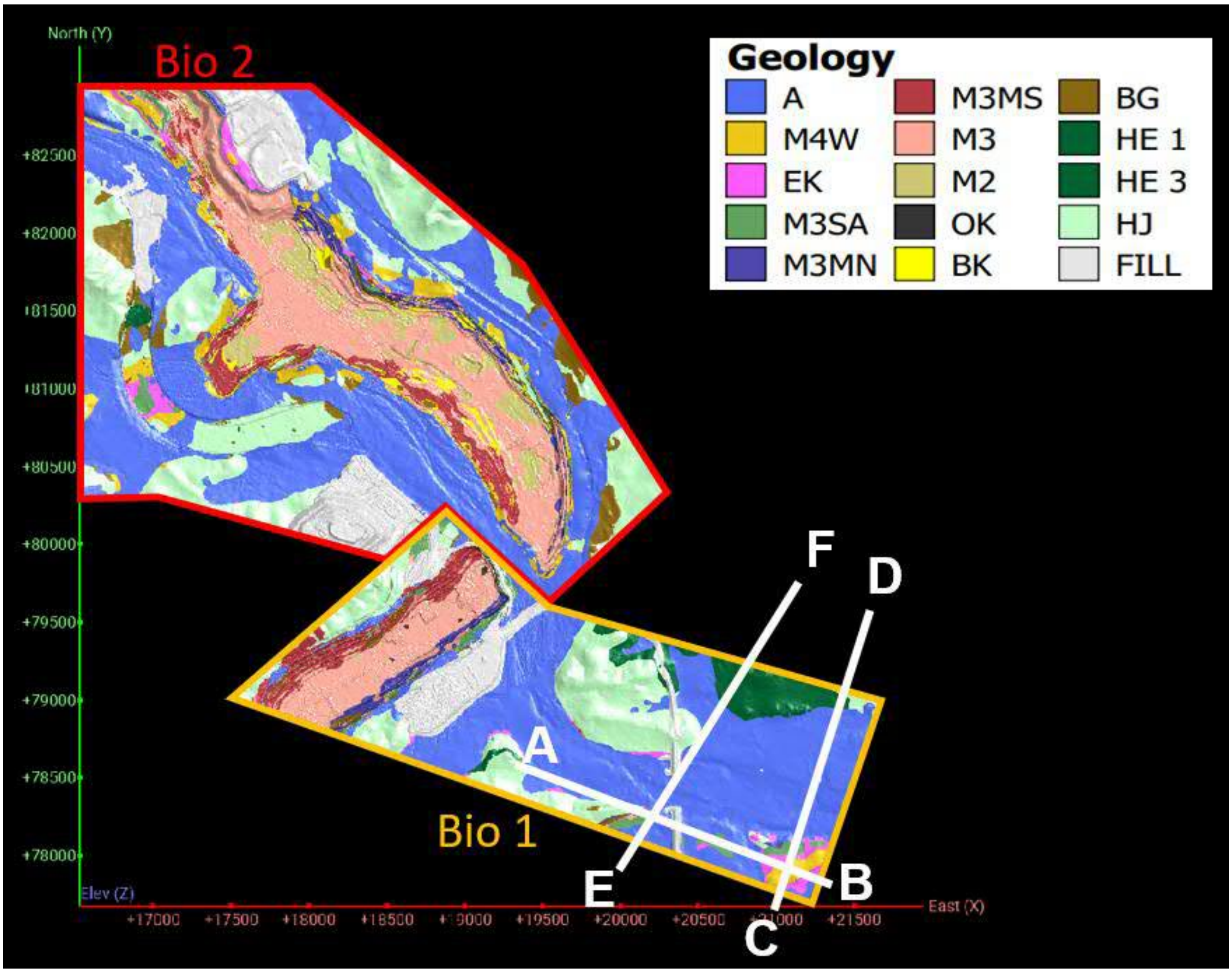


Figure 4.1. Plan view of the contiguous model extents within the Study Area (Bio 1 and Bio 2), showing stratigraphic units.

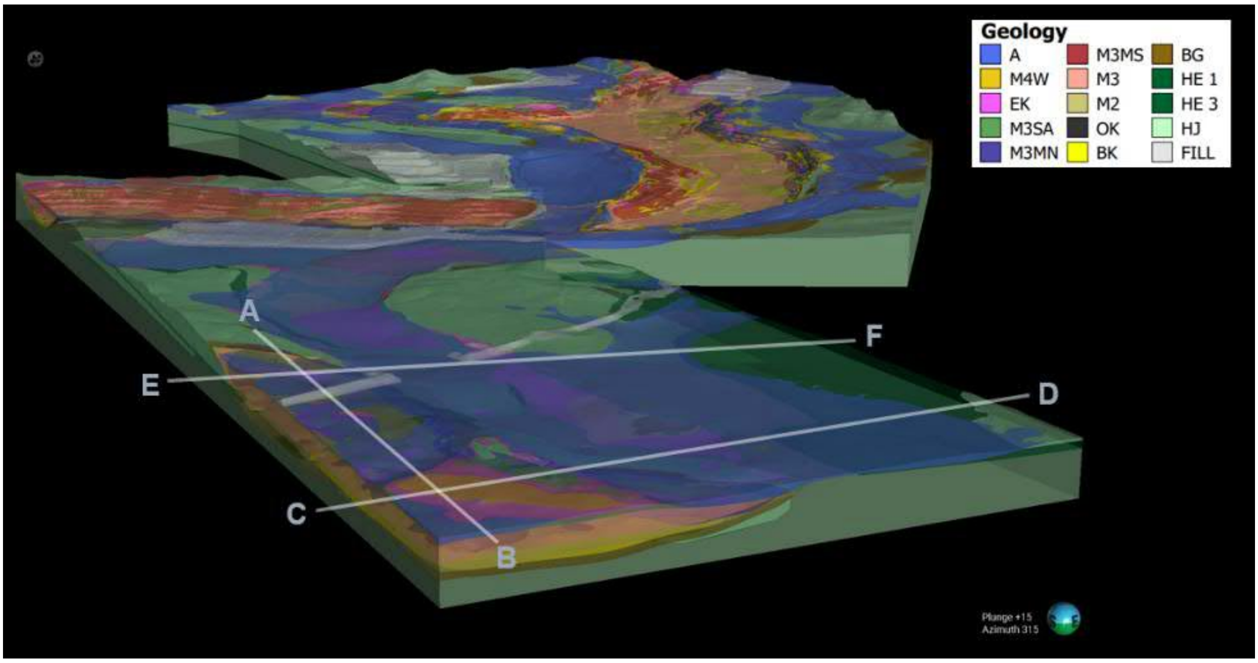


Figure 4.2. Oblique view of the stratigraphic models, showing the full depth extent of the modelling.

The typical stratigraphic sequence, from the top (surface) to bottom (deep units) within the two model areas is as follows (refer Figure 4.3):

- Alluvials (A – dark blue);
- Eastern Clay (EK – pink);
- Eastern CID (M4W – orange);
- Upper CID Units (M3 – dusky pink, M3MS – red, M3MN – purple, M3SA – green);
- Ochreous Clays (OK – black);
- Lower CID Unit (M2 – beige);
- Basal Clays (BK – yellow);
- Munjina Member Basal Conglomerate (BG – brown);
- Dolerite Dykes/ Sills (HE – dark green); and
- Weeli Wolli Formation (HJ - light green).

Dolerite dykes (HEK) within the Weeli Wolli Formation have been split into four separate dyke systems for modelling purposes. They form impermeable sills when fresh and where subject to weathering, they typically degrade to clay. The 3D modelling is unconstrained by depth, but the local weathering basement is generally provided by dolerite and fresh BIF within the Weeli Wolli Formation, approximately 70-80 m below surface, with some local variability due to topographic relief.

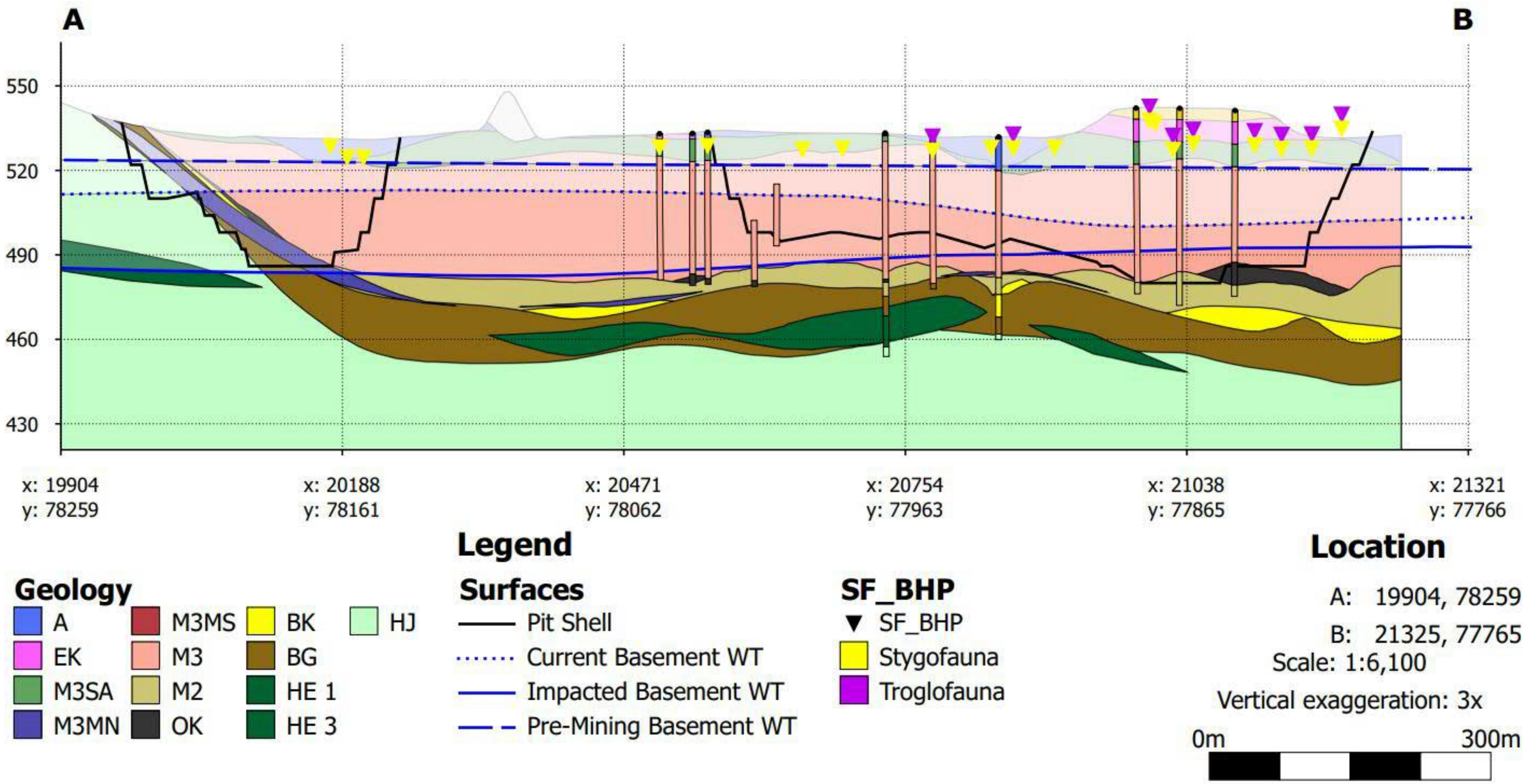


Figure 4.3. Cross-section (A-B) through the typical stratigraphic sequence within the Study Area, based on 3D modelling. Triangle symbols indicate subterranean fauna records from sampling.

4.2 Habitat suitability modelling

Drill hole logging information, diamond core photos, hydrological bore schematics and downhole geophysical data were used to assess and categorize the lithologies from the stratigraphic 3D model into four potential habitat categories (high, medium, low, and uncertain) (Figure 4.4). These results were cross-referenced against the subterranean fauna sampling data where available. Full results of the habitat assessment are provided in Table 4.1.

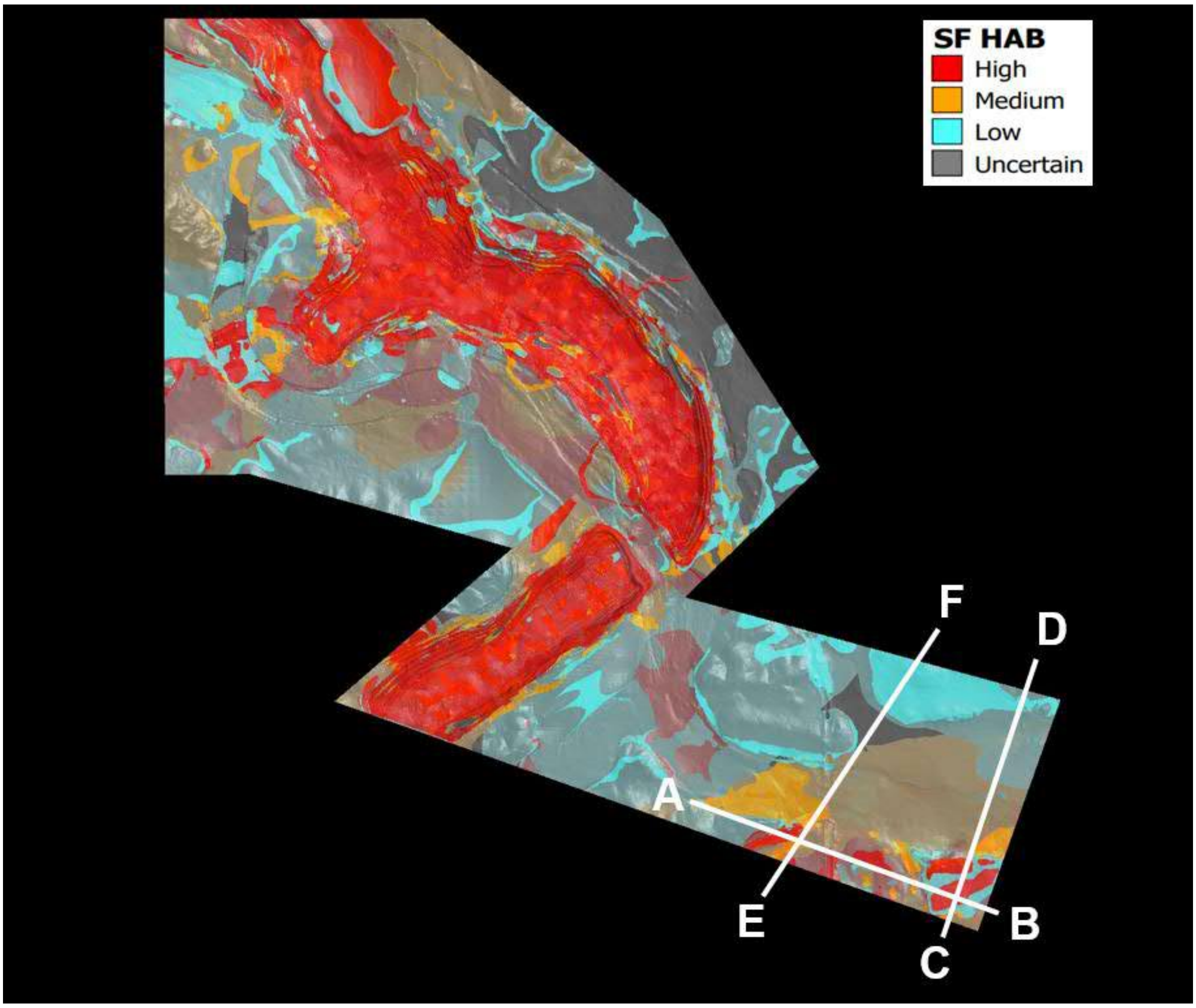


Figure 4.4. Oblique view of the 3D habitat model, showing the potential habitats for subterranean fauna within the Study Area.

The Upper and Lower CID units consistently presented the most highly suitable potential habitats for subterranean fauna (Table 4.1). There was a high prevalence of voids, vugs, and fractures throughout diamond cores and drill log data (Appendix A), and subterranean fauna were detected throughout the CID (Bennelongia 2024). Several sub-units occur within and immediately below the CID (Table 4.1), comprising the Eastern Clay, Ochreous Clay, the Basal Clay, and the Munjina Member Basal Conglomerate. Although clays are generally considered to represent low potential habitat for subterranean fauna, drill core analysis (Appendix A) revealed that intervals logged as these sub-units are made up of weathered/fractured rock and gravel as well as clay, and therefore can provide medium to high suitability habitat for subterranean fauna in some cases (Table 4.1).

Some potential habitat was modelled in the weathered Weeli Wolli Formation beneath the CIDs and drainage lines (Figure 4.5). Drill core analysis (Appendix A) revealed that the weathering is locally variable (Table 4.1), ranging from high to medium potential habitat (well developed cavities and open fractures), but the majority of the Weeli Wolli Formation is modelled as Uncertain habitat potential where the rock weathering characteristics are not logged by sufficient data (Appendix A) (Figure 4.5).

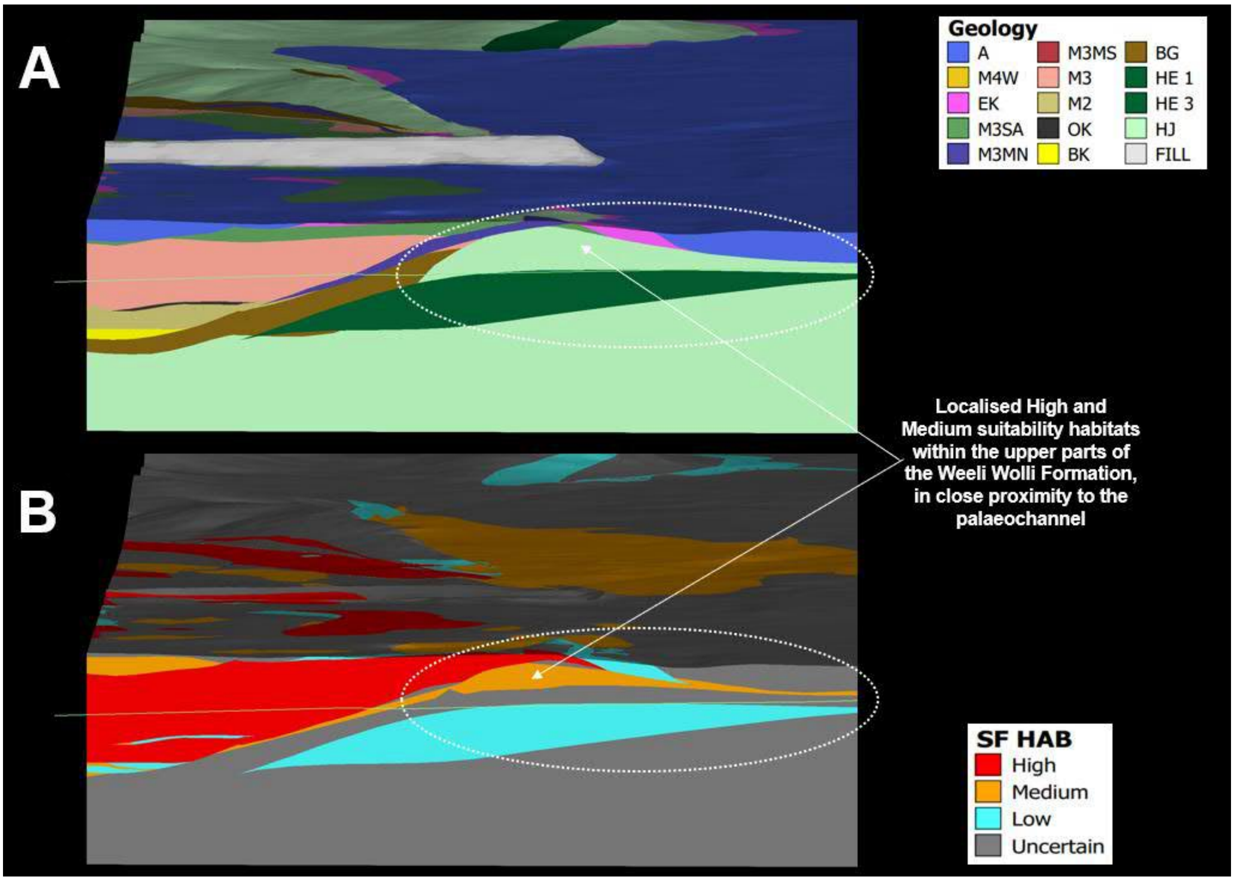


Figure 4.5. A) Stratigraphic units and B) potential subterranean fauna habitat modelled at East 8 (cross-section C-D), showing potential habitat within the Weeli Wolli Formation.

Superficial detritals (alluvial and colluvial material) associated with Marillana Creek and other drainage channels provide extensive potential habitat within the Study Area. Habitat potential varies from low to high at localised spatial scales depending on the granularity of the material and pore spaces available (Table 4.1). This localised variability is challenging to assess and model due to data density limitations, therefore the suitability is mostly averaged to medium, while some data poor areas are classed uncertain.

Table 4.1: Potential habitat suitability of stratigraphic units within the 3D Model

Stratigraphic unit (2D geology map code)	BHP Code	Description	Habitat potential	Subterranean fauna habitat suitability assessment	Colour band
Detritals & CID					
Quaternary Detritals	SZ, A	Surface Scree and Alluvials (Talus and Colluvium)	Low – Med-High	Deposits that may provide some AWT or BWT habitat, locally variable based on texture – clay, silt, sand, gravel.	
Tertiary (Pliocene) Detritals	CID	Channel Iron Deposit – undifferentiated and non-denatured	High	Void spaces expected to occur frequently throughout the CID (e.g. secondary weathering, vugs, fractures, porosity). Typically forms highly suitable subterranean fauna habitat.	
	DCID	Denatured Channel Iron Deposit – undifferentiated and non-denatured	High		
	HCID	Hardcapped Channel Iron Deposit – undifferentiated and non-denatured	High		
Tertiary (Oligocene – Miocene) Detritals	TO	Oakover Formation	High	Calcrete formation. Void spaces expected to occur frequently (e.g. secondary weathering, vugs, fractures, porosity).	
	M4W	Marillana Formation, Lower Member (MFLM) – Eastern CID – Weathered	High	Void spaces expected to occur frequently throughout the CID (e.g. secondary weathering, vugs, fractures, porosity). Typically forms highly suitable subterranean fauna habitat.	
	M4	MFLM Eastern CID	High		
	EK	MFLM Eastern Clay	Low	Clay layer within the CID. Impermeable barrier for subterranean fauna.	
	M3SA	Marillana Formation, Barimunya Member (MFBM) – Upper CID High Silica, High Alumina	High	Void spaces expected to occur frequently throughout the CID (e.g. secondary weathering, vugs, fractures, porosity). Typically forms highly suitable subterranean fauna habitat.	
	M3W	MFBM – Weathered	High	Void spaces expected to occur frequently throughout the CID (e.g. secondary weathering, vugs, fractures, porosity). Typically forms highly suitable subterranean fauna habitat.	
	M3HA	M3 – High Alumina	High		

Stratigraphic unit (2D geology map code)	BHP Code	Description	Habitat potential	Subterranean fauna habitat suitability assessment	Colour band
Tertiary (Oligocene – Miocene) Detritals	M3	MFBM – Upper CID	High	Void spaces expected to occur frequently throughout the CID (e.g. secondary weathering, vugs, fractures, porosity). Typically forms highly suitable subterranean fauna habitat.	
	M3MN	MFBM – Upper CID – Northern Marginal Zone	High		
	M3MS	MFBM – Upper CID – Southern Marginal Zone	High		
	M2	MFBM – Lower CID	High		
	M2U	MFBM – Lower CID	High		
	M1	MFBM – Lower CID	High		
	OK	MFBM – Ochreous clay	Low-Med	A variable basal ocherous clay unit, subject to various degrees of weathering.	
	BK	Marillana Formation, Munjina Member (MFMM) – Basal Clay	Low-Med	A basal clay unit creating a barrier for subterranean fauna with sparse areas of connectivity.	
	BG	MFMM – Basal Conglomerate	Low – Med-High	Commonly a conglomerate with varied weathering and occasional voids and vugs.	
Bedrock					
Intrusives	HE, K	Dolerite Dykes/ Sills	Low	Either fresh or weathered completely to clay.	
Hamersley Province	HJ, WW	Weeli Wolli Formation interbedded shale and BIF	Low – Med-High	Fresh and weathered units can be fractured which is favourable for subterranean fauna and tend to be within close proximity to the palaeochannel. Deeper units are fresh and impermeable.	
Unknown	UN, FILL, B	Unknown, Surface Landform Fill – mine waste dumps, bunds etc	Unknown	Mining operational waste product e.g. waste dumps, bunds/barriers.	

4.3 Habitat modelled at East 7/8

At East 7/8 (Model Bio 1), highly suitable habitat occurred prior to mining in the Marillana Formation CIDs in two major areas associated with the current East 7 pit and occurs in the proposed East 8 pit area (Figure 4.6). The CID at East 7 pit has been subject to mining, but relatively thin areas of the Lower CID unit (M2) immediately surrounding the pit (up to 20 m thick) remain intact. Localised medium suitability habitats within the detritals and weathered Weeli Wolli Formation also remain intact surrounding the East 7 pit.

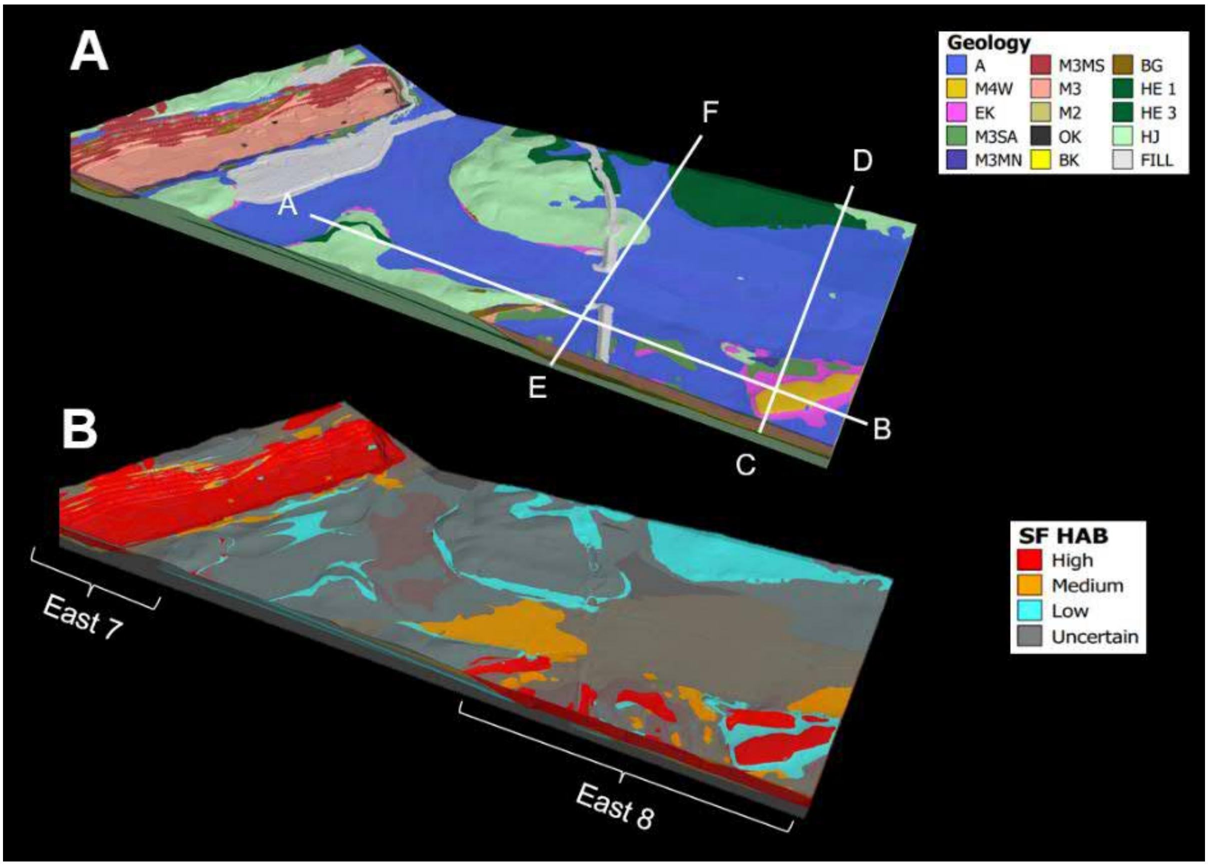


Figure 4.6. A) Stratigraphic units and B) potential subterranean fauna habitat modelled at East 7/8.

At East 8, the Marillana Formation CID is currently intact and forms a thick, uninterrupted layer of highly suitable habitat. The Ochreous Clay does not form a continuous layer in the profile at East 8 and occurs only as few localised patches. Owing to a lack of potential barriers, the highly suitable subterranean habitat at the East 8 area is interpreted as continuous throughout the current extent of CID.

Alluvial habitats surround the CID and extend out into the Marillana Creek floodplain. The modelling of the alluvial habitats in this area is based on more limited drilling information than the CID, but the available drilling logs, cores and geophysics interpretations indicated that the alluvials are likely to represent medium suitability habitat (i.e. see Figure 4.7), with localised variability depending on sediment texture. Sampling data (Bennelongia 2024) confirmed the occurrence of stygofauna and troglofauna from high suitability CID and medium suitability alluvial habitats at the E8 proposed pits and along the Marillana Creek in the immediate vicinity of E8.

Further potential habitat may occur within the BK and the BG units at East 8. Both units occur at depth where the CID transitions to basement (Weeli Wolli Formation). While these basal units are typically considered low permeability, drill core analysis in the East 8 proposed pit areas showed some weathering/fracturing in these units (i.e. see Figure 4.6, Figure 4.7, Appendix A), which suggested some potentially habitable lithologies beneath the CID.

The drill core analysis in the East 8 proposed pit areas did not reveal local weathering/fracturing in the Weeli Wolli Formation below the CID (Figure 4.7). Very few diamond drill holes intercepted the deeper areas of the Weeli Wolli Formation; therefore, the available data may be underrepresented. There were some drill holes to the north of the East 8 pits (closer to Marillana Creek) where weathered/fractured Weeli Wolli was observed and modelled (Figure 4.6), but for the most part, the Weeli Wolli Formation was categorised as uncertain habitat suitability in the immediate surrounds of East 8.

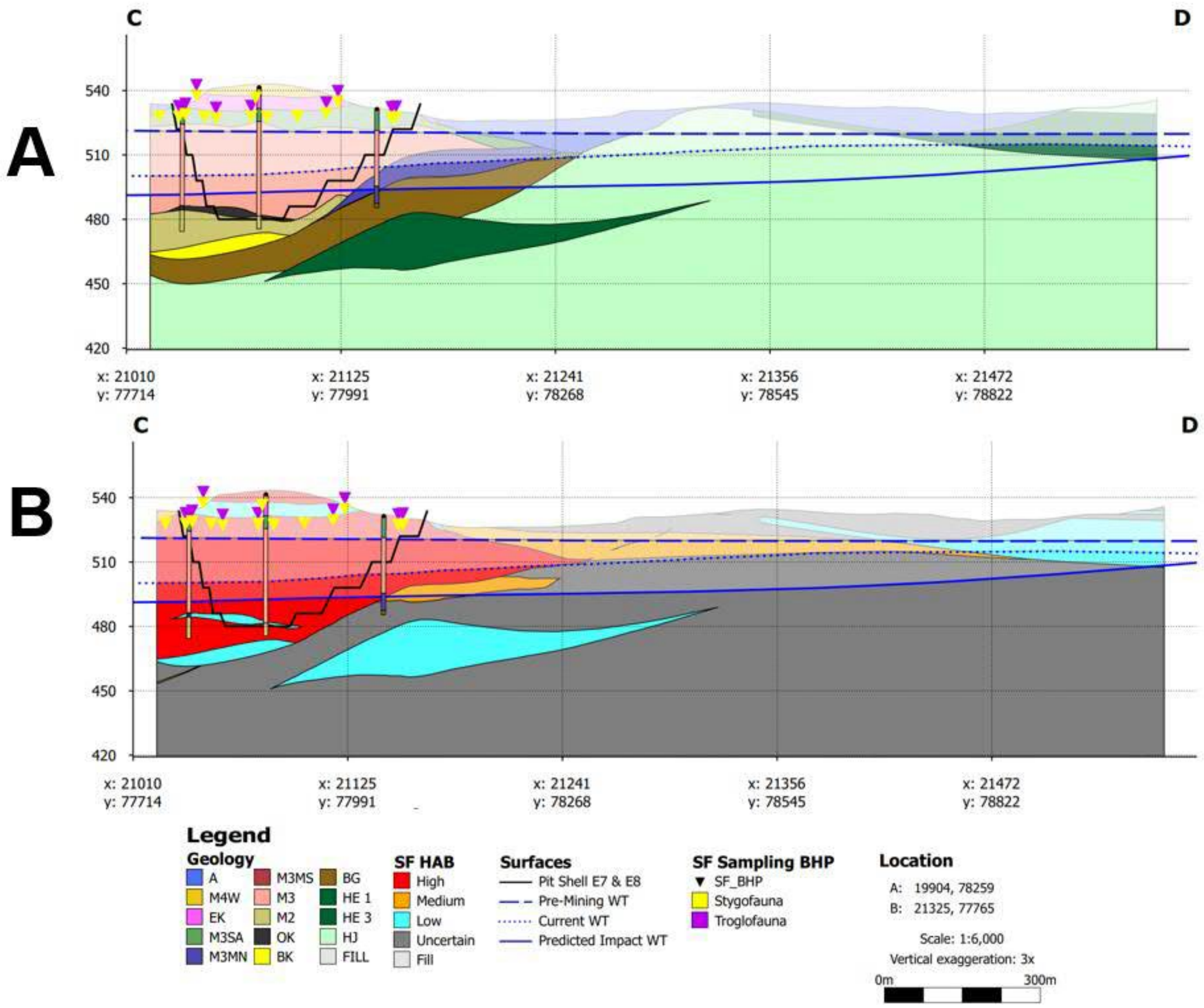


Figure 4.7. Cross section C-D (east to west) at E8 Eastern Pit showing A) stratigraphy and B) potential suitable habitats for subterranean fauna. Triangle symbols indicate subterranean fauna records from sampling.

4.3.1 Above vs below water table habitat

The current groundwater level is modelled at approximately 490 – 500 mRL in the East 8 area (Figure 4.9), approximately 40-50 m below surface depending on topography. At this water level, the majority of suitable habitat in CID at the East 8 proposed pits is AWT (i.e. troglofauna habitat), while the BWT fraction of the CID (i.e. stygofauna habitat) is approximately 15-25 m thick from the water table to basement (Figure 4.9).

Further north in the vicinity of Marillana Creek, the current groundwater level is modelled mainly within lithologies categorised as uncertain habitat (Figure 4.7). The uncertain classification of lithologies in this area reflects the low density of drilling/ data, but it does not preclude the possible occurrence of habitable lithologies in this area, if suitably weathered or permeable.

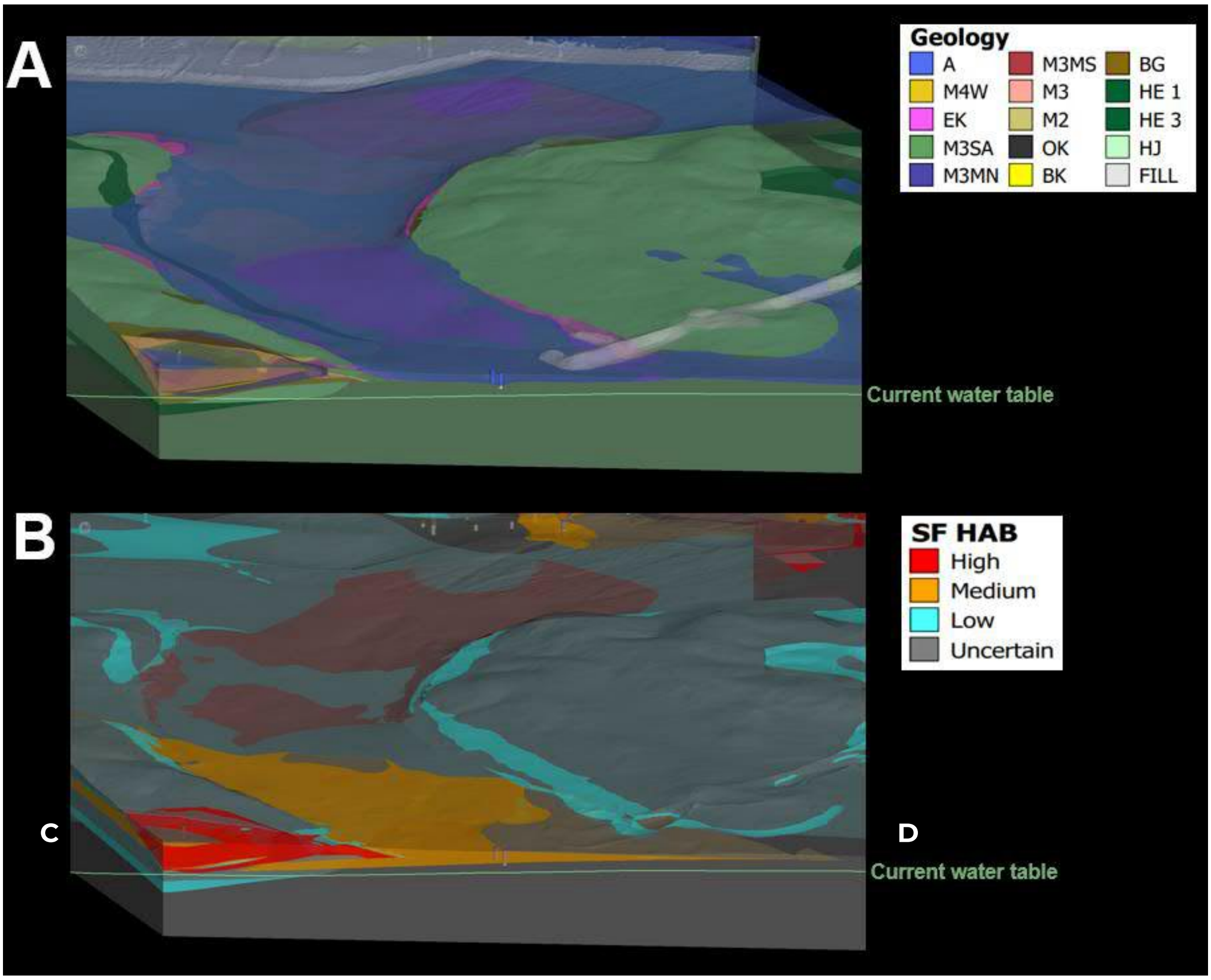


Figure 4.8. Oblique view of cross-section C-D (looking west) showing A) stratigraphy and B) potential suitable habitats for subterranean fauna.

Overall, the potential alluvial habitats as modelled north of East 8 (in the vicinity of Marillana Creek) appear to be unsaturated, i.e. occur only above the current groundwater table (Figure 4.7). Periodically, groundwater levels have been observed to rise by up to 12 m following heavy rainfall (BHP, 2023); therefore, the alluvials may become saturated following flood events, and provide temporary habitat for stygofauna. However, based on current modelling, the most likely remnant BWT habitat in the East 8 area appears to occur only within the CID.

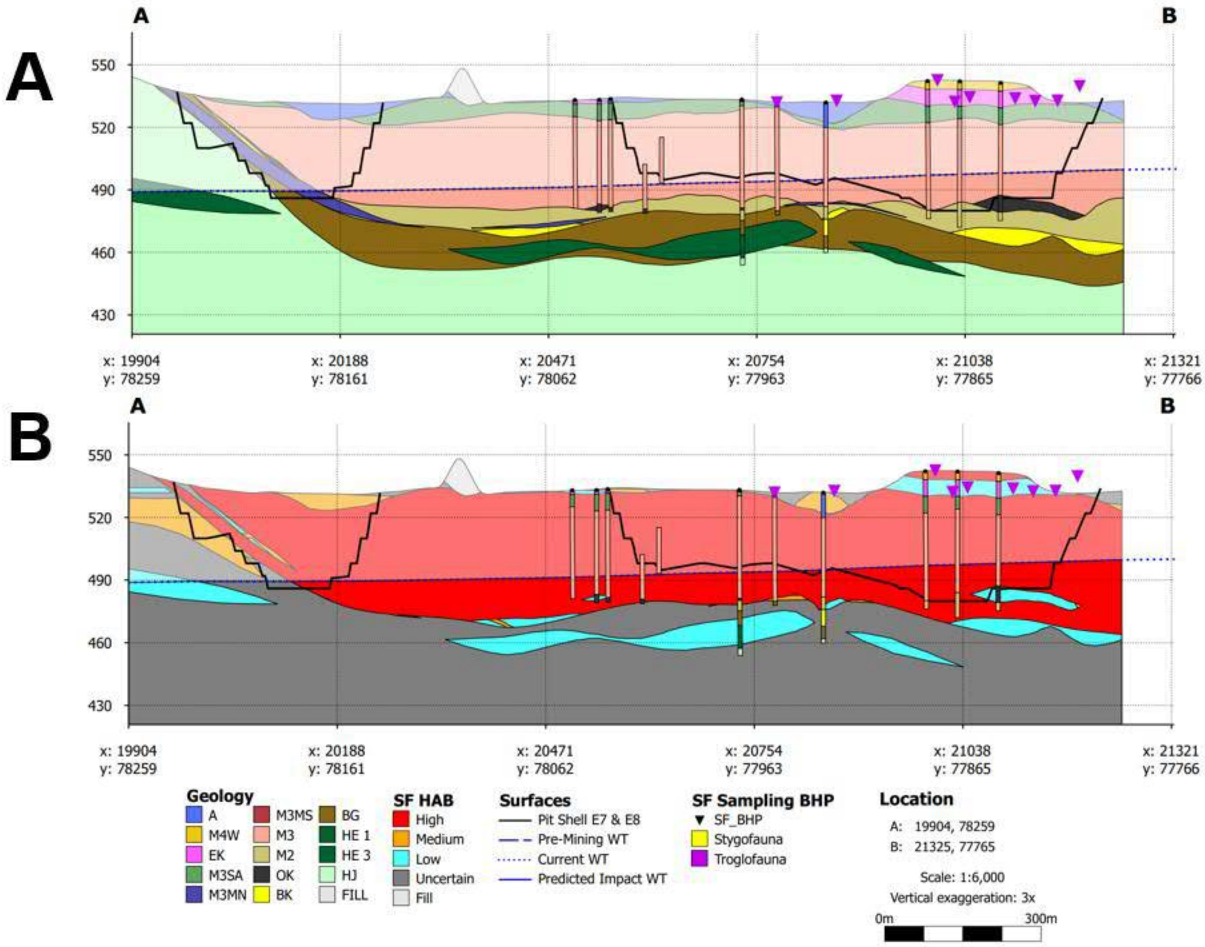


Figure 4.9. Cross-section (A-B) through the East 8 area, showing A) Stratigraphy and B) potential suitable habitats AWT and BWT based on current water levels.

4.4 Habitat modelled East 3,4,5,6

At East 3,4,5,6 (Model Bio 2), the Marillana Formation CIDs have been largely removed through historic mining, but a thin layer (up to 15 m) of CID remains intact around the pit shells and under the benches (Figure 4.9, Figure 4.10). A wider extent of potential habitat remains intact beyond the pits throughout the alluvial detritals, and in areas where the Weeli Wolli Formation is weathered and fractured. Potential habitats within these lithologies are comparatively thinner than the CID was prior to mining, but intact areas modelled as medium to high suitability habitat may remain suitable for subterranean fauna (Figure 4.10).

Given the significant changes in groundwater levels due to dewatering, it is expected that the majority of intact detrital habitat would occur AWT, while some patches of intact Weeli Wolli Formation have been modelled BWT (Figure 4.10). Episodic flows within Marillana Creek and its major tributaries may also provide some temporary shallow stygofauna habitat within the alluvials, where the original drainage corridor has remained intact (Figure 4.10).

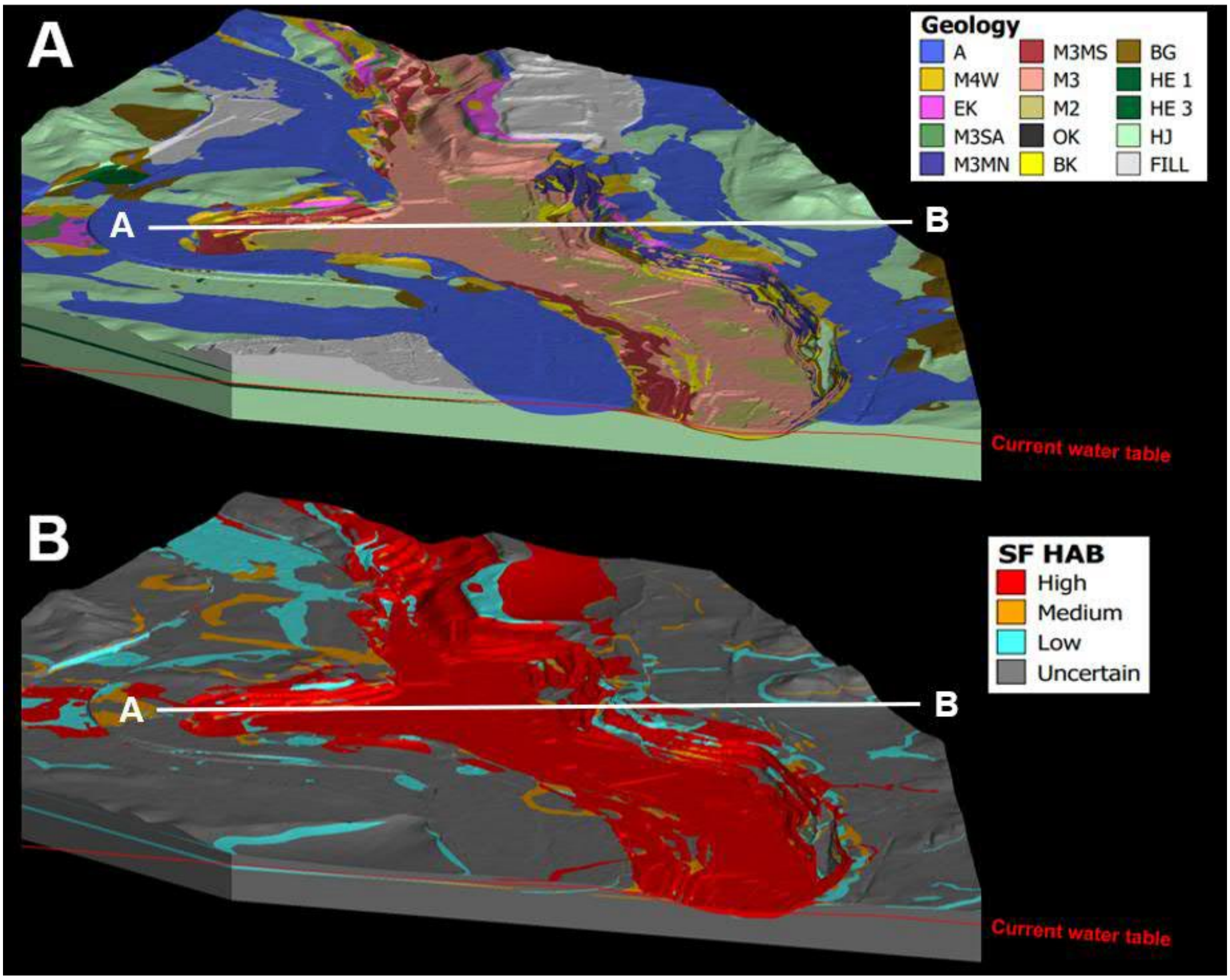


Figure 4.10. A) Stratigraphy and B) potential suitable habitats for subterranean fauna at East 3,4,5,6.

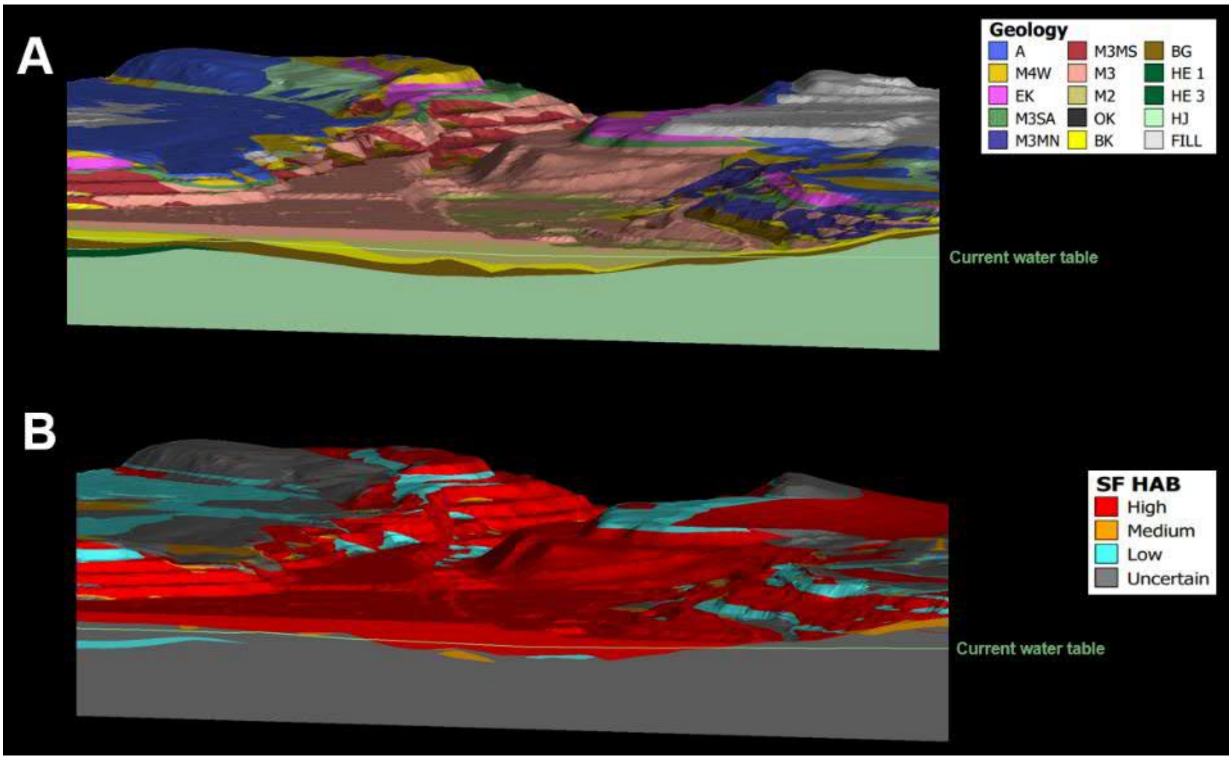


Figure 4.11. Cross-section (A-B) through the East 3,4,5,6 area, showing A) Stratigraphy and B) potential suitable habitat for subterranean fauna.

5 Habitat impact assessment

Noting that there are two proposed pits at E8, all target species were detected at the eastern pit (refer Figure 5.1 and Figure 5.2). The seven target subterranean fauna species were recorded from the following specimens and locations:

Troglofauna:

- *Hanseniella* sp. indet. – a singleton recorded within the eastern pit at E8;
- *Cryptops* sp. 'BSCOL091' - recorded from two sites within the eastern pit, approximately 300 m apart;
- *Hesperanillus* sp. 'BCO247' - a singleton recorded within the eastern pit;
- Haplodesmidae sp. 'BDI080' - a singleton recorded within the eastern pit; and
- Trigoniulidae sp. 'BDI079' - a singleton recorded within the eastern pit.

Stygofauna:

- *Elaphoidella* sp. 'BHA342' - recorded from two sites, inside and outside of the eastern pit, approximately 600 m apart; and
- *Parastenocaris* sp. 'BHA343' - a singleton recorded within the eastern pit.

Detailed assessment of the potential impacts to suitable habitats for each of the seven target subterranean fauna species is outlined below.

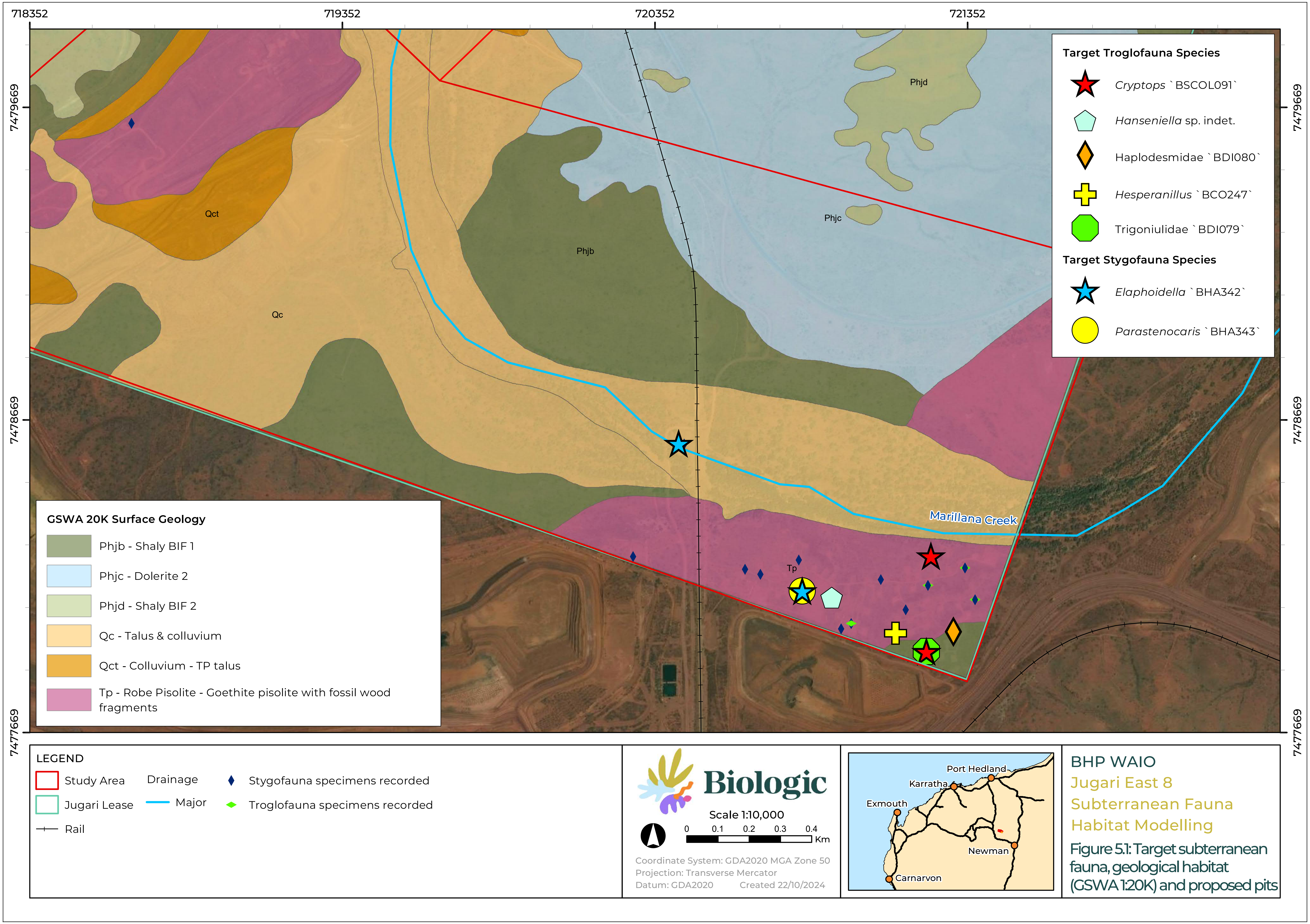
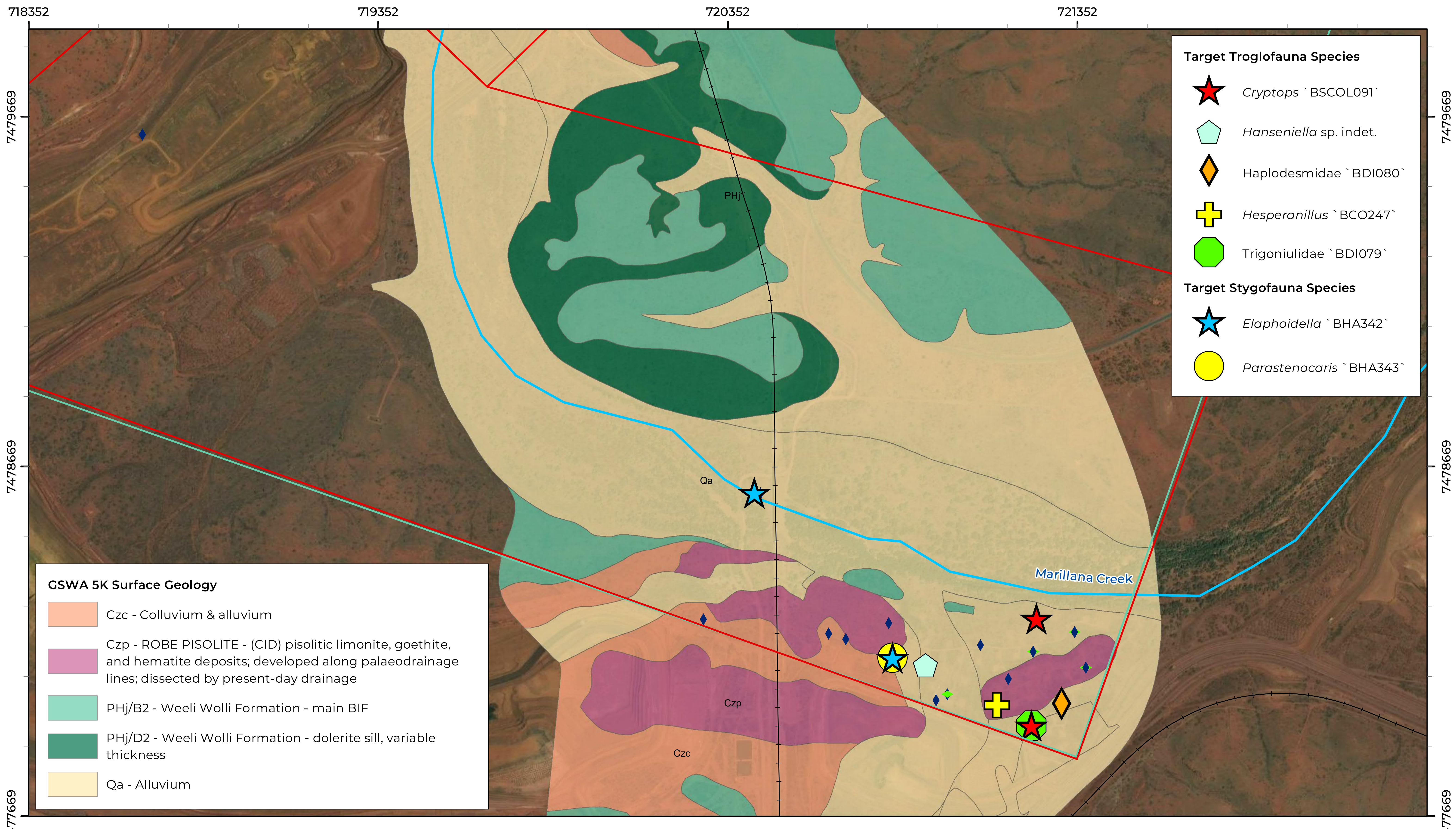


Figure 5.1: Target subterranean fauna, geological habitat (GSWA 1:20K) and proposed pits



LEGEND

Study Area

Jugari Lease

Rail

Drainage

Major

Stygofauna specimens recorded

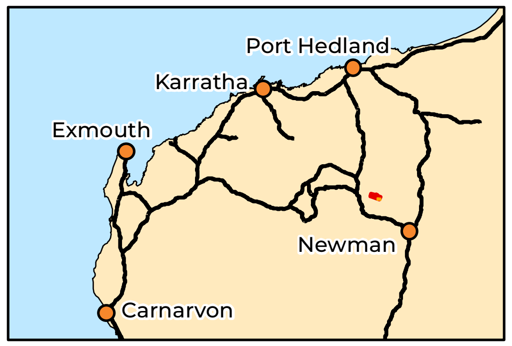
Troglofauna specimens recorded

Biologic

Scale 1:10,000

0 0.1 0.2 0.3 0.4 Km

Coordinate System: GDA2020 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA2020 Created 22/10/2024



BHP WAIO

Jugari East 8 Subterranean Fauna Habitat Modelling

Figure 5.2: Target subterranean fauna, geological habitat (GSWA 1:5K) and proposed pits

5.1 *Hanseniella* sp. indet.

The symphylan *Hanseniella* sp. indet. was collected from a single site within the proposed eastern E8 Pit (Figure 5.1, Figure 5.2). This taxon is poorly resolved at species level and therefore its wider occurrence cannot be determined. From a total of 46 *Hanseniella* OTUs in Biologic's sequence library at the time of writing, approximately half of the OTUs were singletons (Biologic unpublished data). Of those with linear ranges, the average linear range was approximately 8 km (min 0.1 km – max 21.8 km) (Biologic, 2021; 2022a; Biologic, unpublished data). As a precaution *Hanseniella* sp. indet. has been treated as a potential singleton herein.

The geology mapping at the location of this record showed CID/Robe Pisolite (Tp, Figure 5.1) and alluvium (Qa, Figure 5.2). Most of the other troglofauna records nearby were collected from the same geological unit/s. 3D modelling showed that a thick layer of CID, overlain by a thin layer of alluvial detritals (Figure 5.3 and Figure 5.4) occurs at the record location. Drill logging data showed the following units AWT:

- A – Alluvials (Talus and Colluvium);
- M3SA – Marillana Fm, Upper CID, high Silica and high Alumina; and
- M3 – Marillana Fm, Upper CID.

Based on drill core analysis (Appendix A), and habitat assessment (section 4), these three units are likely to provide a well-connected network of high to medium suitability habitat AWT.

The habitat modelling predicted high suitability CID habitat (Figures 5.3 and 5.4) beneath the pit floor at the known sample location of *Hanseniella* sp. indet., although it is mainly BWT under the current groundwater scenario. The CID extends west between the two E8 pits and there are no known habitat barriers (Figure 5.3 and Figure 5.4).

The impacts from the proposal to *Hanseniella* sp. indet. are unlikely to be significant, because:

- The proposed pits are relatively small, compared to the wider extent of potential habitat that will remain intact in the CID and alluvials surrounding the pits;
- There are no potential dispersal barriers that would suggest a confined habitat within impact areas; and
- There is no evidence that this taxon has a restricted distribution, but we have treated it as a singleton herein, as a precaution.

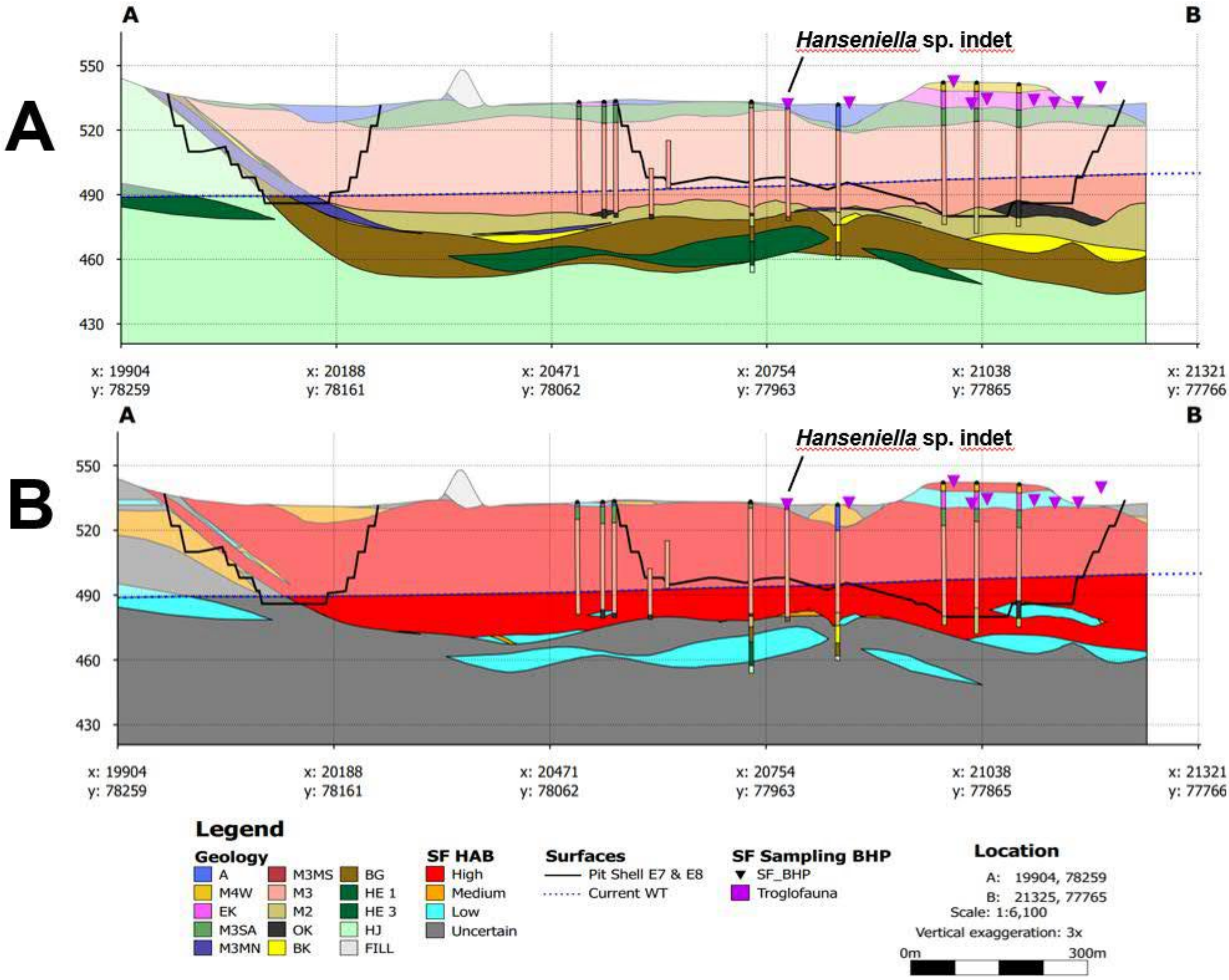


Figure 5.3. Cross section A-B (west to east) at E8 pits showing potential AWT habitat for *Hanseniella* sp. indet.; A) Stratigraphy and B) high, medium, and low potential habitat. Triangle symbols indicate subterranean fauna records from sampling.

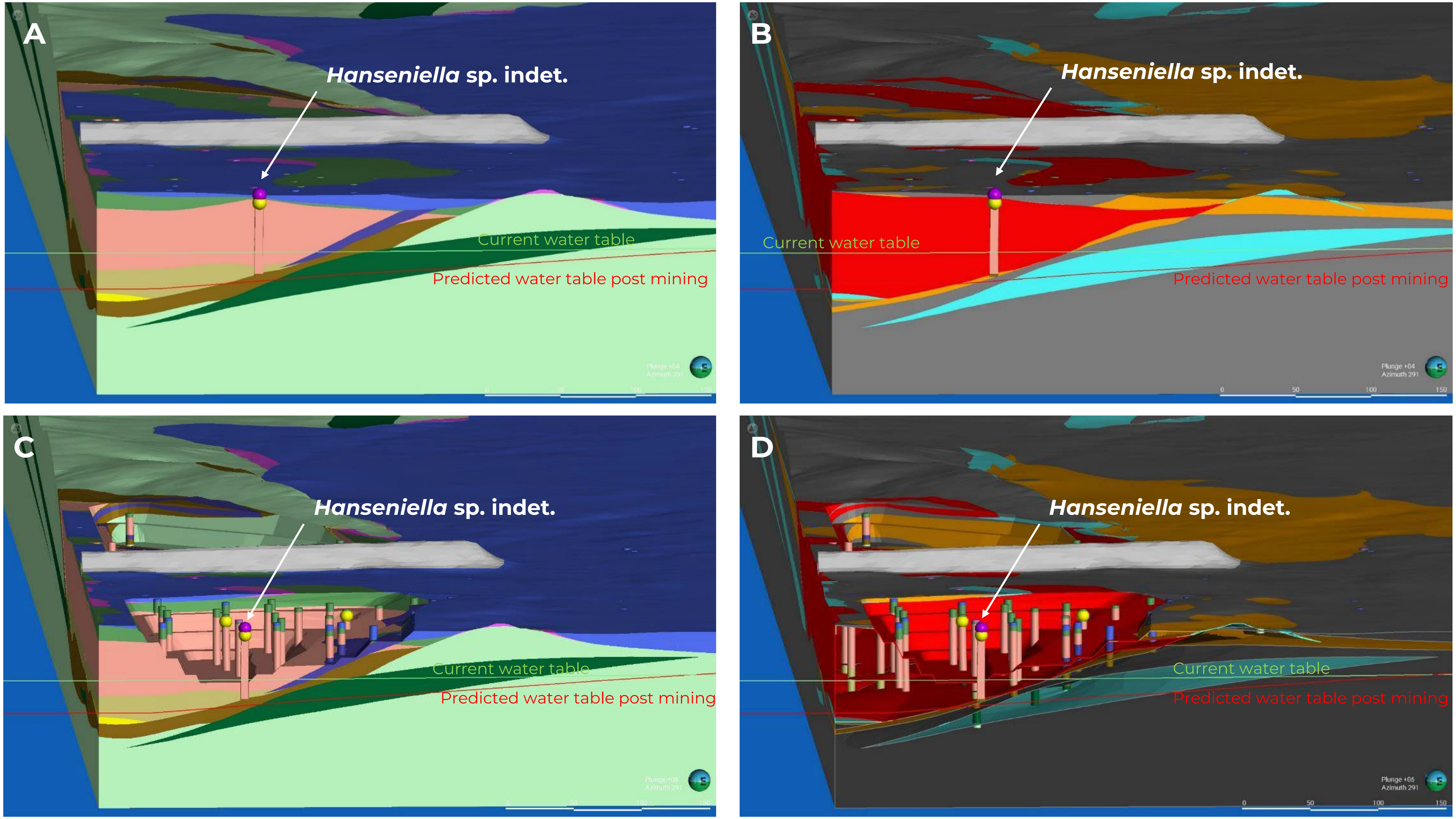


Figure 5.4. Oblique view from east of the 3D model, location of *Hanseniella* sp. indet.; A) Current stratigraphy, B) Current high, medium, and low potential habitat, C) Stratigraphy after mining, and D) high, medium, and low potential habitat remaining after mining. Units coloured as per Figure 5.3.

5.2 *Cryptops* 'sp. BSCOL091'

The centipede *Cryptops* 'sp. BSCOL091' is known from two sites, located approximately 300 m apart, within the proposed Eastern E8 Pit (Figure 5.5, Figure 5.6). Genetic analysis against available sequence libraries from Biologic (2024) and Bennelongia (2024) failed to detect a wider regional match, therefore this OTU is currently known only from its collection records within the Study Area (Appendix B). From the 22 *Cryptops* OTUs in the Biologic sequence library at the time of writing, the majority of OTUs were singletons, although a few widely occurring OTUs were recorded with ranges up to 44 km (Biologic, 2019; 2022b; Biologic, unpublished data).

2D geology mapping at these two sites showed CID/Robe Pisolite (Tp) and Shaly BIF (Phjb) (Figure 5.1), and alluvium (Qa, Figure 5.2). 3D modelling the following units AWT at these sites:

- A – Alluvials (Talus and Colluvium);
- M3SA – Marillana Fm, Upper CID, high Silica and high Alumina;
- M3 – Marillana Fm, Upper CID;
- M3MN – Marillana Fm, Upper CID - Northern Marginal Zone;
- BG - Marillana Fm, Munjina Member – Basal conglomerate; and
- HJ - Weeli Wolli Fm, interbedded shale and BIF.

The most likely potential habitat layers comprise the CID (with no difference in suitability between subunits M3SA, M3, and M3MN) and the alluvials, based on drill core analysis (Appendix A).

There may also be some habitat potential within weathered/ fractured rocks in the basal conglomerate (BG) and the Weeli Wolli (HG, shaly BIF); however, in the immediate vicinity of the E8 pits, these two units are mostly BWT (based on current groundwater levels). To the north of the E8 pits, the model has predicted some medium suitability habitat within the Shaley BIF, although this has not been confirmed by sampling for troglofauna (refer mid-section of Figure 5.5B).

Both records of *Cryptops* 'sp. BSCOL091' were detected at the very edge of the eastern E8 pit, where mining disturbance will be relatively shallow, and CID habitat occurs AWT at current groundwater levels (Figure 5.5 and Figure 5.6). The modelling predicts that high suitability habitat will remain intact beneath the margins of the eastern E8 pit at proposed groundwater levels, and more broadly between the two E8 pits. To the north of the E8 pits, medium suitability habitat will remain intact throughout the alluvials (Figures 5.5 and 5.6).

The impacts from the Proposal to *Cryptops* 'sp. BSCOL091' are unlikely to be significant, because:

- The proposed pits are small and the wider extent of suitable habitat will remain intact in the CID and alluvials;
- There are no potential dispersal barriers between impacted and non-impacted habitats; and
- The two known specimens were recorded on the outer edges of the proposed pit, and suitable AWT habitat will remain intact at these locations and in the surrounding local area.

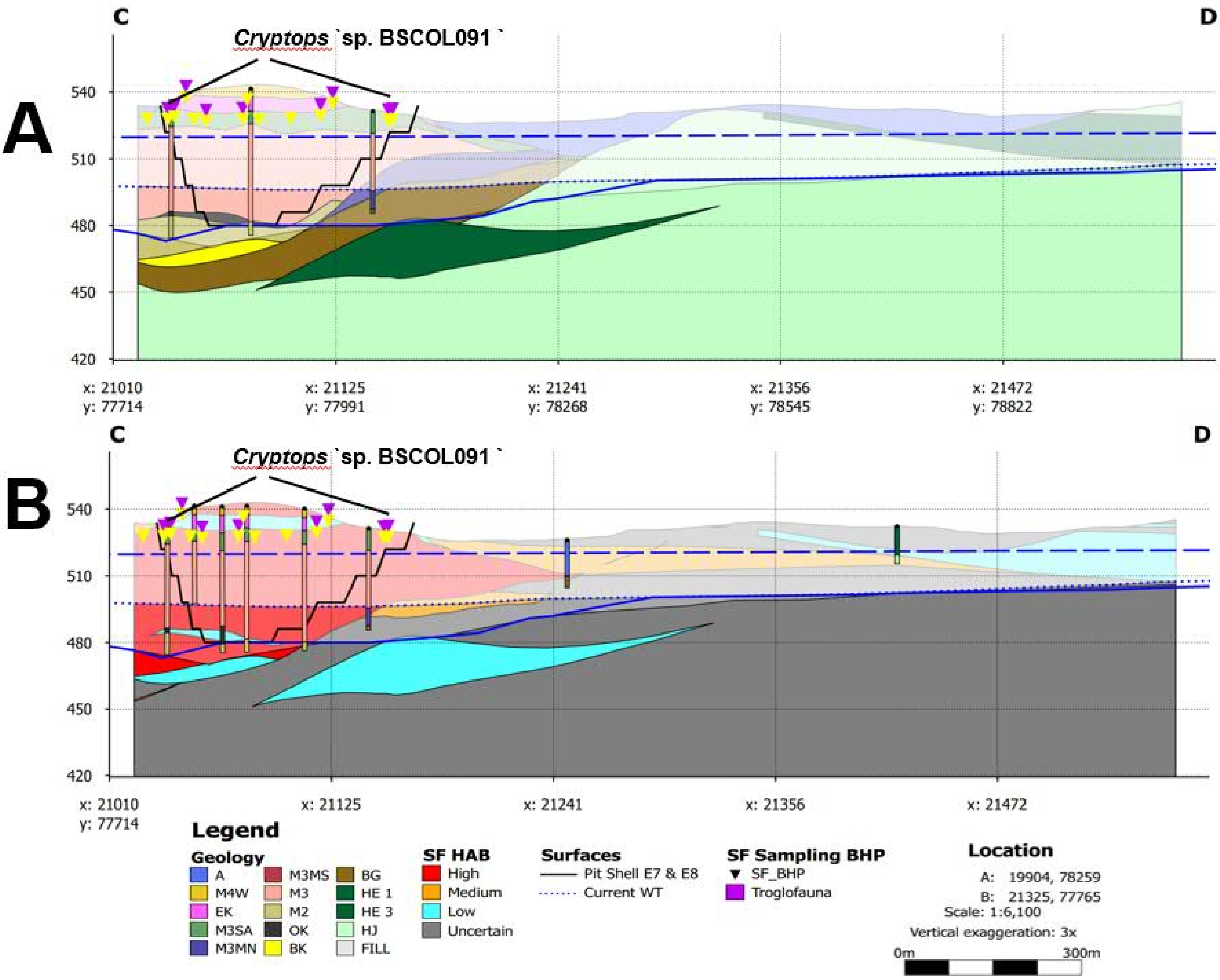


Figure 5.5. Cross-section C-D (south to north) at E8 Eastern pit showing potential AWT habitat for *Cryptops* `BSCOL091`; A) Stratigraphy and B) high, medium, and low potential habitat. Triangle symbols indicate subterranean fauna records from sampling.

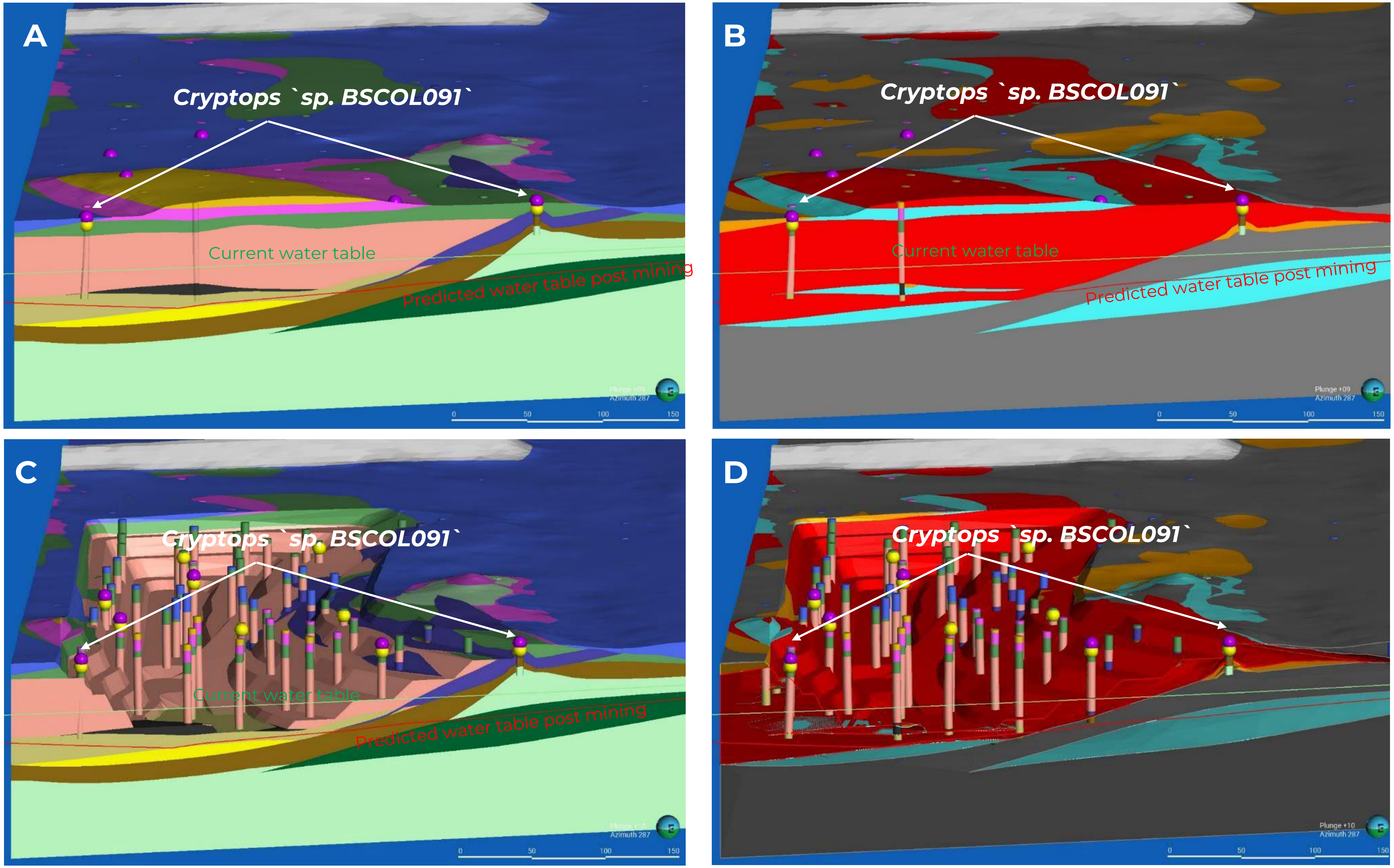


Figure 5.6. Oblique view from east of the 3D model, location of *Cryptops* `sp. BSCOL091`; A) Current stratigraphy, B) Current high, medium, and low potential habitat, C) Stratigraphy after mining, and D) high, medium, and low potential habitat remaining after mining. Units coloured as per Figure 5.5.

5.3 *Hesperanillus* 'sp. BCO247'

The beetle *Hesperanillus* 'sp. BCO247' was collected from a single site within the proposed eastern E8 Pit (Figure 5.1, Figure 5.2). Bennelongia (2024) failed to sequence the specimens, therefore this OTU is currently known only from its collection records within the Study Area. At the time of writing, Biologic sequence libraries contained 11 Anillini OTUs (Biologic unpublished data). Approximately half of the OTUs were known only from singletons but several OTUs were locally or regionally widespread, up to 185 km(Biologic, 2021; 2022b; Biologic, unpublished data).

2D geology mapping at this species' location revealed an association with the CID/ Robe Pisolite (Tp/Czp in Figure 5.1 and Figure 5.2), similar to most of the other troglofauna records in the local area. Drill logging data at this species' location recorded the following units AWT:

- M4W – Marillana Fm, Lower Member - Eastern CID;
- EK – Marillana Fm, Lower Member - Eastern Clay;
- M3SA – Marillana Fm, Upper CID, high Silica and high Alumina; and
- M3 – Marillana Fm, Upper CID.

Of these, only the Eastern clay (EK) is not likely to provide suitable habitat, while the CID units would all be expected to provide high suitability habitat (e.g. relatively consistent fractures, porosity and void spaces), based on drill core analysis (Appendix A).

The modelling predicts that some suitable habitat will remain intact directly underneath the known record location of *Hesperanillus* `sp. BCO247` within the CID (Figure 5.7 and 5.8). A broader extent of highly suitable habitat in CID is predicted to remain intact between the eastern and western E8 pits (Figure 5.7 and 5.8), and medium suitability alluvial habitats will also remain intact to the north.

The impacts from the Proposal to *Hesperanillus* sp. `BCO247` are unlikely to be significant, because:

- The proposed pits are small and the wider extent of high and medium suitability habitat in the CID and alluvials will remain intact; and
- There are no habitat barriers between impacted non-impacted habitats.

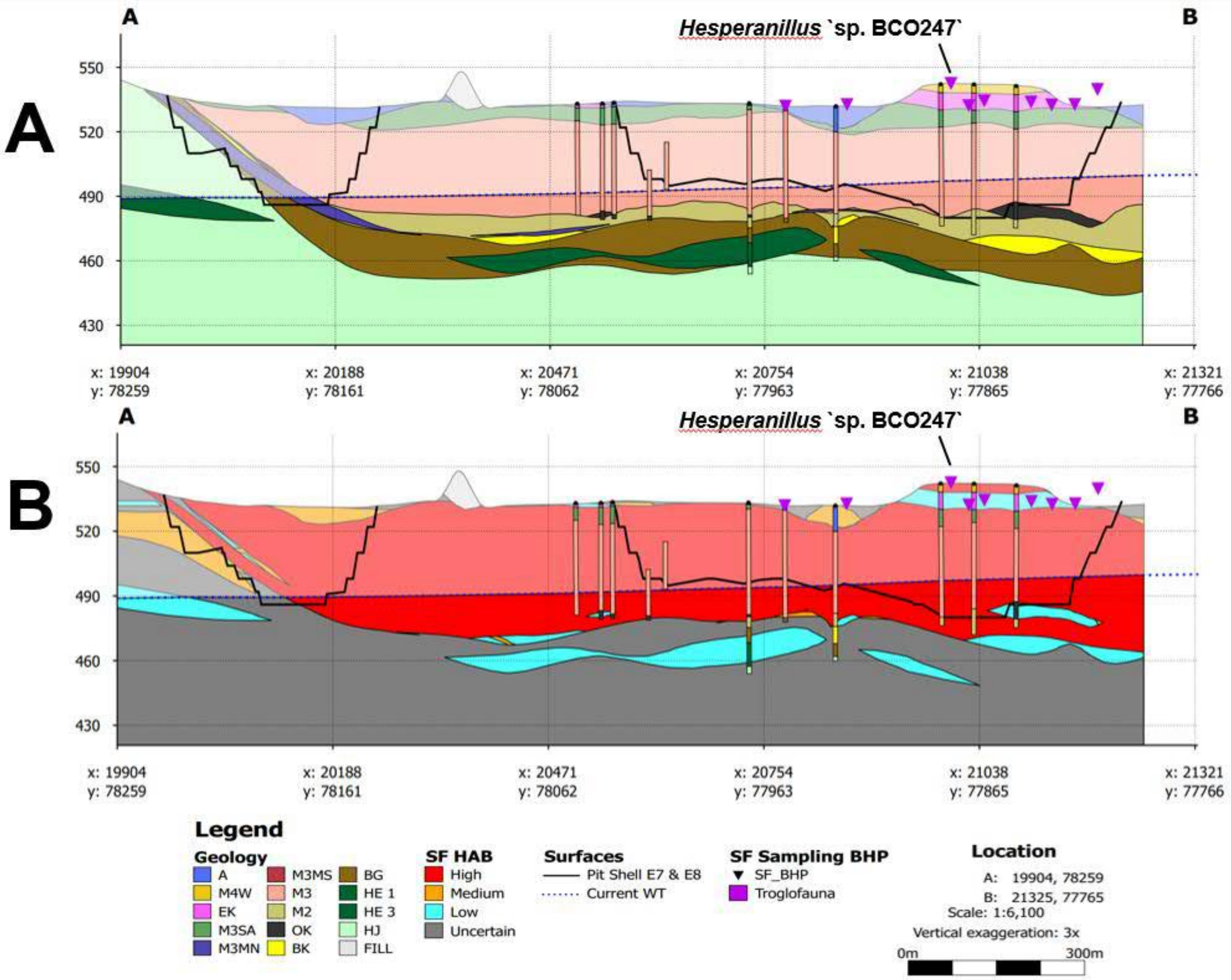


Figure 5.7. Cross section A-B (west to east) at E8 pits showing potential AWT habitat for *Hesperanillus* `BSCO247`; A) Stratigraphy and B) high, medium, and low potential habitat. Triangle symbols indicate subterranean fauna records from sampling

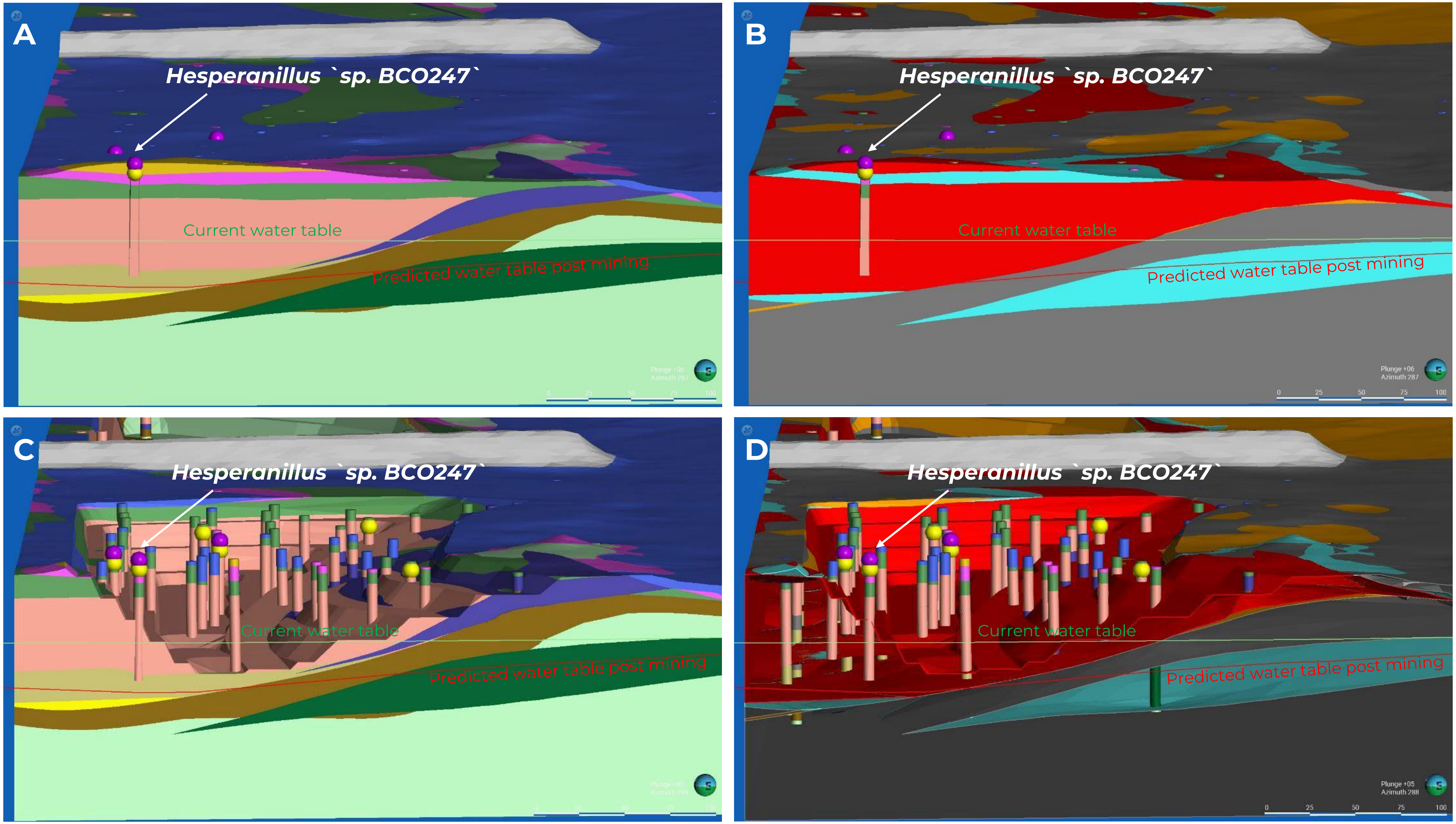


Figure 5.8. Oblique view from east of the 3D model, location of *Hesperanillus* `sp. BCO247'; A) current stratigraphy, B) Current high, medium, and low potential habitat, C) Stratigraphy after mining, and D) high, medium, and low potential habitat remaining after mining. Units coloured as per Figure 5.7

5.4 Haplodesmidae 'sp. BDI080'

The millipede Haplodesmidae 'sp. BDI080' was recorded from a single site within the proposed eastern E8 pit (Figure 5.1 and Figure 5.2). Bennelongia (2024) failed to sequence the specimens, therefore this OTU is currently known only from its collection records within the Study Area. Troglofaunal haplodesmids are relatively rare, and the material in available regional sequence libraries at the time of writing (biologic unpublished data) does not provide context for potential linear ranges.

2D geology mapping at this species' location showed CID/ Tp and alluvials (Figure 5.1 and Figure 5.2), similar to most other troglofauna records. Drill logging data at this species' location recorded the following units AWT:

- EK – Marillana Fm, Lower Member - Eastern Clay;
- M3SA – Marillana Fm, Upper CID, high Silica and high Alumina; and
- M3 – Marillana Fm, Upper CID.

Of these, only the EK layer is unlikely to provide potential habitat, while the CID subunits would both be expected to provide high suitability habitat (Appendix A, Figure 5.9, Figure 5.10). 3D modelling predicts that thin CID habitats will remain intact beneath the pit floor at this species location (Figure 5.9, Figure 5.10).

The broader extent of CID between the eastern and western E8 pits is predicted to remain intact post mining, and medium suitability habitats occur throughout the alluvial detritals to the north. Haplodesmidae 'sp. BDI080' was recorded close to the Jugari mine lease boundary, so the modelled habitat could potentially extend outside of the mine lease boundary, although the potential impact status of third-party areas beyond the Jugari mine lease is unable to be included in this assessment.

The impacts from the Proposal to Haplodesmidae 'sp. BDI080' are unlikely to be significant, because:

- The proposed pits are small and the wider extent of high and medium suitability habitats in the CID and alluvials will remain intact; and
- There are no habitat barriers between impacted and non-impacted habitats.

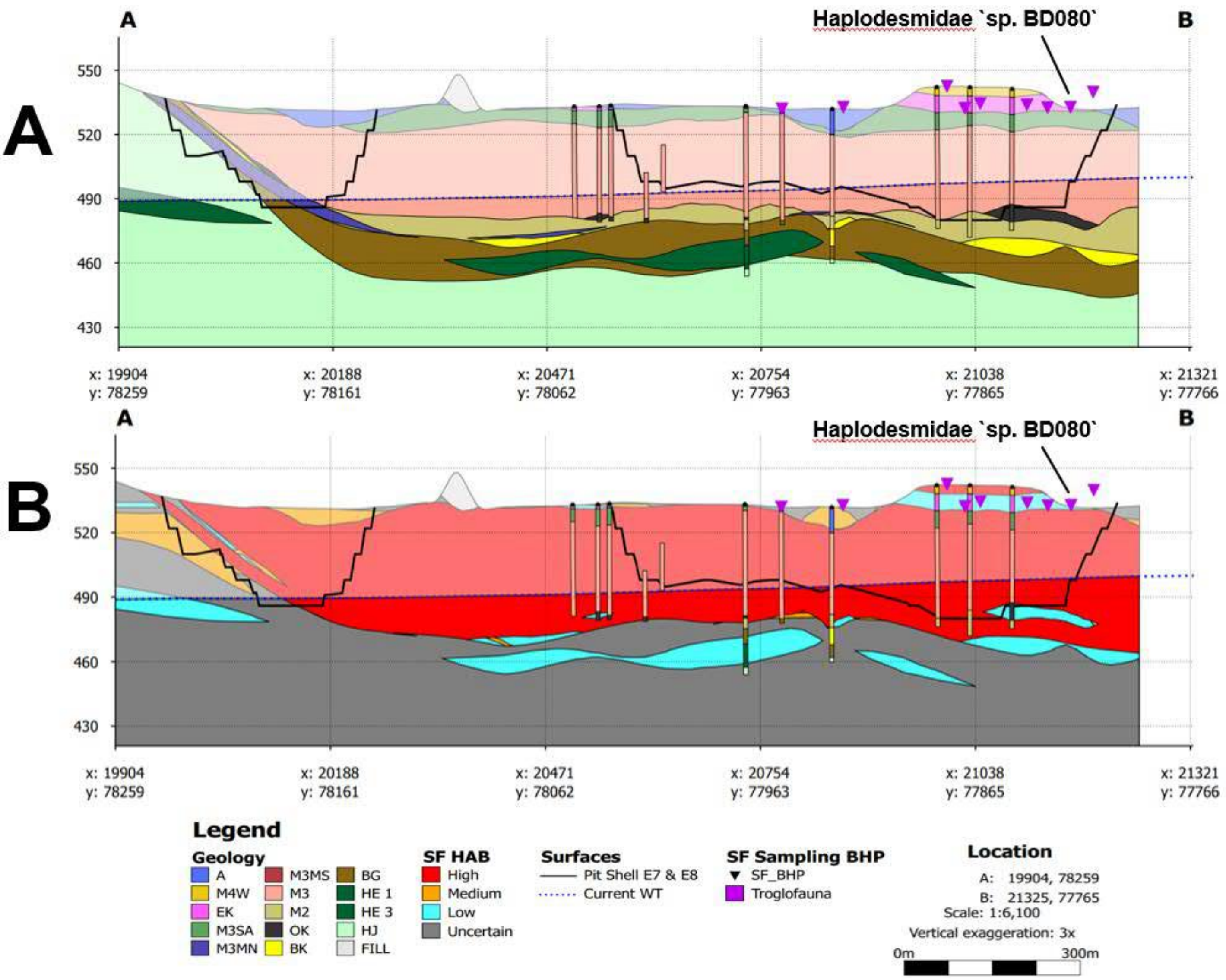


Figure 5.9. Cross section A-B (west to east) at E8 pits showing potential AWT habitat for Haplodesmidae `sp. BDI080`; A) Stratigraphy and B) high, medium, and low potential habitat. Triangle symbols indicate subterranean fauna records from sampling.

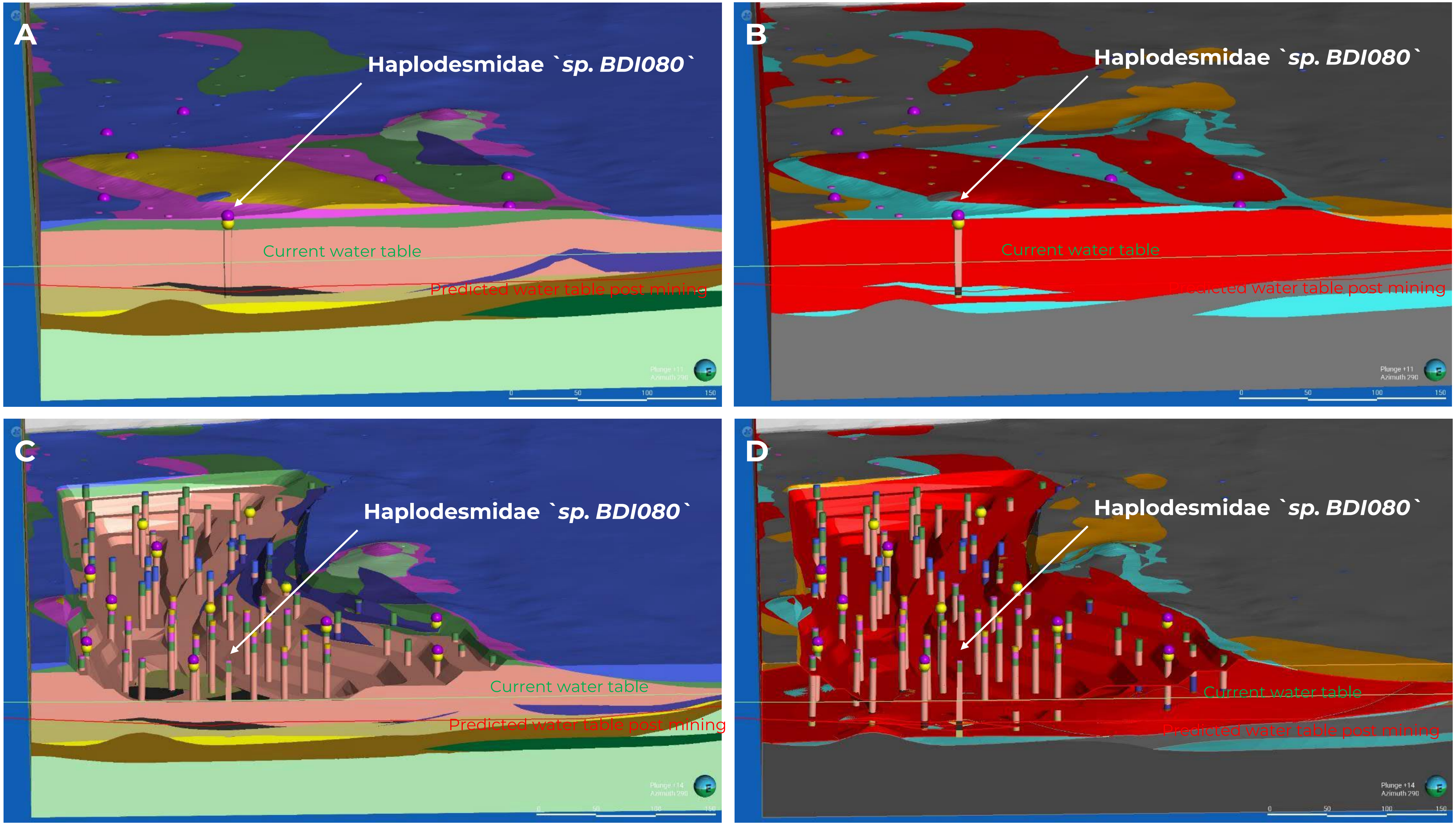


Figure 5.10. Oblique view of the 3D model from east, location of Haplodesmidae `sp. BDI080`; A) Current stratigraphy, B) Current high, medium, and low potential habitat, C) Stratigraphy after mining, and D) high, medium, and low potential habitat remaining after mining. Units coloured as per Figure 5.9.

5.5 Trigoniulidae 'sp. BDI079'

The millipede Trigoniulidae 'sp. BDI079' was recorded from a single site within the proposed eastern E8 pit (Figure 5.1, Figure 5.2). Genetic analysis against sequence libraries from Biologic (2024) and Bennelongia (2024) failed to detect a wider regional match, therefore this OTU is currently known only from its collection records within the Study Area. Troglofaunal trigoniulids are relatively rare, and the material in available regional sequence libraries at the time of writing does not provide context for potential linear ranges (Biologic unpublished data).

2D geology mapping at this species' location showed CID/ Tp and alluvials (Figure 5.1 and Figure 5.2). Drill logging data at this species' location recorded the following units AWT:

- A – Alluvials (Talus and Colluvium);
- M3SA – Marillana Fm, Upper CID, high Silica and high Alumina; and
- M3 – Marillana Fm, Upper CID.

The two CID units are expected to provide high suitability habitat, and the alluvial detritals are likely to provide medium suitability habitat based on drill core analysis (Appendix A).

The species was recorded at the edge of the proposed eastern E8 pit, where mining is expected to be relatively shallow (Figure 5.11, Figure 5.12). 3D habitat modelling predicts that highly suitable habitat will remain beneath the proposed pit shell within the CID (Figure 5.12), as well as between the two E8 pits (Figure 5.11). medium suitability habitat is also likely to occur throughout the alluvial detritals to the north and west.

The impacts from the Proposal to Trigoniulidae 'sp. BDI079' are unlikely to be significant, because:

- The proposed pits are small and the wider extent of high and medium suitability habitat in the CID and alluvials will remain intact;
- The species was recorded at the edge of the pit and it is likely that AWT habitat will remain in intact below the proposed pit shell; and
- There are no habitat barriers between impacted and non-impacted habitats.

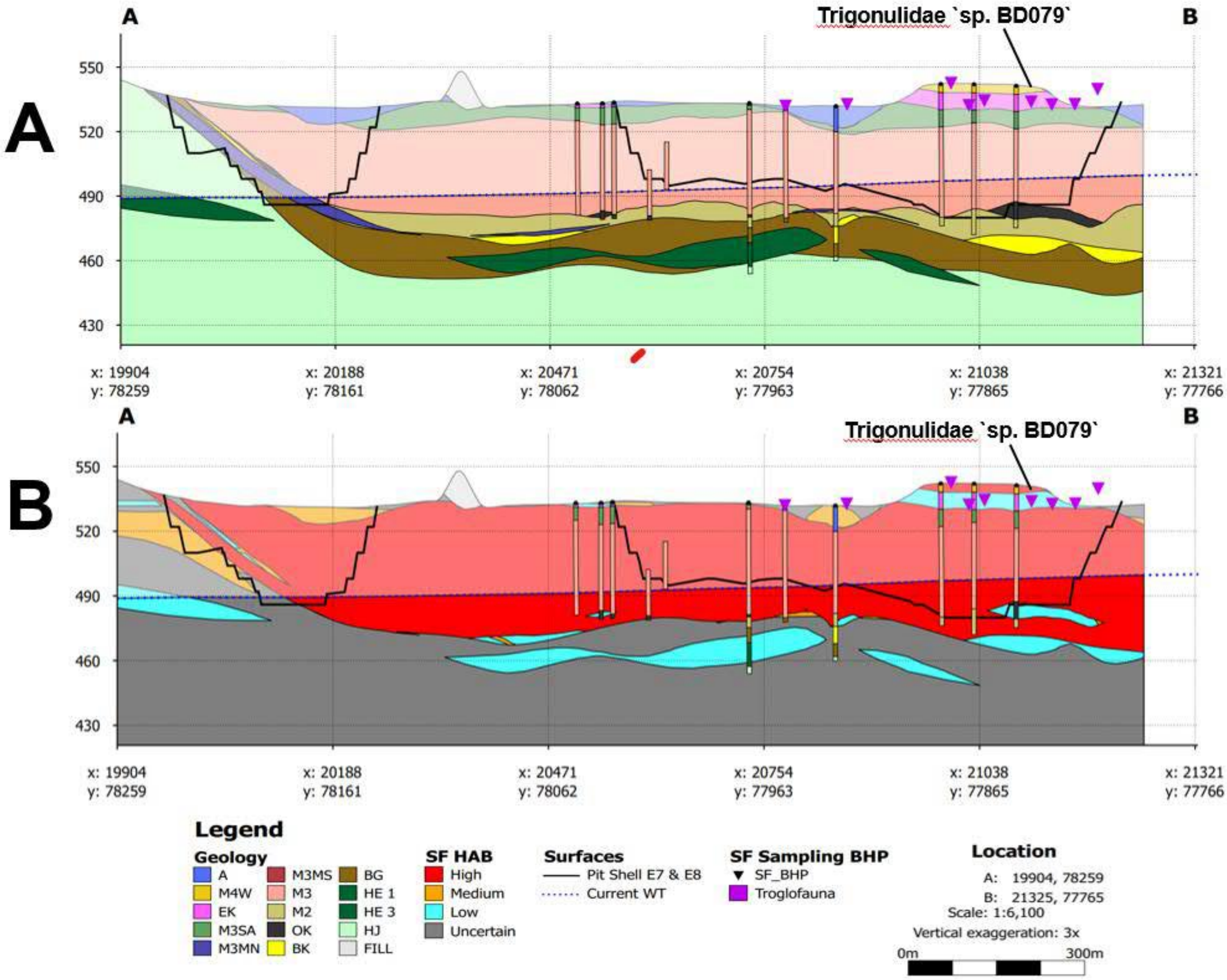


Figure 5.11. Cross section A-B (west to east) at E8 pits showing potential AWT habitat for Trigoniulidae `sp. BDI079`; A) Stratigraphy and B) high, medium, and low potential habitat. Triangle symbols indicate subterranean fauna records from sampling.

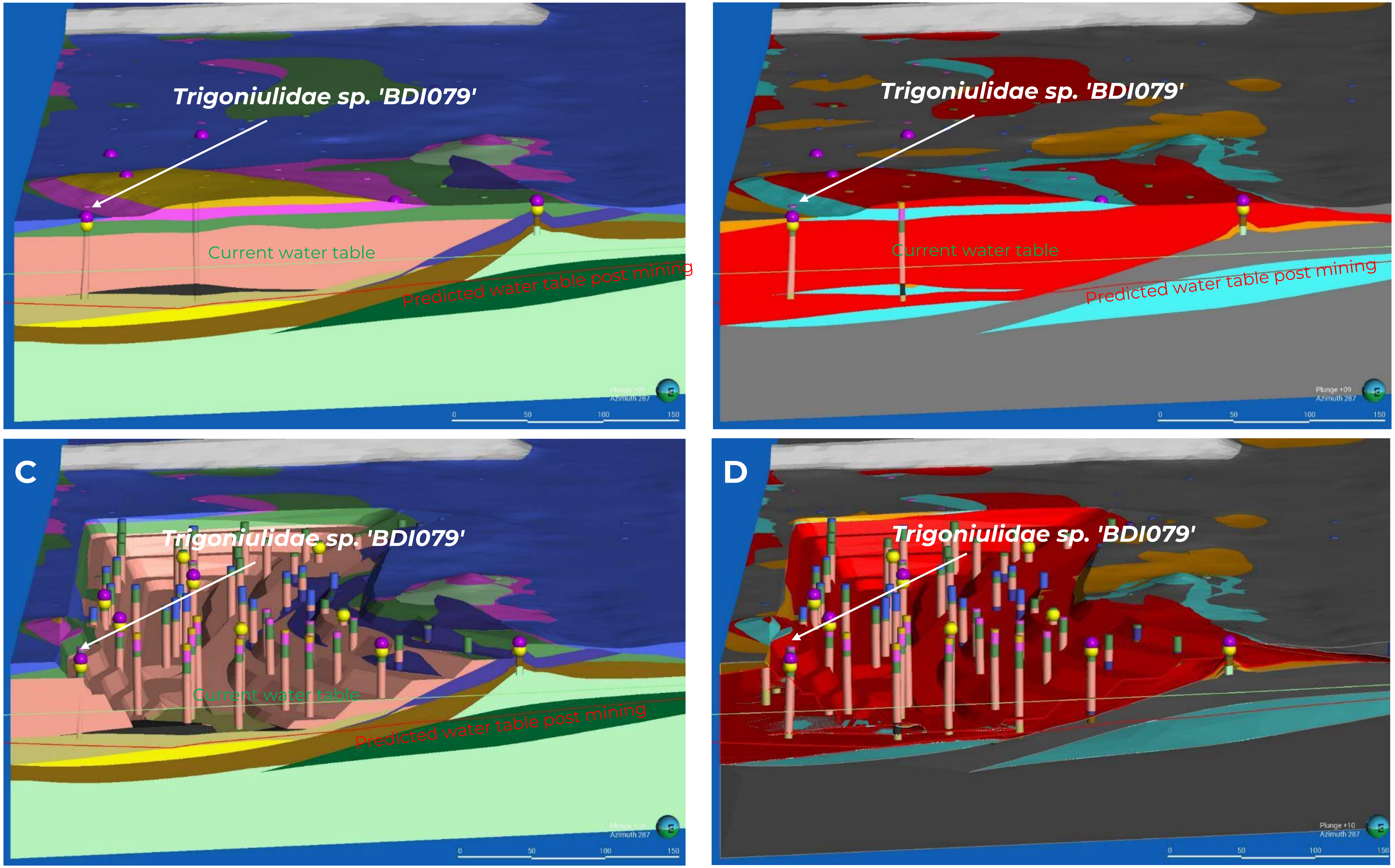


Figure 5.12. Oblique view of the 3D model from east, location of Trigoniulidae `sp. BDI079`; A) Current stratigraphy, B) Current high, medium, and low potential habitat, C) Stratigraphy after mining, and D) high, medium, and low potential habitat remaining after mining. Units coloured as per Figure 5.11.

5.6 *Elaphoidella `sp. BHA342`*

The harpacticoid *Elaphoidella `sp.* BHA342` was recorded from two sites, located approximately 600 m apart, within and outside of the proposed eastern E8 Pit (Figures 5.1, 5.2). BLAST analysis against available DNA sequence libraries detected a regional match with sequence material collected during aquatic hyporheic sampling at Jugaricoogina Creek (Biologic 2024).

Biologic had identified the hyporheic specimens as `cf. *Australocamptus* sp. Biologic-HARP064`, but the genetic analysis matched *Elaphoidella `sp.* BHA342` (Appendix B). Both genera occur in the family Canthocamptidae, and there may be some taxonomic uncertainty at the genus level. A genetic phylogeny of publicly available specimens identified as *Elaphoidella* and *Australocamptus* showed that these two genera were not monophyletic (i.e. not clearly separated in the phylogenetic tree), suggesting that a taxonomic and genetic review may be required for this family (Biologic, 2024; Appendix B).

Notwithstanding the issues that this may pose for determining species distribution for widespread named species, a review of OTUs in Biologic's sequence libraries showed an average linear range of approximately 54 km across 15 genetically determined OTUs (min 1 km, max 162 km), with about half of the OTUs represented from singletons (Biologic unpublished data).

The DNA match extends the known linear range of the target taxon (*Elaphoidella `sp.* BHA342`/ cf. *Australocamptus* `sp. Biologic-HARP064`) to approximately 4.6 km, beyond its known records at the Study Area (Figure 5.13). Jugaricoogina Creek occurs within Marillana Creek catchment, and it is not unusual for stygofauna to be distributed throughout connected tributaries and the wider catchment. `cf. *Australocamptus* sp. Biologic-HARP064` was collected from hyporheic habitats, which are known to occur widely throughout the Marillana Creek catchment (Biologic, 2023).

The impacts from the Proposal to *Elaphoidella `sp.* BHA342`/ `cf. *Australocamptus* sp. Biologic-HARP064 are unlikely to be significant, because:

- This species is known to occur beyond the impact area approximately 4.6 km away at Jugaricoogina Creek; and
- The species is known to inhabit hyporheic habitats and may occur more widely than currently recorded throughout the Marillana Creek and Jugaricoogina Creek catchment.

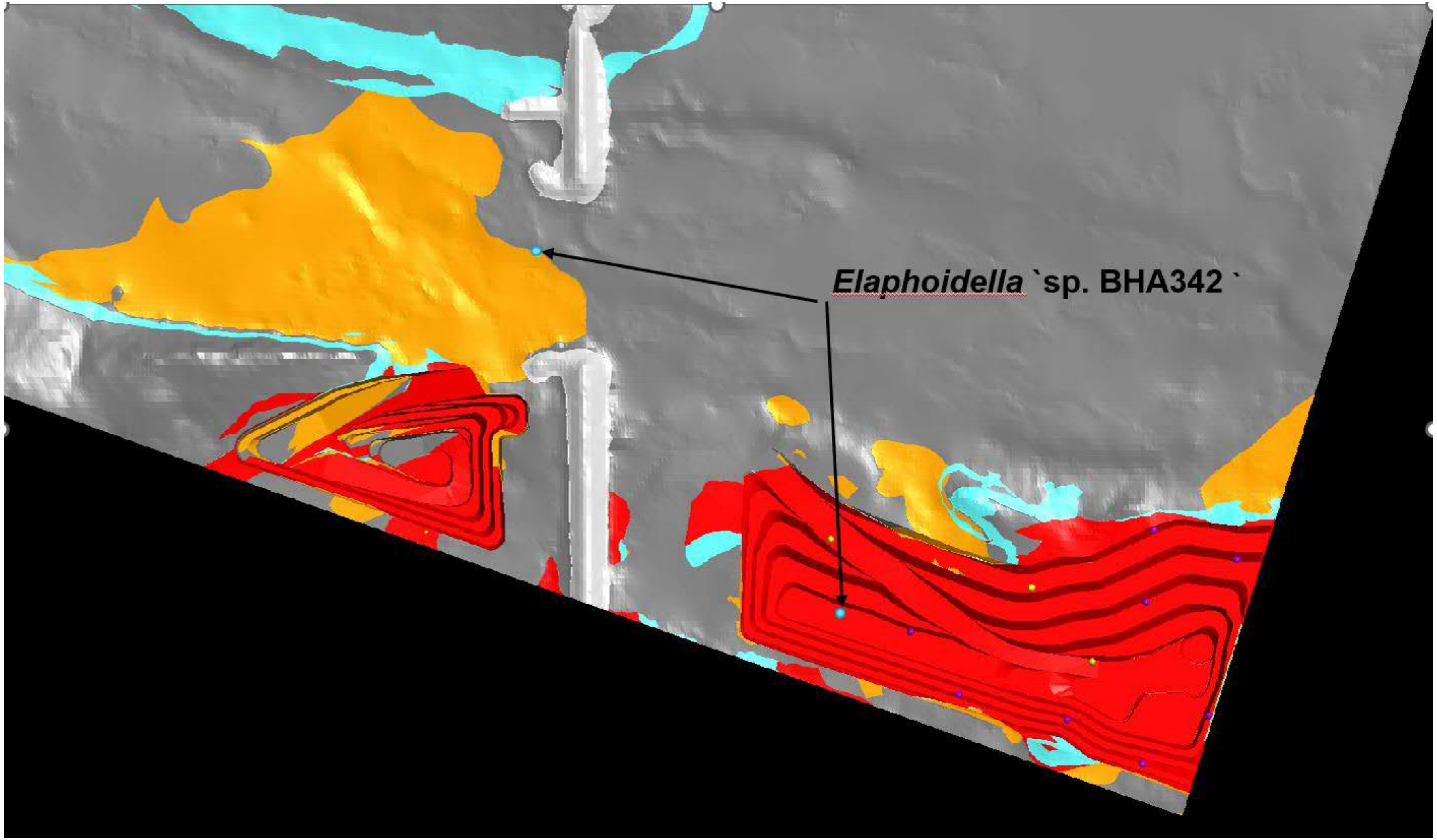


Figure 5.13. *Elaphoidella* `BHA342` records in relation to high suitability habitat (CID) and medium suitability habitat (alluvial detritals)

5.7 *Parastenocaris `sp. BHA343`*

The harpacticoid *Parastenocaris* `*sp.* BHA343` was collected from a single site within the easternmost of the proposed E8 Pits (Figure 5.1, Figure 5.2). Bennelongia (2024) failed to sequence this OTU, therefore it is currently known only from its single collection record within the Study Area.

Parastenocaris copepods are among the smallest stygofauna crustaceans, and most named species and morphospecies in the Pilbara region are typically considered to be widespread throughout regional catchments. It has not been common to genetically sequence *Parastenocaris* specimens until recently, which is revealing greater diversity of species and ranges than previously recognised (Biologic unpublished data).

Of the 25 *Parastenocaris* OTUs in Biologic's sequence libraries at the time of writing, approximately two-thirds are represented by singletons. Of the remaining seven OTUs, the average linear range was 101 km (min 7 km, max 325 km) (Biologic unpublished data). Several OTUs (including OTUs with narrow and wide ranges) were collected from hyporheic sampling during aquatic surveys, particularly in the Weeli Wolli Creek/ Marillana Creek catchments. Nevertheless, none of these OTUs could be directly compared to *Parastenocaris* `*sp.* BHA343` due to the lack of sequence data for this species, therefore as a precaution the OTU is assessed as a potential singleton.

2D geology mapping at this species' location showed CID/ Tp and alluvials (Figure 5.1 and Figure 5.2). Drill logging data BWT at this species' location showed:

- M3 – Marillana Fm - Upper CID;
- M2 - Marillana Fm - Lower CID; and
- OK - Marillana Fm – Ochreous clay.

Based on available drilling data and modelling, the upper and Lower CID units are likely to provide high suitability stygofauna habitat while the ochreous clay (OK) layer is less suitable due to lower permeability. In the eastern pit at E8, the basal conglomerate (Munjina Member, BG) is somewhat fractured and weathered, and may provide some potential habitat at depth, but the few available drill cores of Weeli Wolli Formation (HJ) appeared to show relatively fresh BIF (Appendix A). The BG and HJ have not been extensively drilled at depths below the E8 pits, therefore they are ranked as uncertain habitat suitability (Figure 5.14b).

Current 3D modelling predicts that the proposed drawdown would significantly reduce the available habitat BWT for *Parastenocaris* `*sp.* BHA343`. The 'Predicted Impact WT' occurs below the majority of high and medium suitability habitat (Figure 5.14, Figure 5.15, Figure

5.16). There appears to be only a few small, fragmented patches of suitable habitat remaining BWT in the CID, and the occurrence of deeper potential habitats in the BG/ HJ is uncertain.

Based on current information, the impacts from the Proposal to *Parastenocaris* `*sp.* BHA343` could be considered significant, because:

- This OTU is currently only recorded from the eastern E8 pit and has been conservatively assessed as a singleton taxon;
- The proposed groundwater drawdown reduces the available BWT habitat to a few shallow, fragmented patches within CID; and
- The potential for deeper potential habitats within other local lithologies are uncertain, and wider potential habitats within the Jugari lease are uncertain, due to historic mining and groundwater drawdown.

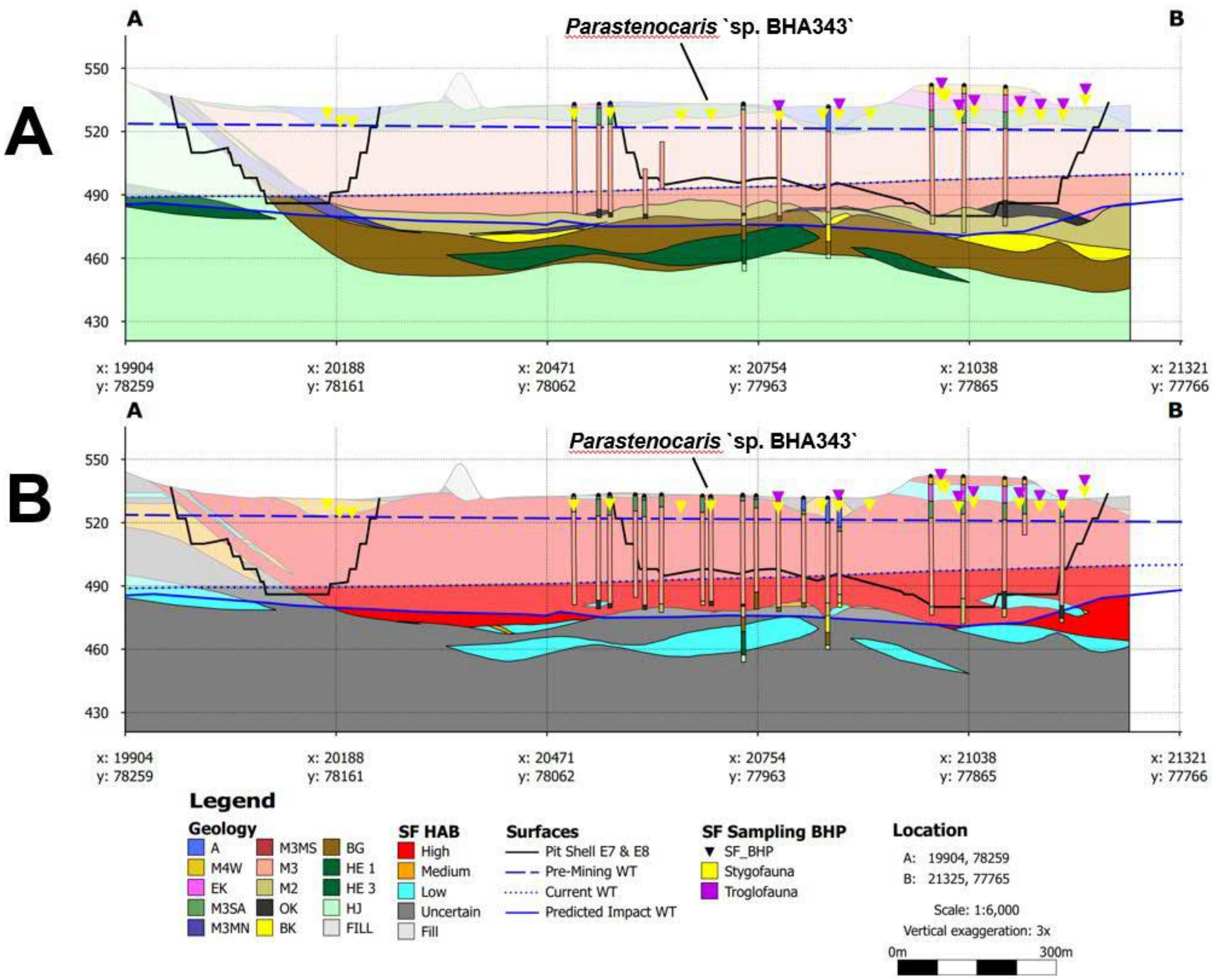


Figure 5.14. Cross section A-B (west to east) at E8 pits showing change in potential BWT habitat for Parastenocaris `sp. BHA343` under different groundwater scenarios. A) Stratigraphy and B) high, medium, and low potential habitat ranks. Triangle symbols indicate subterranean fauna records from sampling.

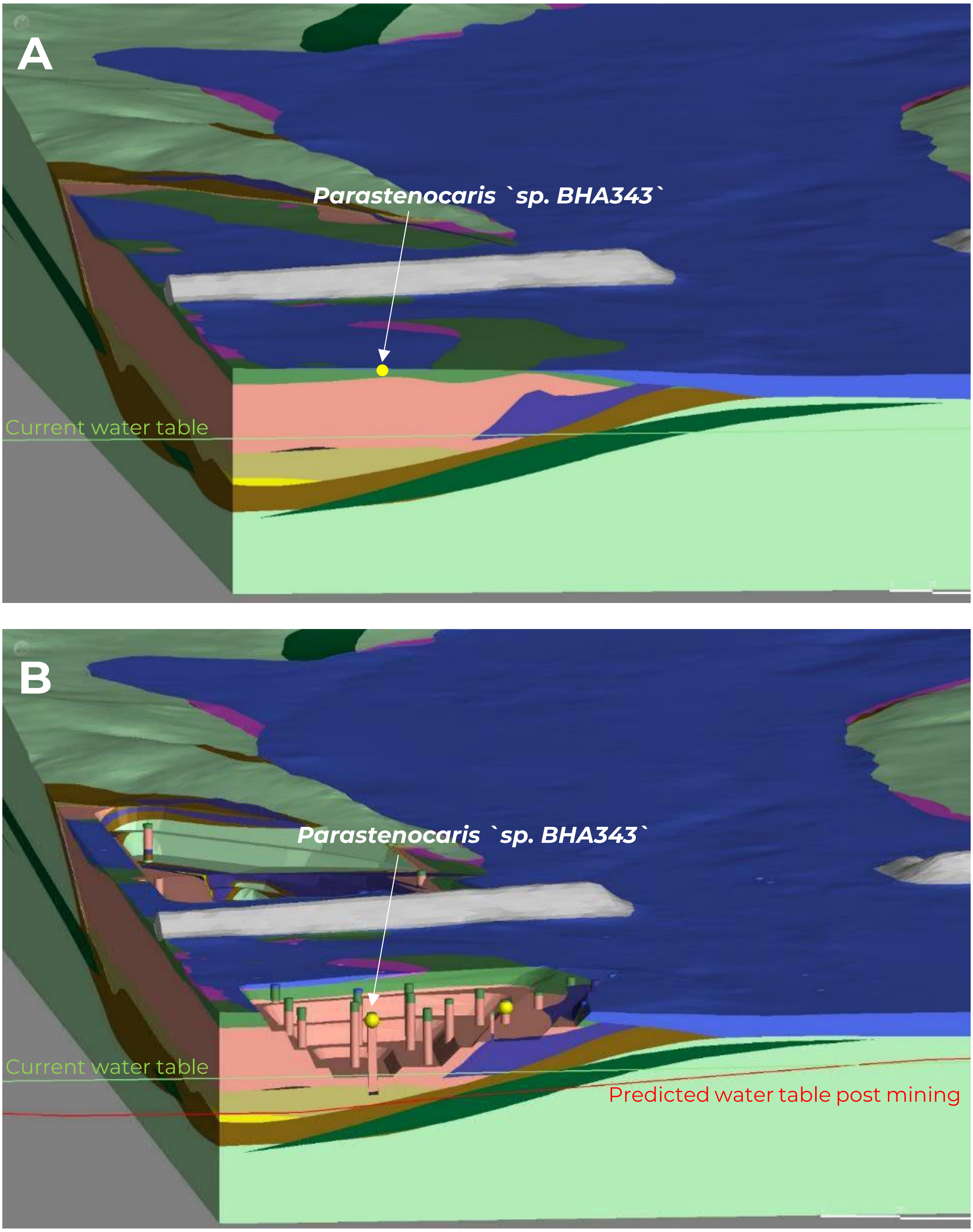


Figure 5.15. Oblique view of the 3D model from east, location of *Parastenocaris* `BHA343`; A) current habitat, B) geological habitat remaining after mining. Stratigraphy coloured as per Figure 5.15.

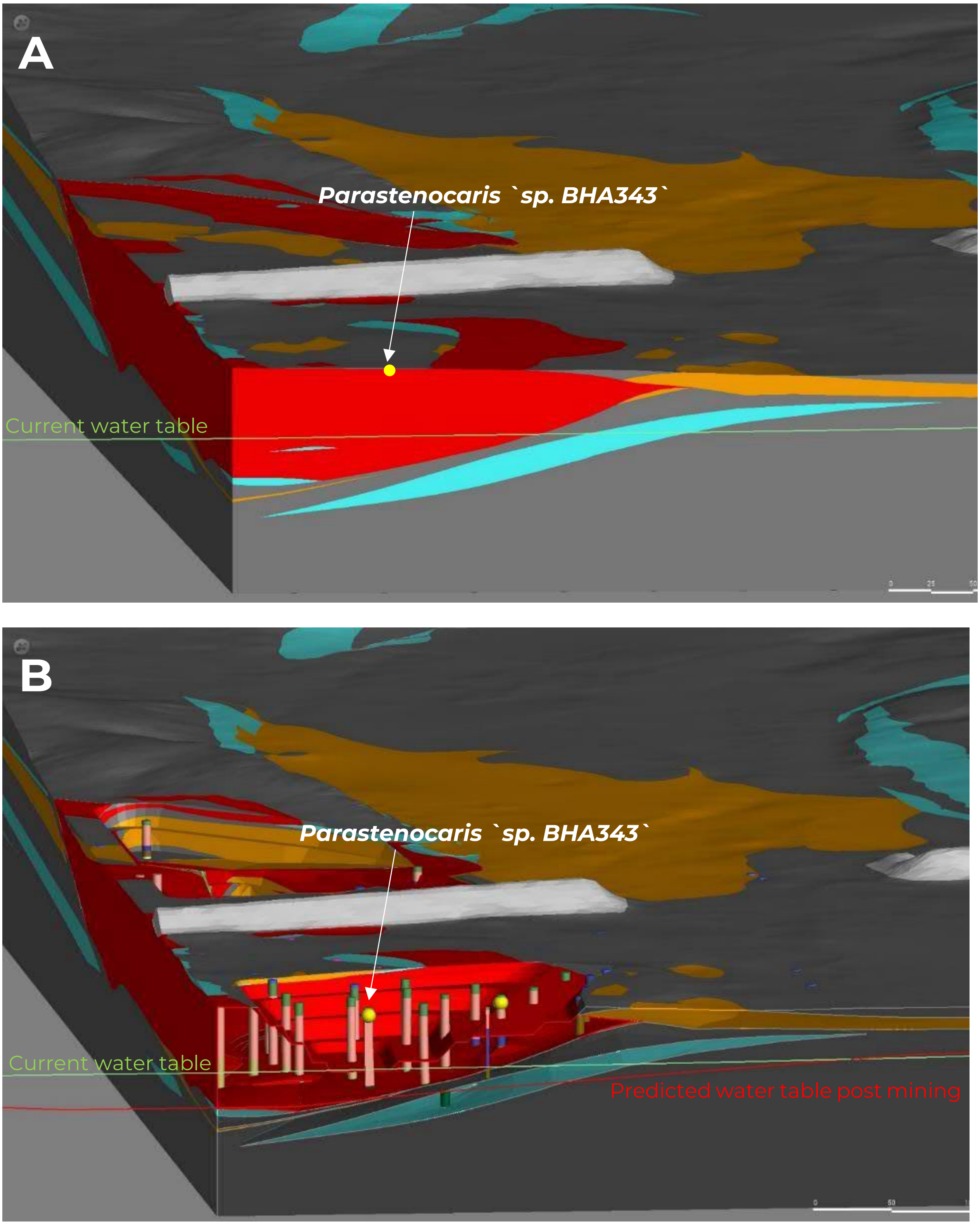


Figure 5.16. Oblique view of the 3D model from east, location of *Parastenocaris* `sp. BHA343`; A) current habitat, B) high, medium, and low potential habitat remaining after mining. Habitat suitability categories coloured as per Figure 5.15.

6 Key Findings

Subterranean fauna surveys for the East 8 Proposal detected five target troglofauna species (*Hanseniella* sp. indet., *Cryptops* sp. 'BSCOL091', *Hesperanillus* sp. 'BCO247', Haplodesmidae sp. 'BDI080', Trigoniulidae sp. 'BDI079'), and two target stygofauna species (*Elaphoidella* sp. 'BHA342' and *Parastenocaris* sp. 'BHA343') that were known only from within potential impact areas. This assessment has modelled the subterranean habitats throughout the Study Area and assessed the impacts to the known extent of suitable habitats for these species.

The proposed mining of the East 8 pits is predicted to result in a localised reduction of troglofauna habitat within the CID. Nevertheless, the habitat modelling has revealed a wider extent of connected, suitable habitat remaining intact outside the proposed pits in CID and alluvials. The impacts of the Proposal to the five target troglofauna species listed above are unlikely to be significant, as the proposed pits are relatively small compared to the wider extent of suitable habitat, and there are no habitat barriers between impacted and non-impacted areas. The assessment suggests that the Proposal should meet the EPA objectives in relation to troglofauna.

The proposed mining is predicted to result in a more substantial reduction of stygofauna habitat. Current groundwater levels have been subject to considerable drawdown from historic mining, and the proposed dewatering for the East 8 pits will further reduce groundwater levels. The copepod *Elaphoidella* sp. 'BHA342' has been found to occur more widely beyond the Study Area at Jugaricoogina Creek; therefore, this species is likely to occur more widely throughout the catchment and is not expected to be seriously impacted.

In contrast, the copepod *Parastenocaris* sp. 'BHA343' is known only from the impact area at the time of writing, and is conservatively assessed as a singleton taxon. The assessment found that the potential impacts to *Parastenocaris* sp. 'BHA343' could be considered significant, as the known extent of its habitat is predicted to be significantly reduced and fragmented following implementation of the Proposal. There are some residual uncertainties concerning the potential wider occurrence of this species beyond the impact area and the possibility of deeper habitats in hydrogeological units that may remain below water table after groundwater drawdown. Nevertheless, the Proposal may not be able to meet the EPA objectives in relation to *Parastenocaris* `sp. BHA343` unless this species' occurrence beyond the impact areas can be confirmed, or pending further mitigation of the predicted impacts to groundwater.

7 References

Barley, M. E., Pickard, A. L., & Sylvester, P. J. (1997). Emplacement of a large igneous province as a possible cause of banded iron formation 2.45 million years ago. Nature, 385, 55-58.

Bell, P., Eberhard, S.M., Perina, G., and Stevens, N. (2010). Troglofauna in the Pilbara region, Western Australia Troglofauna in the Pilbara region, Western Australia – Patterns in diversity and distribution, and sampling considerations for conservation. *KIP Abstracts. 19*.

Bennelongia. (2024). Yandi Operations Subterranean Fauna Survey Report. Prepared for: BHP WAIO. Jolimont, WA.

BHP. (2023). Yandi Conceptual Hydrogeological Model. Internal BHP WAIO Report.

Biologic. (2019). Hope Downs 1 Subterranean Fauna Molecular Systematics Analysis. East Perth, WA.

Biologic. (2021). McPhee Creek Subterranean Fauna Assessment. East Perth, WA.

Biologic. (2021a). Memorandum: Subterranean Fauna Habitat Assessment and Modelling. Report to Rio Tinto Iron Ore. April 2021. Proponent response to submissions on the Greater Paraburdoo Iron Ore Hub Proposal Public Environmental Review.

Biologic. (2021b). McPhee Creek Subterranean Fauna Assessment: 3D Habitat Modelling Memo Report to Atlas Iron Limited August 2021. Appendix S for the McPhee Creek Iron Ore Project Public Environmental Review.

Biologic. (2022a). Greater Brockman Subterranean Fauna Survey. East Perth, WA.

Biologic. (2022b). Greater Brockman: Subterranean Fauna Survey. Unpublished report prepared for Rio Tinto Iron Ore.

Biologic. (2023). MAC Phase 4: Marillana Creek Baseline Aquatic Ecosystem Survey Dry 2021 and Wet 2022. East Perth.

Biologic. (2024). Memo: DNA comparisons of subterranean fauna sequences from AVL and TMAL projects. East Perth, WA.

EPA. (2016). Environmental Factor Guideline: Subterranean Fauna. Perth, Western Australia: Environmental Protection Authority.

EPA. (2021). Technical Guidance: Sampling Methods for Subterranean Fauna. Perth, Western Australia: Environmental Protection Authority.

EPA. (2023). Statement of environmental principles, factors, objectives and aims of EIA. Perth, Western Australia: Environmental Protection Authority.

Halse, S. (2018). Research in calcretes and other deep subterranean habitats outside Caves. Cave Ecology, 415-434.

Halse, S., & Pearson, G. B. (2014). Troglofauna in the vadose zone: comparison of scraping and trapping results and sampling adequacy. Subterranean Biology, 13, 17-34.

Harrison, S. E., Guzik, M. T., Harvey, M. S., & Austin, A. D. (2014). Molecular phylogenetic analysis of Western Australian troglobitic chthoniid pseudoscorpions (Pseudoscorpiones: Chthoniidae) points to multiple independent subterranean clades. Invertebrate Systematics, 28(4), 386-400.

Howarth, F.G. (1980). The Zoogeography of Specialized Cave Animals: A Bioclimatic Model. *Evolution*. vol. 34, no. 2, pp. 394-406.

Howarth, F.G. (1983). Ecology of Cave Arthropods, *Annual Review of Entomology*, vol. 28, pp. 365-89.

Perring, C. & Hronsky, J. (2019). BHP Guide to the Geology of the Hamersley Iron Ore Province (The Blue Book) Vol II. BHP Western Australian Iron Ore, Perth.

8 Appendices

Appendix A - Jugari East 8 Diamond Core Assessment Summary

Jugari East 8 Project Subterranean Fauna Habitat Assessment

Drill Core Photo Analysis

Biologic

Subterranean fauna habitat assessment summary – Diamond cores photo logging (metre intervals)

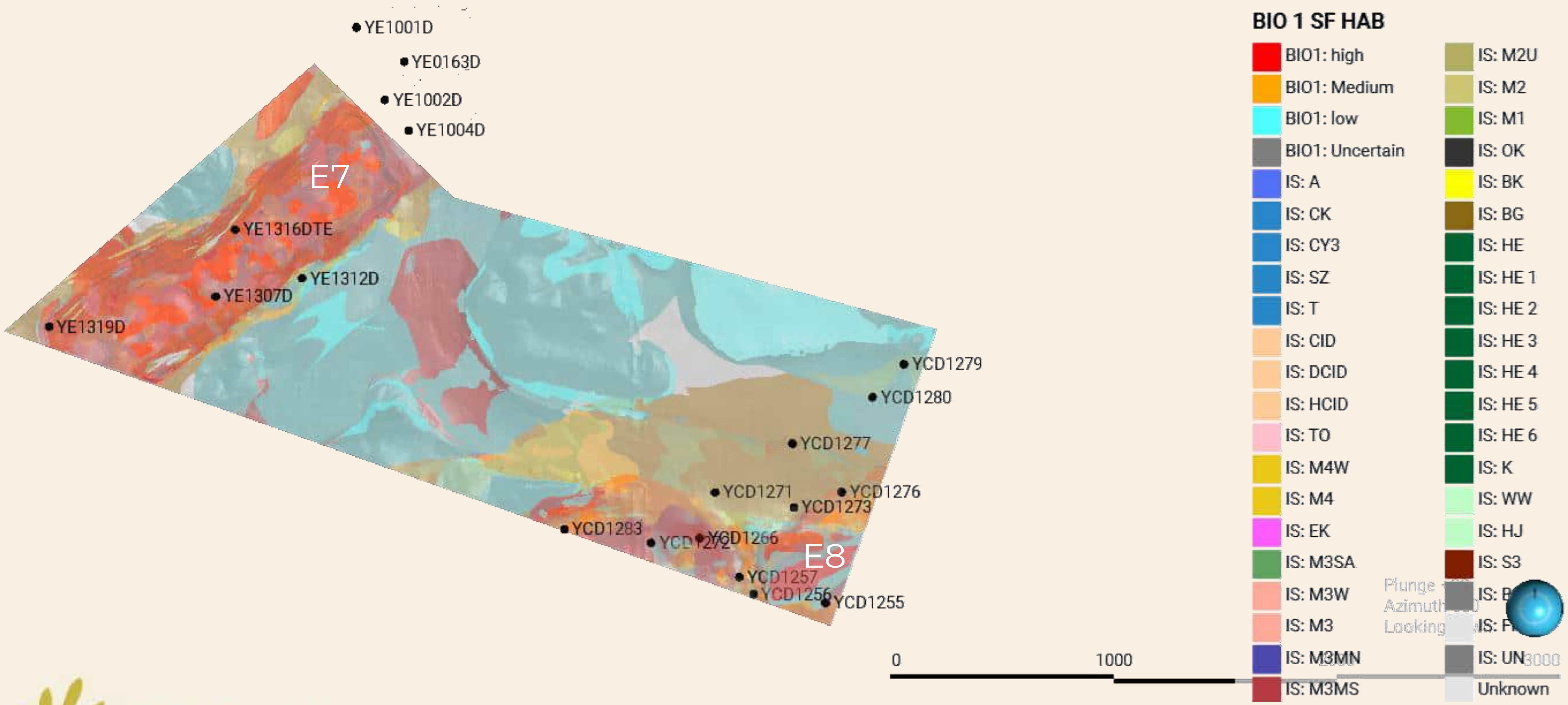
	Meters logged				
Unit	High	Medium	Low	Unknown	Total
A		53.00	61.30	106.20	220.50
SZ				15.00	15.00
M4W	5.04			8.00	13.04
M4	9.10				9.10
EK		16.71	5.70	15.00	37.41
M3SA	82.78	9.20		26.00	117.98
M3	460.97			80.00	540.97
M3MN	11.86				11.86
M3MS	18.00	5.30	2.00		25.30
M2	50.61	23.40	11.00	8.00	93.01
OK			9.00		9.00
BK	13.35	30.35	37.40	11.00	92.10
BG	64.12	18.10	35.82		118.04
HE			47.08	15.80	62.88
HJ	11.40	17.23	6.65		35.28

Constituent units of Jugari geological model (metres, count, %)

Unit	Count	Length	%
A	927	5712.51	3.83
SZ	83	447.25	0.30
CK	1	0.60	0.00
CID	34	1311.10	0.88
M4W	989	6760.30	4.54
M4	12	83.76	0.06
EK	1494	10809.54	7.25
M3SA	2543	18208.67	12.22
M3	2310	56060.76	37.61
M3W	1	5.70	0.00
M3MN	517	4676.27	3.14
M3MS	491	3833.20	2.57
M2	1269	14526.44	9.75
M1	17	241.50	0.16
OK	116	312.87	0.21
BK	1343	6906.34	4.63
BG	1785	9252.50	6.21
HE	2	23.13	0.02
HE 6	13	192.60	0.13
HE 5	11	92.95	0.06
HE 4	41	379.65	0.25
HE 3	8	148.15	0.10
HE 2	6	141.00	0.09
HE 1	19	244.40	0.16
HJ	667	4720.86	3.17
WW	40	409.50	0.27
FILL	72	1328.17	0.89
UN	82	2205.58	1.48
B	3	19.60	0.01
		149054.89	100.00

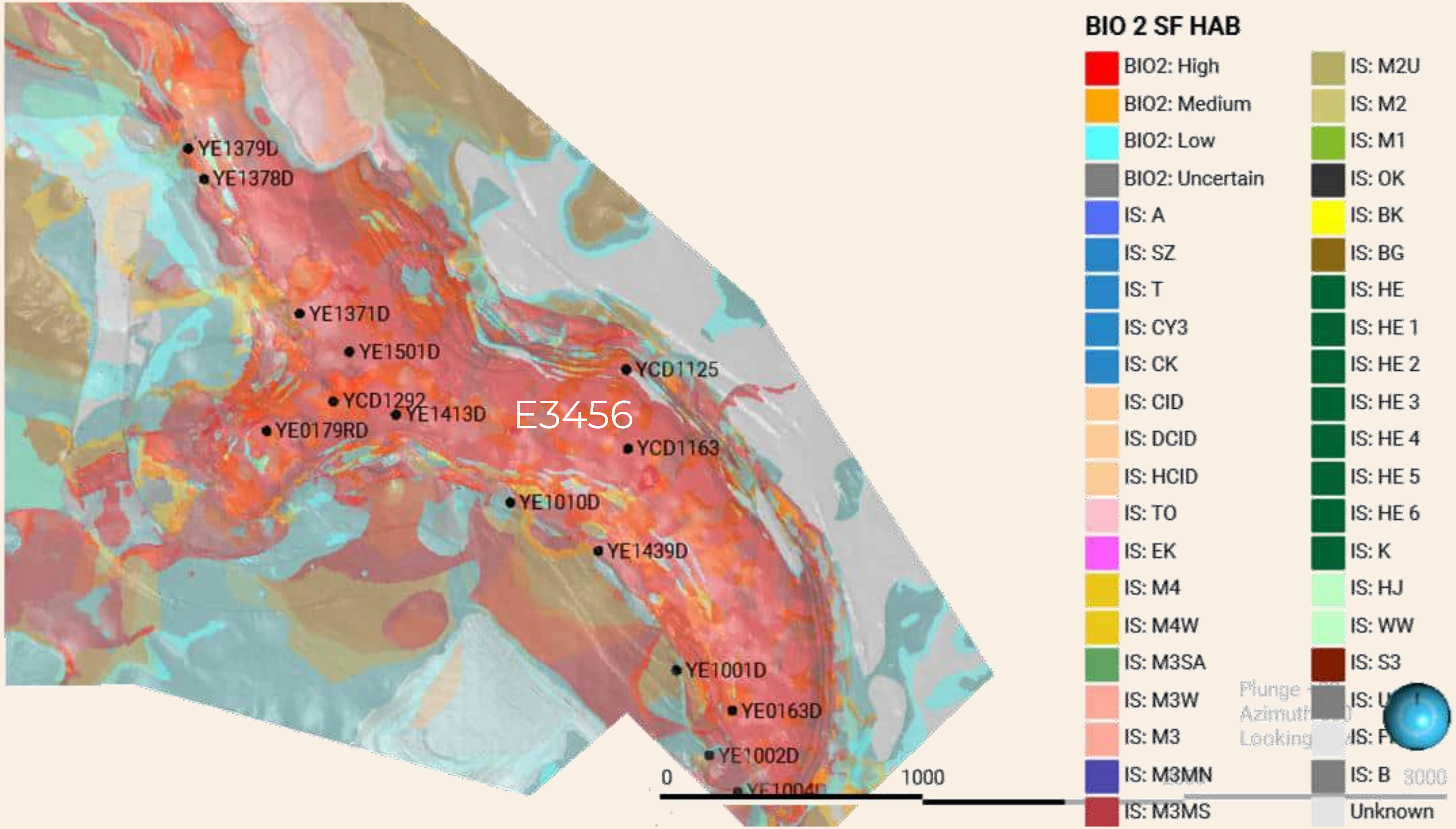
Biologic

BIO 1 (East 7/8 area) photo logged diamond core sites



Biologic

BIO 2 (East 3456 area) photo logged diamond core sites

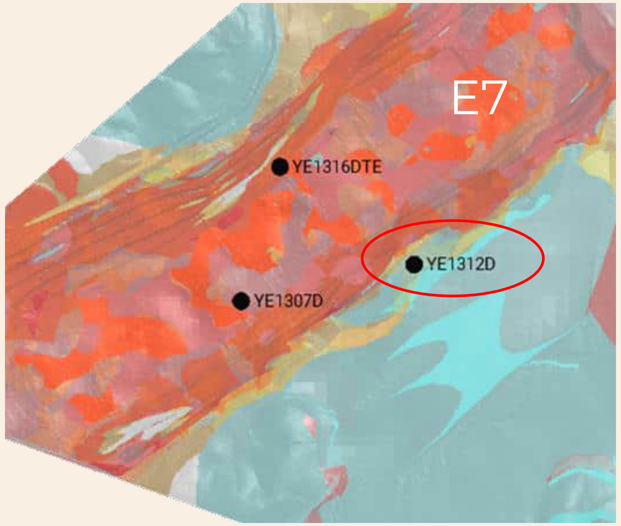


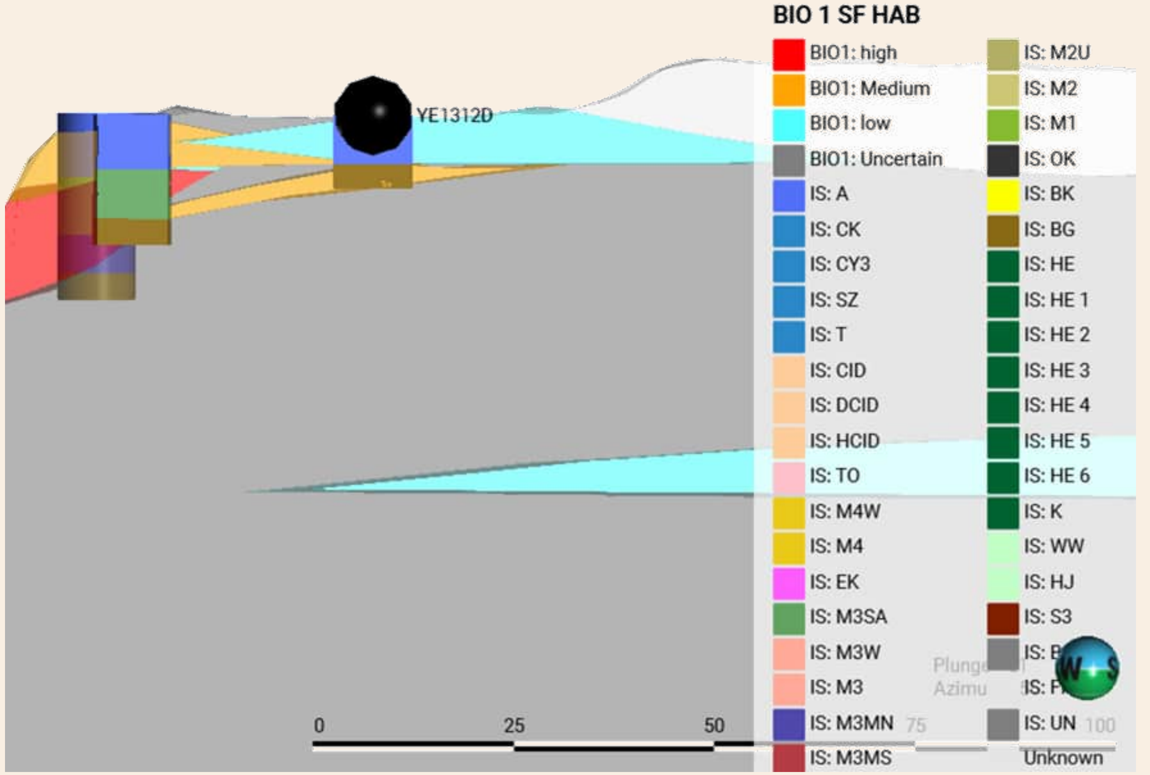
Biologic

Alluvials & Surface Scree - A, SZ - GAMMA API data applied

Compacted and clay rich matrix. Soft fractures

Medium habitat potential



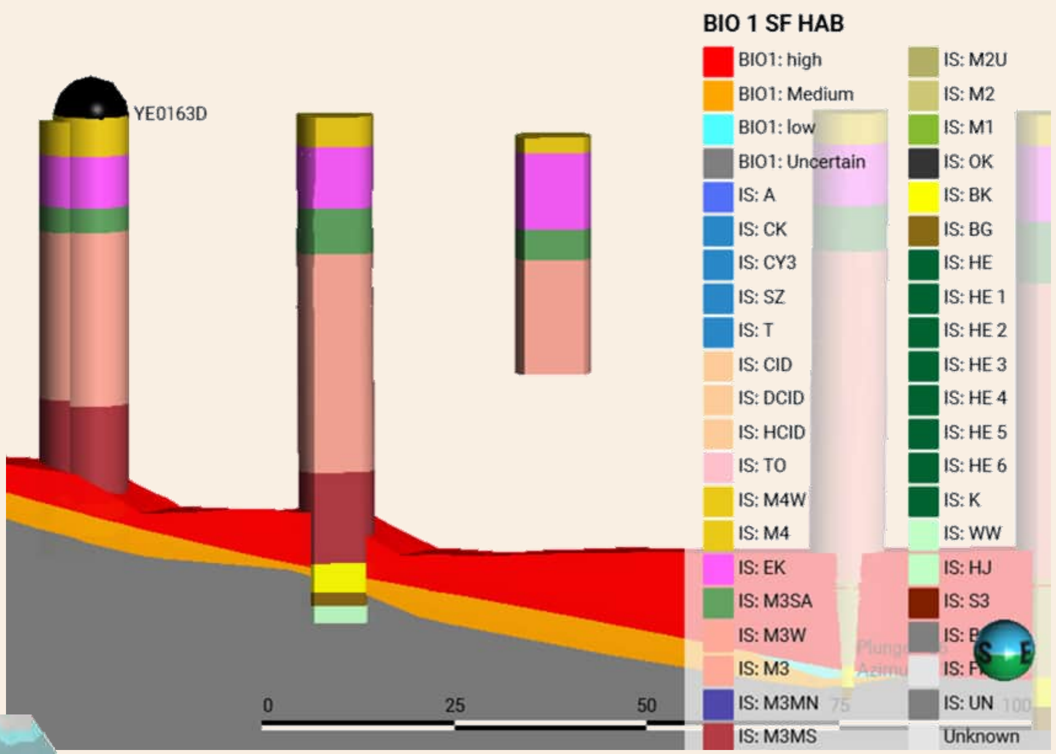


Biologic

CID - M4/W

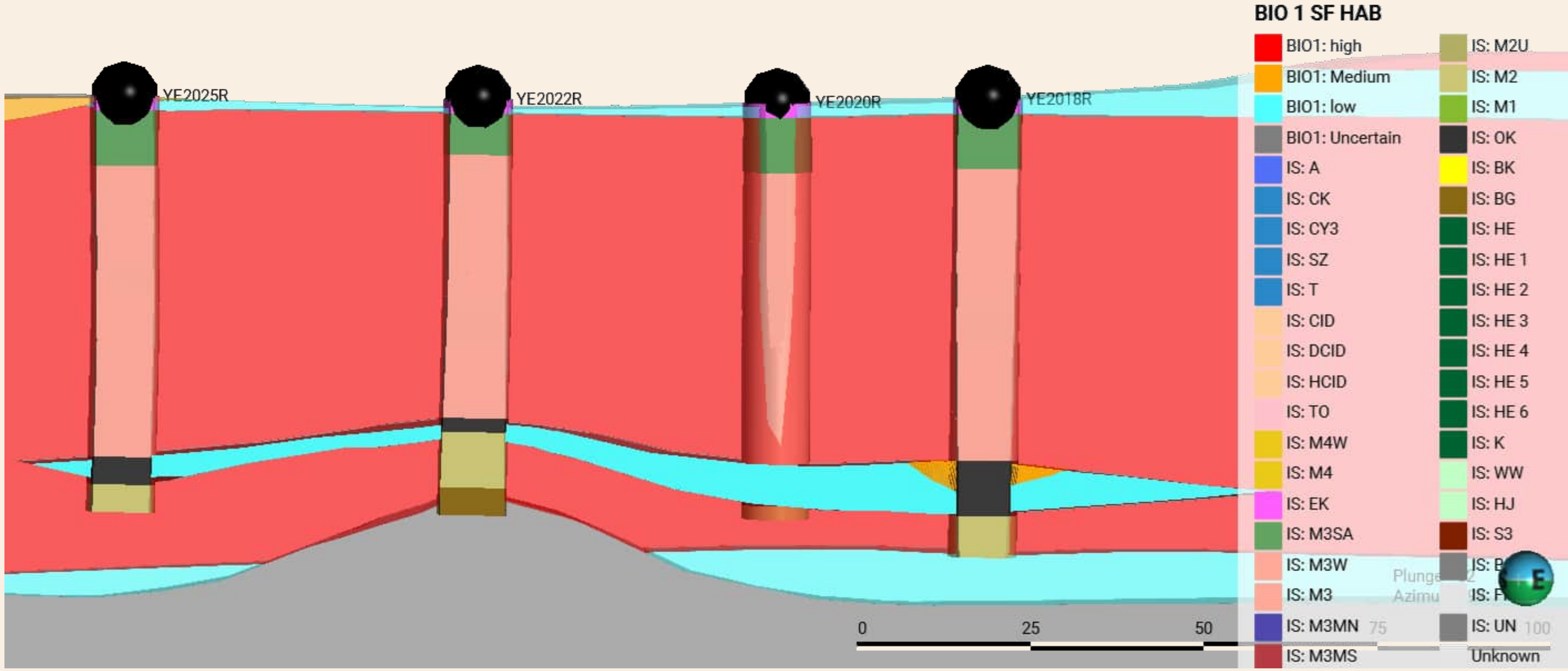
Vuhgy, fractured

High habitat potential

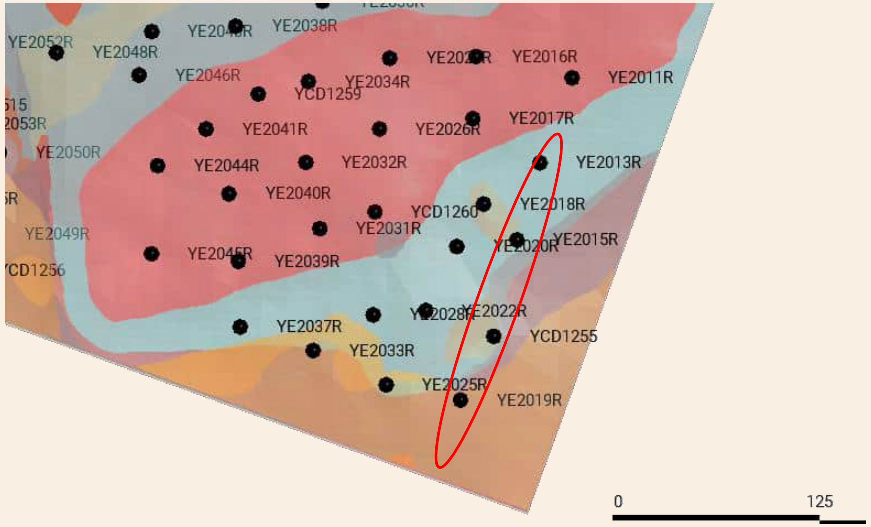


Biologic

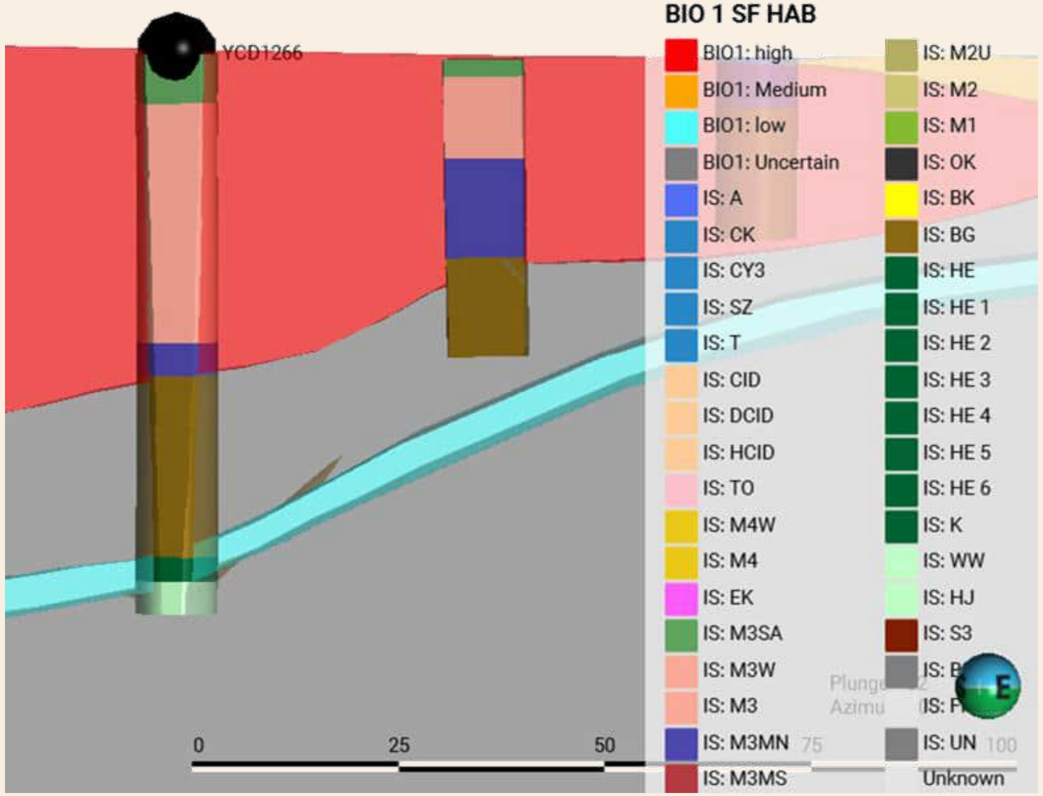
Clay - EK



Clay rich, low habitat potential

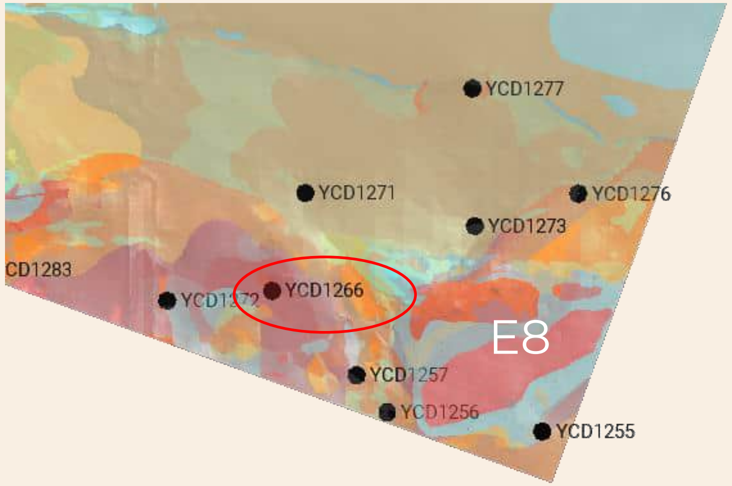


CID - M3SA



Vuhgy, well developed fractures

High habitat potential

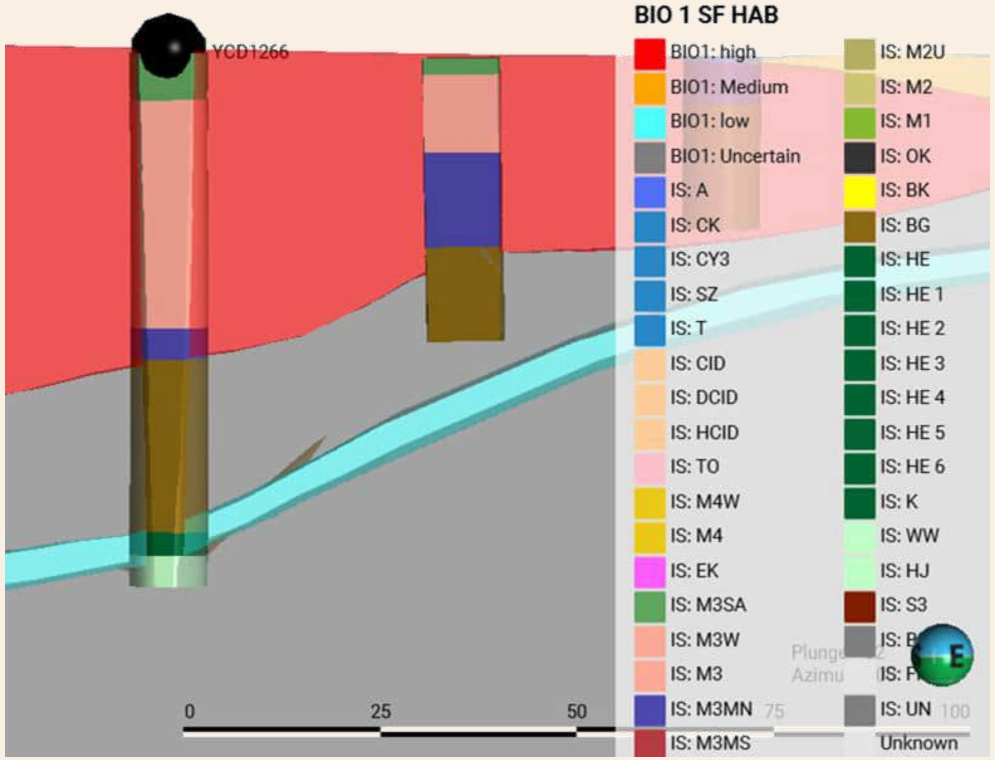


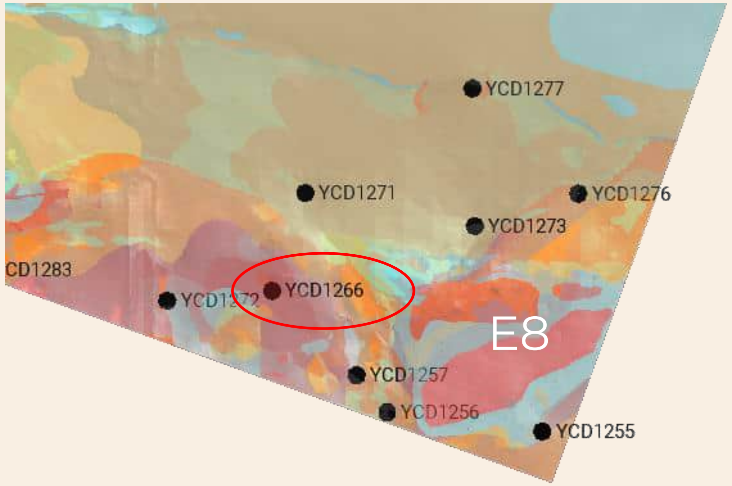
Biologic

CID - M3MN/S

Highly vuhgy and fractured

High habitat potential



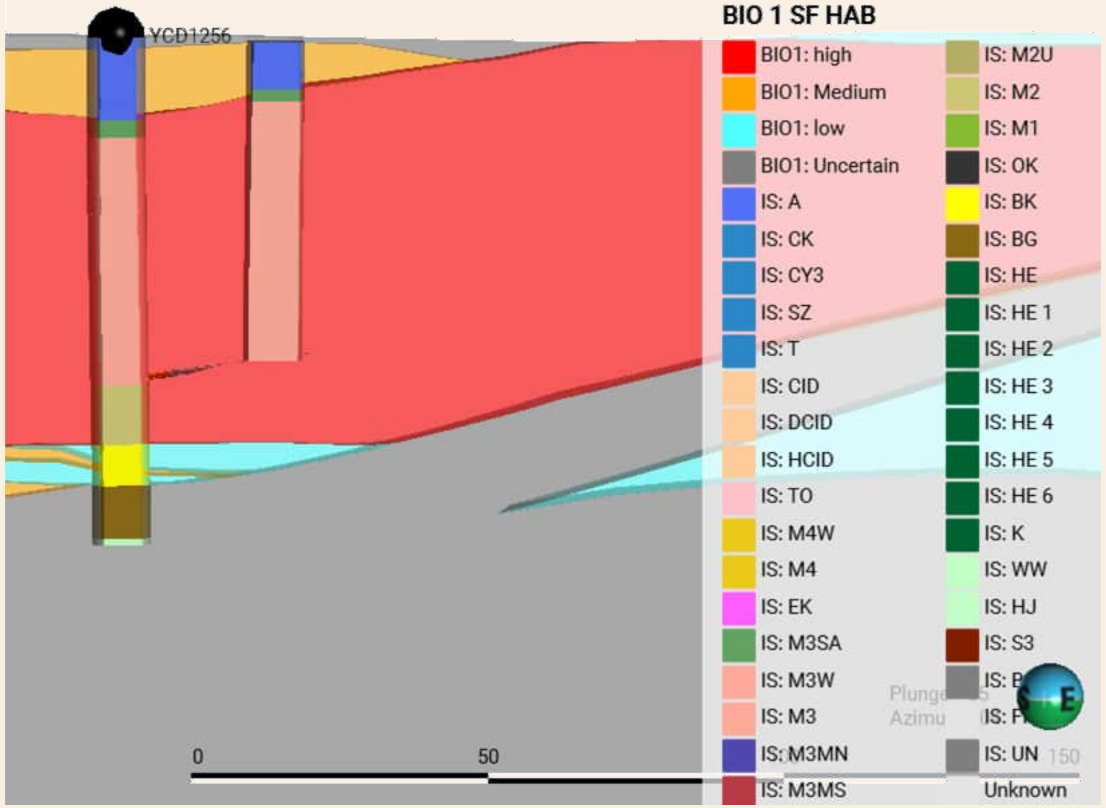


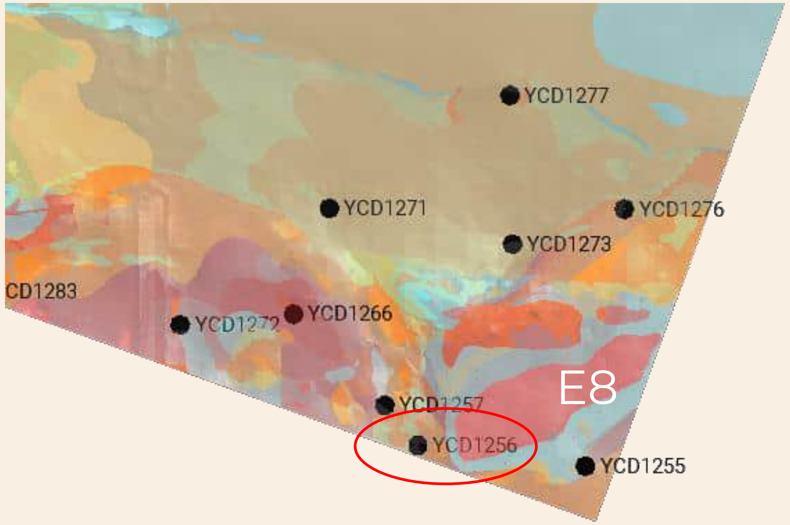
CID - M3/2

Vughy and highly fractured

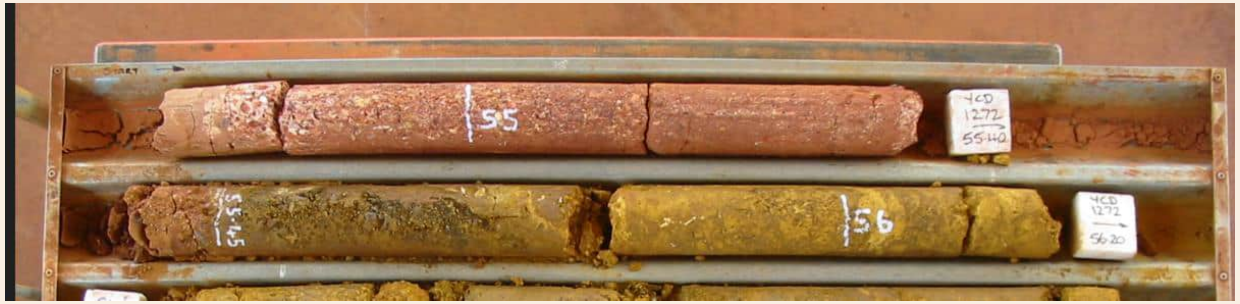
High habitat potential

Biologic

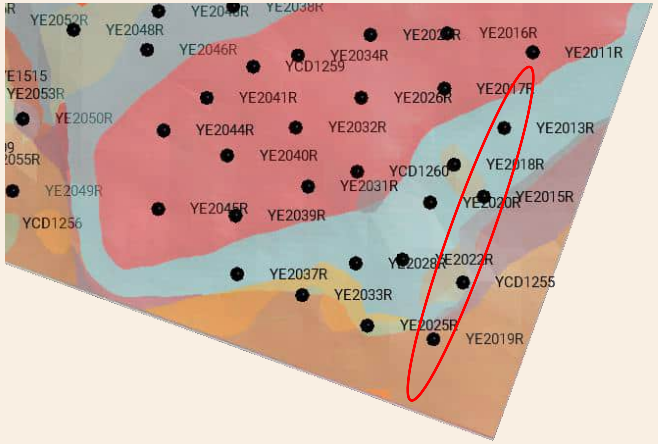


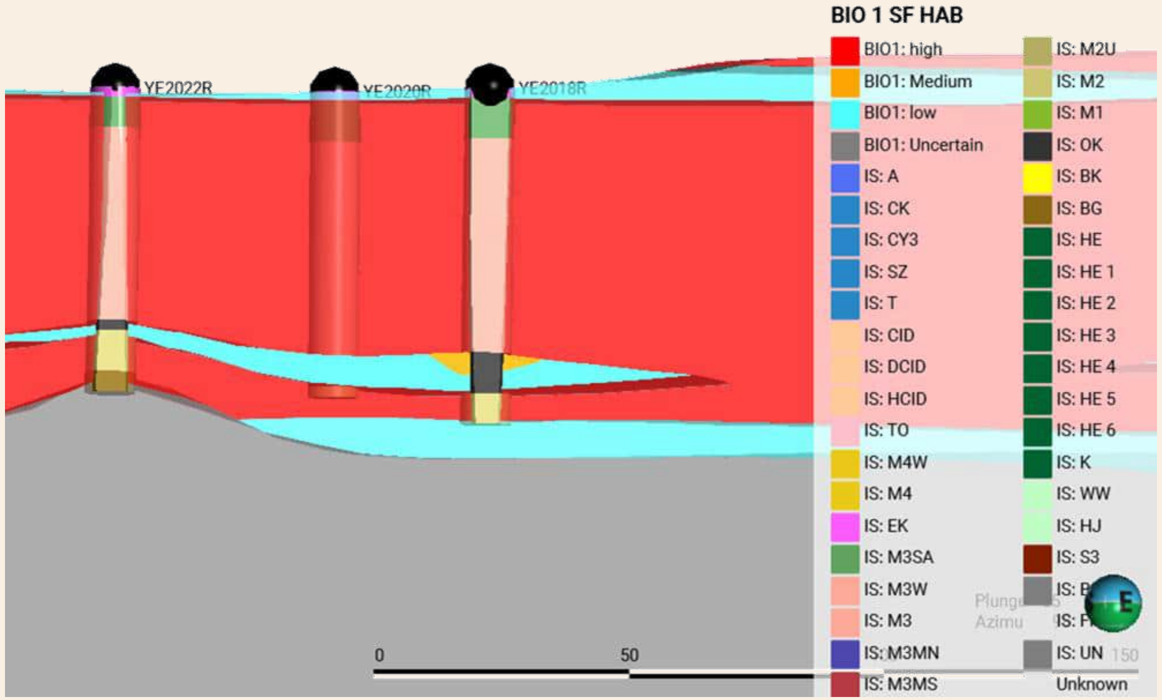


Ocherous Clay - OK – GAMMA API data applied

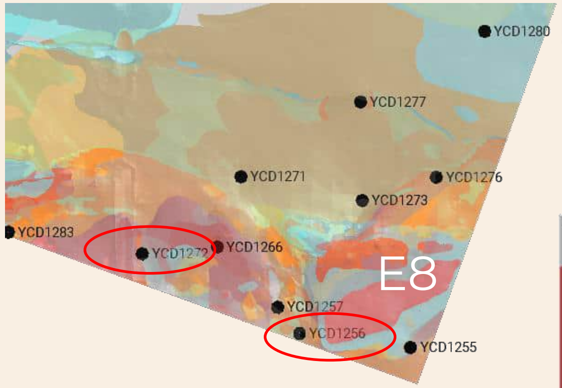


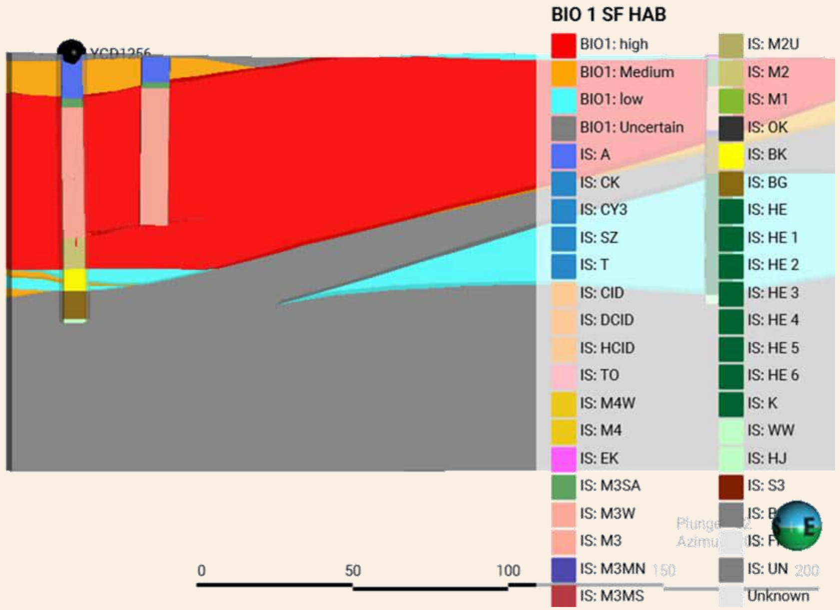
Clay and infrequent fractures.
Low, to Medium where fractured.

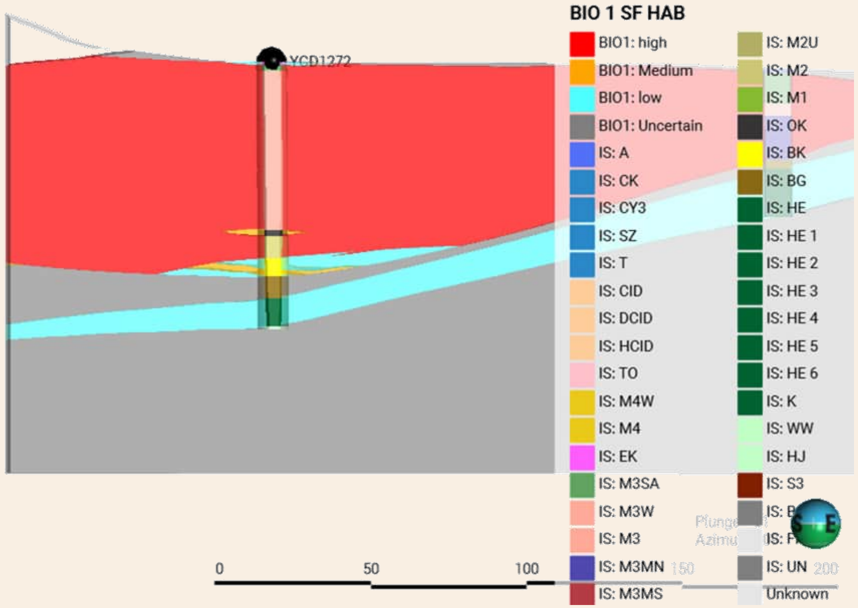




Basal Clay - BK – GAMMA API data applied







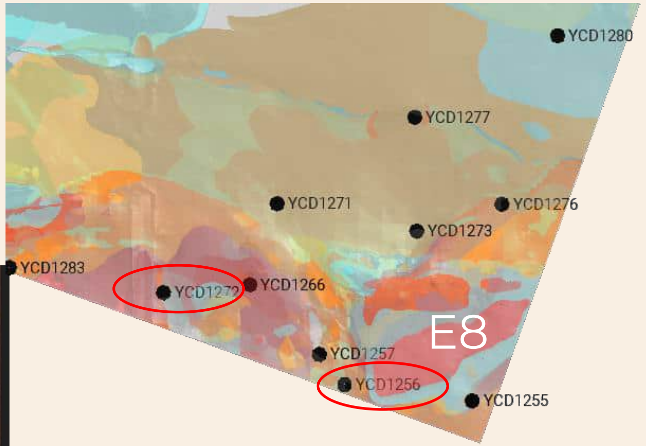
Highly fractured, broken, gravel to clay. Low to Medium potential

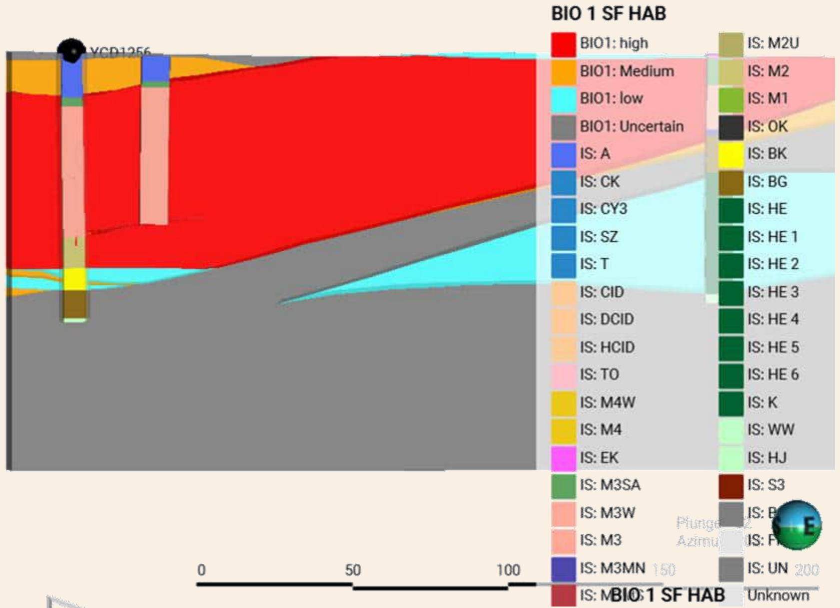
Biologic

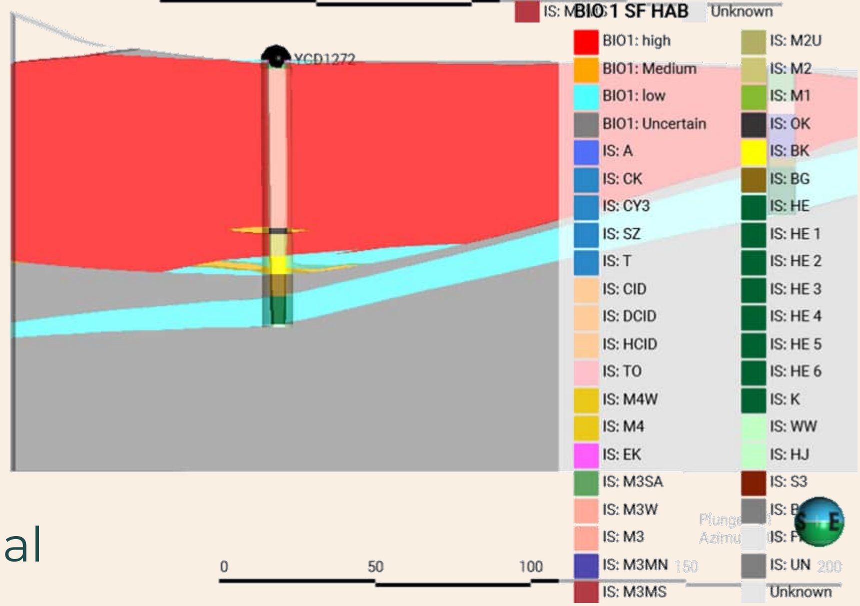
Basal Unit- BG – GAMMA API data applied

Low - Conglomerate with clay matrix

Low – Prevalent clay, soft fractures





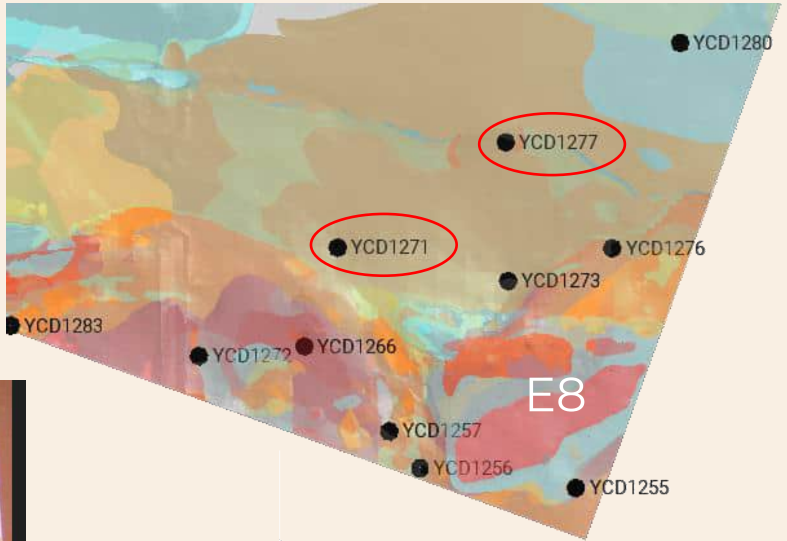


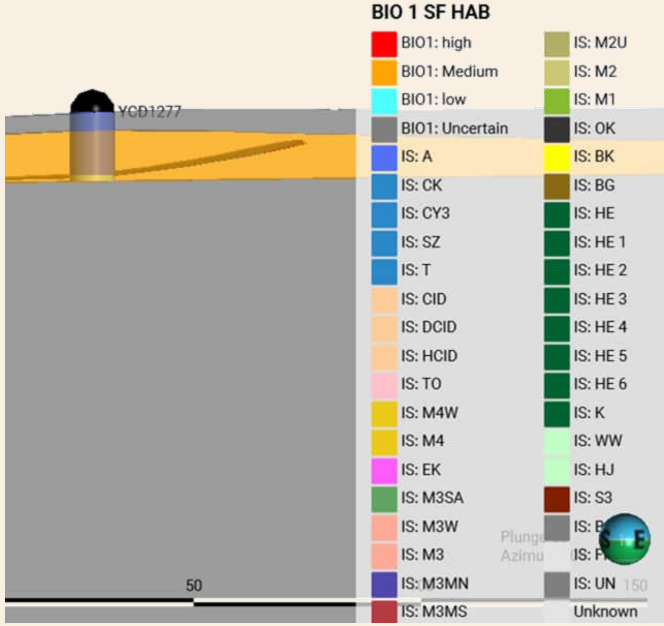
Unit locally variable in habitat potential

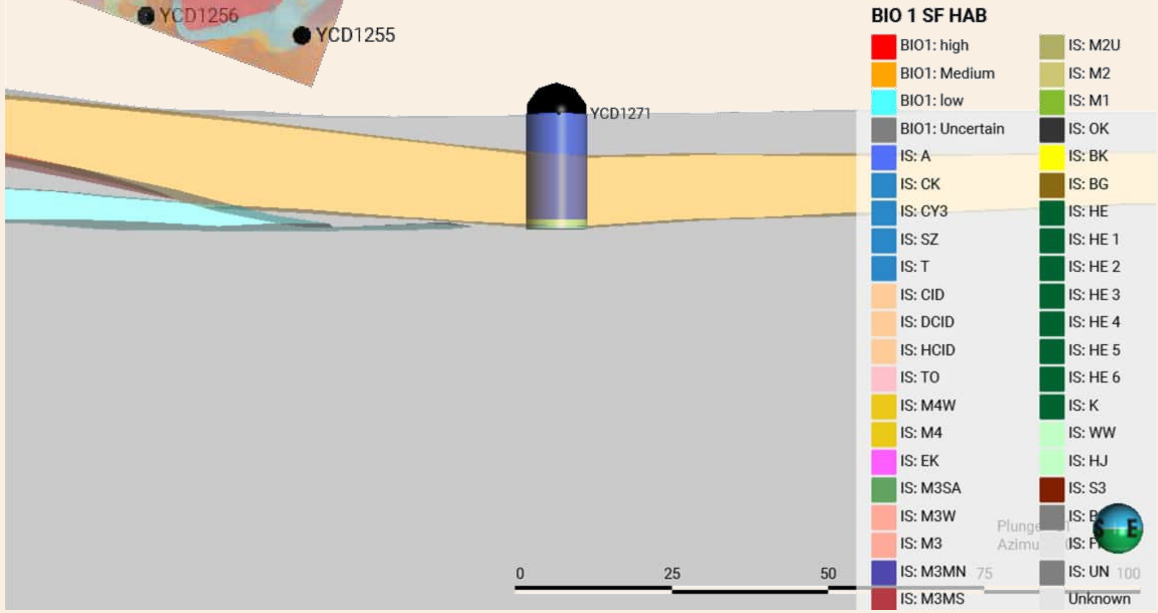
Weeli Wolli- WW – GAMMA API data applied

Medium – many small fractures, evidence of water penetration

Low – Competent BIF (below green marker)



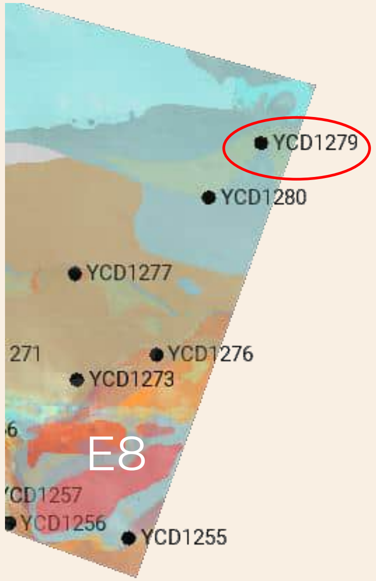


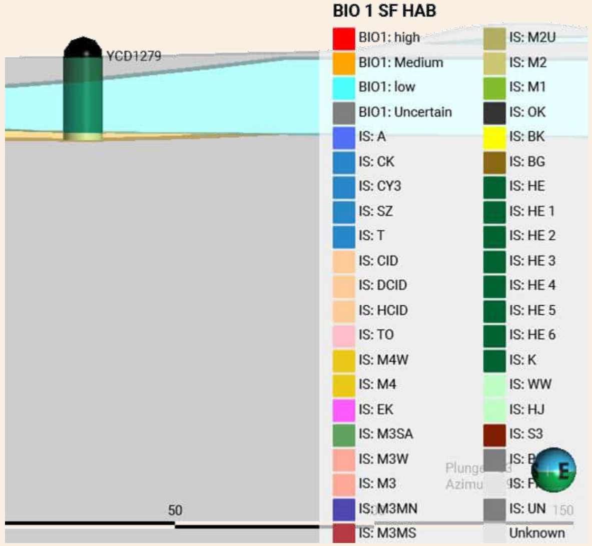


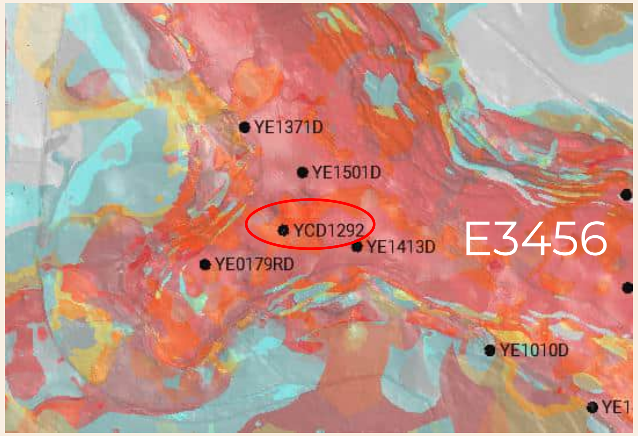
Dolerite - HE

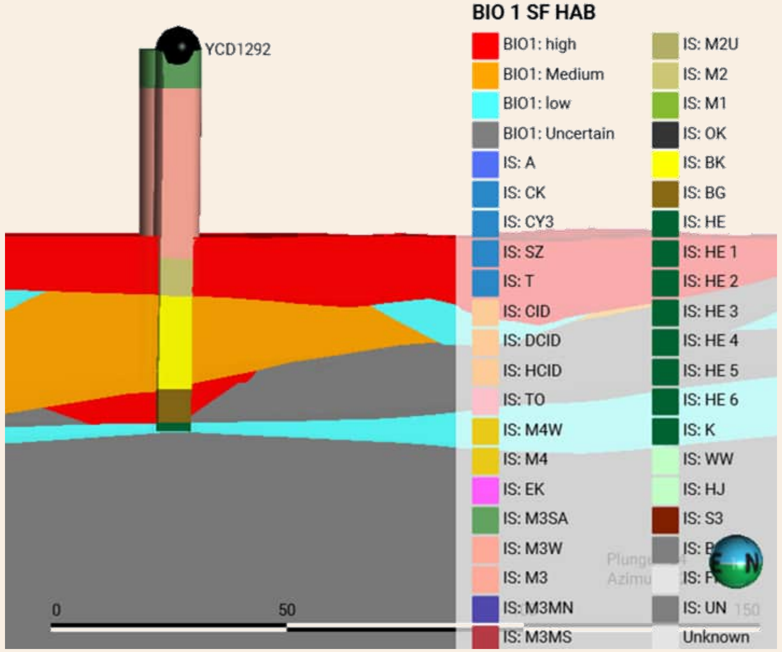
Weathered to clay - Low

Competent fresh rock - Low



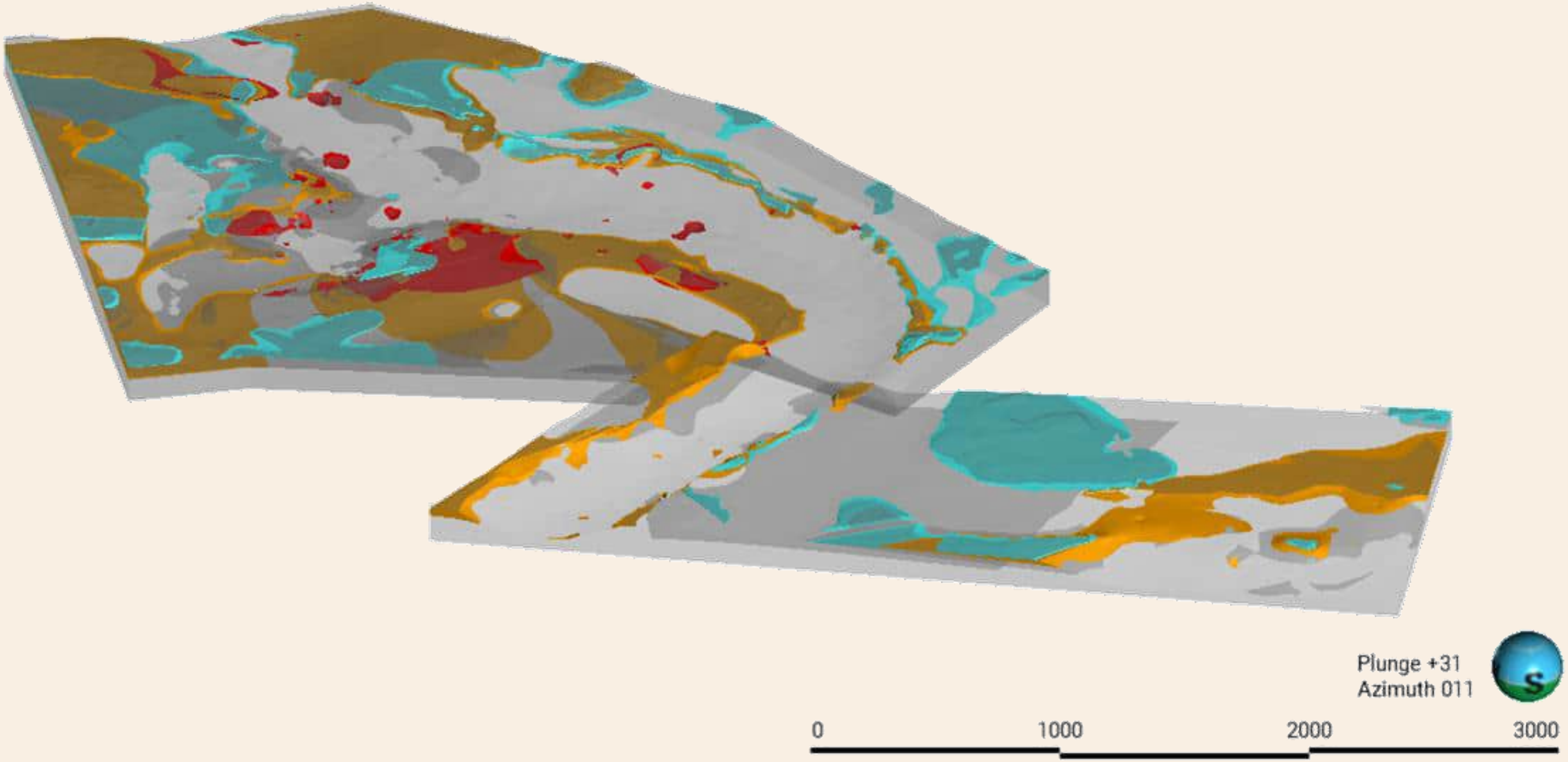






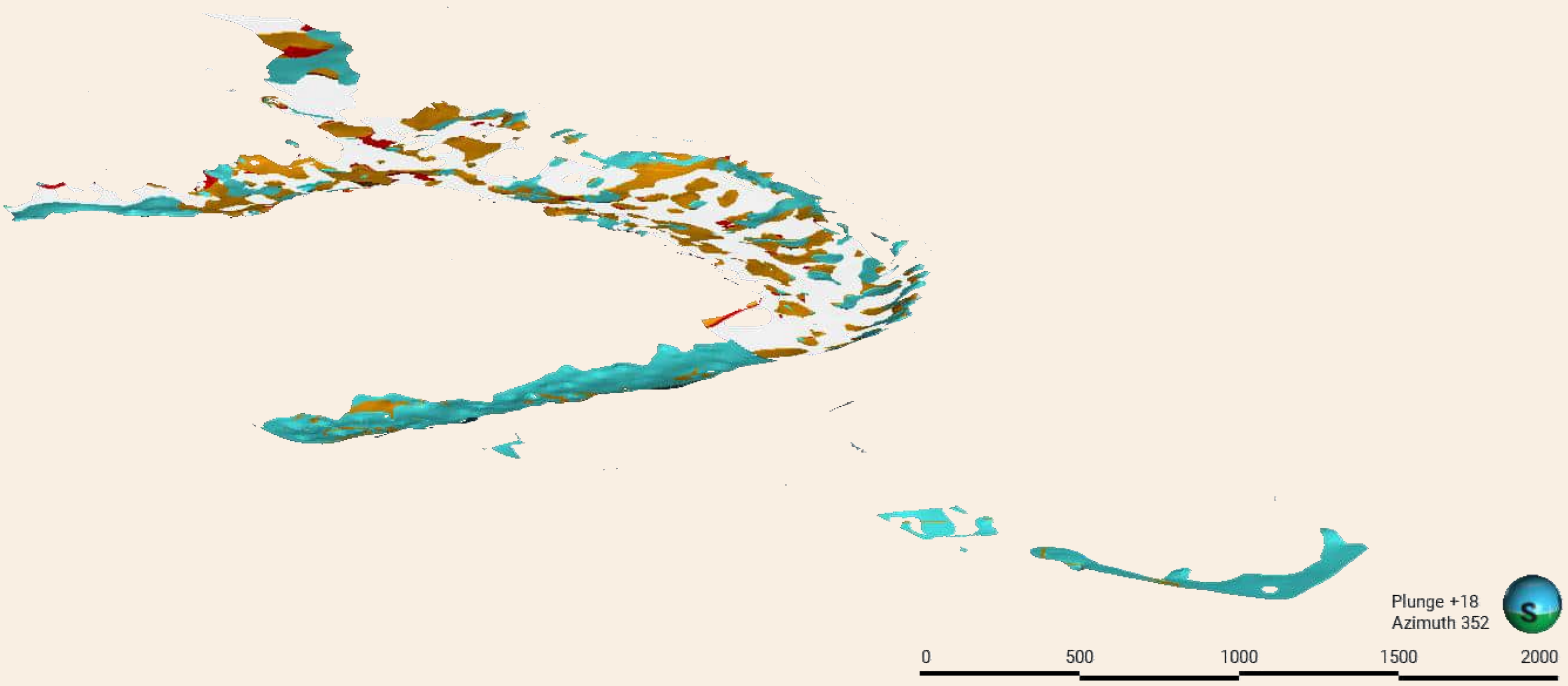
Biologic

Evaluation from Gamma API data – HJ (Weeli Wolli Formation)



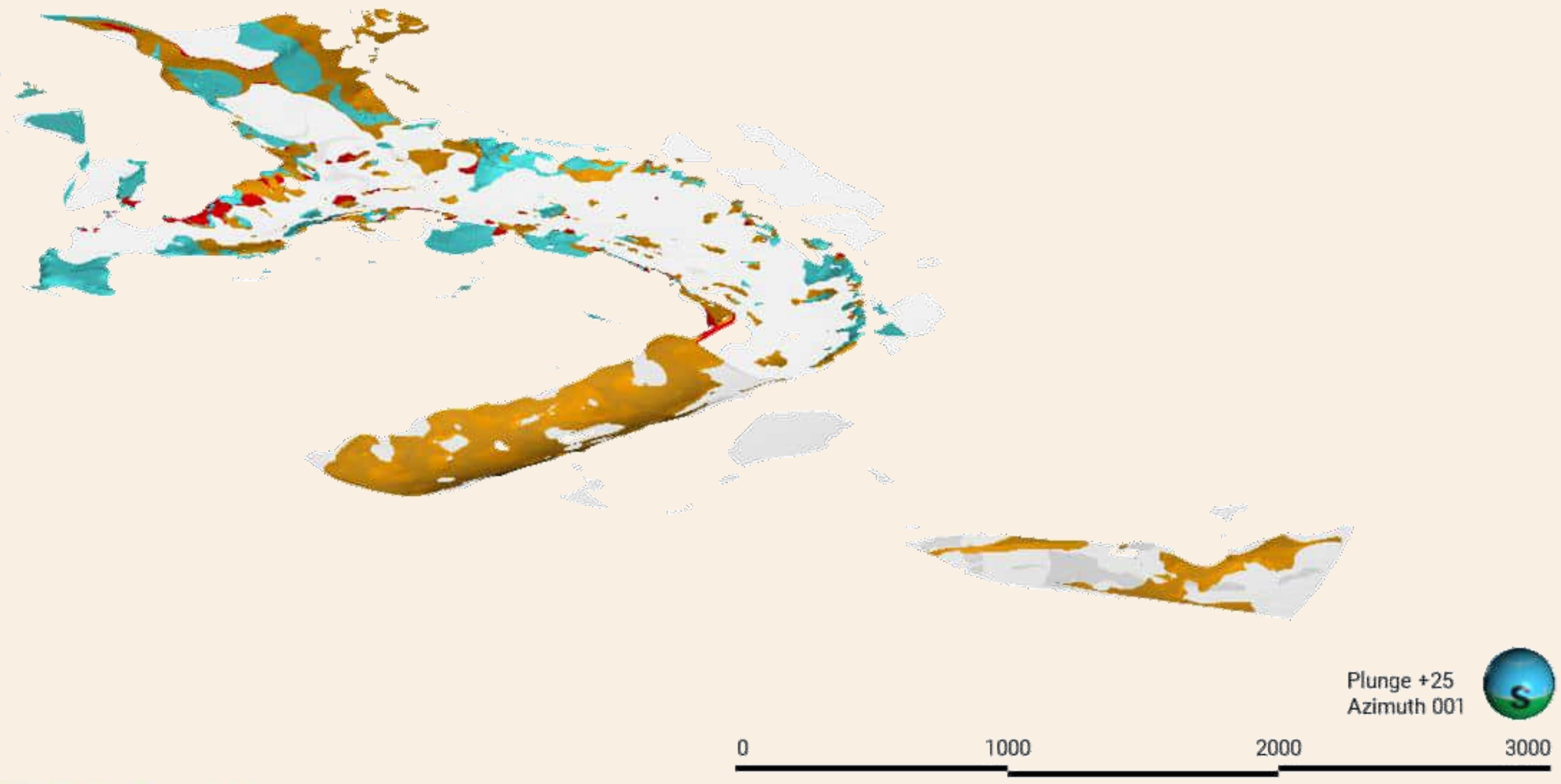
Biologic

Evaluation from Gamma API data – BK (Basal clay)



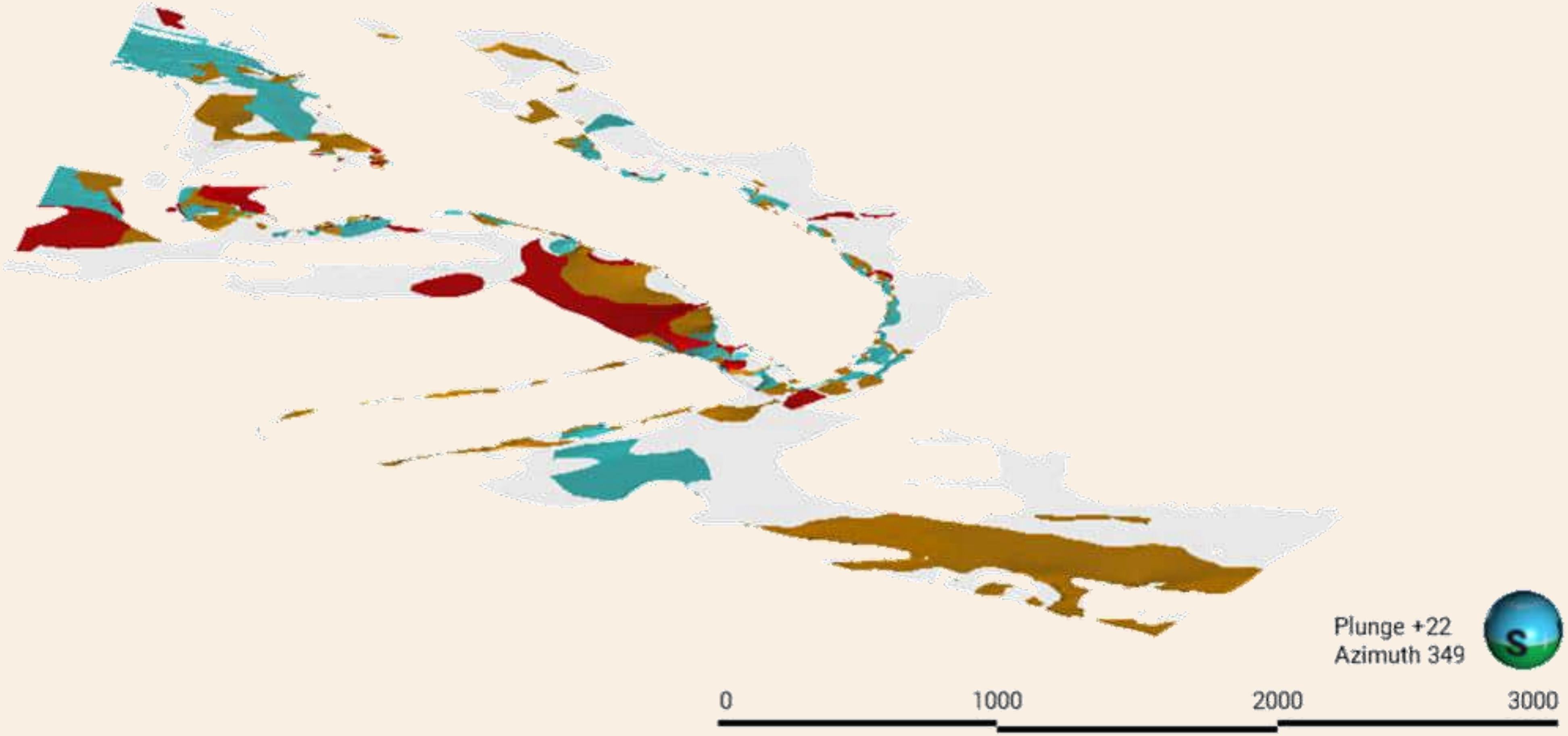
Biologic

Evaluation from Gamma API data – BG (Basal conglomerate)



Biologic

Evaluation from Gamma API data – AL/SZ (Alluvials)



Biologic

Appendix B – Jugari East 8 Molecular Analysis Memo

24-26 Wickham St
Perth WA 6004

(08) 6365 5066
www.biologicenv.com.au

3 September 2024

Suzi Wild
Principal – Biodiversity Assessment
West Australia Iron Ore
125 St Georges Tce, Perth WA 6000

Re: Jugari East 8 Molecular Analysis Memo

Dear Suzi

Attached is a short memo describing the comparison of 28 DNA sequences from the Jugari E8 survey (Bennelongia, 2024) to Biologic's DNA sequence library. If you have any questions about these results, please do notf hesitate to contact me.

Yours sincerely

DR. JOEL HUEY

Manager Molecular Systematics | Principal Geneticist

joel@biologicenv.com.au
0423626382

1 Introduction

On the 7th June 2024, Suzi Wild (BHP West Australia Iron Ore) provided 28 DNA sequences from the Jugari E8 survey (Bennelongia, 2024). Biologic were requested to compare these sequences against available sequence databases to detect any potential matches and update linear range distributions for these taxa. The sequences were provided in fasta format, and their details can be found in Table 1.

Table 1: Summary of DNA sequence data supplied to Biologic

Specimen Number	Sequence text string	Description text string	Seq length
747336	Atopobathynella_B07_YC3601R_C3_747336_7967	| 09/03/2023 BHP4863 Net	583
746985	Atopobathynella_B07_YW3907DG_Yandi_746985_7966	| 08/03/2023 BHP5133 Net	818
746983	Candonopsis_BOS1831_YW3907DG_Yandi_746983_7972	| 08/03/2023 BHP5133 Net	682
748960	Chydaekata_MJ1-UM1_HMJ0005_Munjina_748960_7941	| 08/03/2023 BHP4871 Net	685
735805	Cryptops_BSCOL091_YE2029R_E8_735805_7960	| 10/05/2022 BHP4846 Net	679
746840	Cryptops_BSCOL091_YE2033R_E8_746840_7961	| 09/03/2023 BHP4847 Net	679
749071	Cryptops_BSCOL111_YW3955DG_W5_749071_8003	| 08/03/2023 BHP5144 Trap 2	685
743230	Draculoides_SCH071_YC3637R_C3_743230_7959	| 13/09/2022 BHP4915 Trap 2	679
747022	Elaphoidella_BHA342_HYE1511_E8_747022_7954	| 09/03/2023 BHP5146 Net	681
742001	Elaphoidella_BHA342_YE2070R_E8_742001_7952	| 14/09/2022 BHP4851 Net	677
749102	Japygidae_BDP155_DPL002_YW3933D_W5_749102_7950	| 08/03/2023 BHP5140 Trap 2	675
747019	Meridiescandona_lucerna_HYE1511_E8_747019_7973	| 09/03/2023 BHP5146 Net	816
736435	Meridiescandona_lucerna_YW3540D_W5_736435_7971	| 11/05/2022 BHP4859 Net	683
742152	Nocticola_BBL038_/_B10_cockingi_sl_YC0020R_Yandi_742152_7944	| 13/09/2022 BHP4869 Scrape	822
743074	Nocticola_BBL044quartermainei_gp_YC3633R_C3_743074_7943	| 13/09/2022 BHP4920 Trap 2	685
747102	Paramelitidae_B16_YE2088R_E8_747102_7939	| 07/03/2023 BHP4921 Scrape	680
741990	Paramelitidae_B16_YW3539D_W5_741990_7937	| 15/09/2022 BHP4860 Net	481
747330	Paramelitidae_Genus_2_B02_YW3932D_W5_747330_7940	| 08/03/2023 BHP5141 Net	825
735824	Pilbaranella_BSY372_YC3601R_C3_735824_7965	| 11/05/2022 BHP4863 Net	682
747338	Pilbaranella_BSY372_YC3601R_C3_747338_7968	| 09/03/2023 BHP4863 Net	826
746862	Prethopalpus_B27_YW3956D_W5_746862_7942	| 08/03/2023 BHP5143 Scrape	848
735837	Symphylella_BSYM120_YC3615R_C3_735837_7945	| 11/05/2022 BHP4861 Net	687
746877	Symphylella_BSYM121_YW3914D_W5_746877_7946	| 08/03/2023 BHP5138 Scrape	679
743129	Trigoniulidae_BDI075_YC0020R_Yandi_743129_7963	| 13/09/2022 BHP4869 Trap 2	623
743059	Trigoniulidae_BDI075_YE2055R_E8_743059_7962	| 13/09/2022 BHP4843 Trap 1	821
746839	Trigoniulidae_BDI079_YE2033R_E8_746839_7964	| 09/03/2023 BHP4847 Net	482
738145	Trinemura_BZY105_YC0020R_Yandi_738145_7969	| 11/05/2022 BHP4869 Trap 2	740
748700	Trinemura_BZY105_YC0025R_Yandi_748700_7970	| 08/03/2023 BHP4867 Scrape	820

2 Methods

2.1 DNA Sequence Quality Assurance and Assessment

DNA sequences were assessed for quality by searching for and removing priming regions, identifying and removing low quality and misaligned nucleotides, testing for translation and the presence of stop codons, and by doing a BLAST (Basic Local Alignment Search Tool) of any unusual sequences to confirm they were on-target (i.e., that the closest matches were similar to their morphological identifications). BLAST is a method for rapidly searching a DNA sequence library to identify similar sequences. Sequences were searched using the "blastn" function, which returns similar matches.

2.2 DNA Sequence BLAST Analysis

After cleaning up the sequence data, sequences were BLASTed against two separate sources: GenBank (a publicly available DNA sequence database) and Biologic's unpublished DNA sequence libraries. Sequences were searched using the "blastn" function, which returns similar matches. In some cases, sequences based on taxonomic identification were included for comparison, by building phylogenies and examining tree topology.

Fauna-specific genetic distance thresholds were used to lump sequences into OTUs, based on published literature and available previous reports. Where these thresholds were not available, the assessment used average divergence thresholds for related groups or higher taxa developed by broad-level studies (e.g. Hebert *et al.*, 2003). In general, ≤8% COI divergence is seen as appropriate to determine OTUs (Hebert et al., 2003a), however, higher or lower divergences are sometimes justified depending on the organism studied. Unless otherwise stated, we considered sequences that exhibited COI divergences ≤8% to belong to the same OTU.

3 Results and Discussion

3.1 DNA Sequence Quality

One sequence (746862, *Prethopalpus* `sp, B27`) was unable to be aligned with any other in the dataset and was not similar to any available sequences on GenBank or in Biologic's sequence database. There are eight *Prethopalpus* sequences on GenBank, and 42 in Biologic's sequence databases. The inability to find a similar match to this sequence, and the poor alignment of this sequence to other COI sequences makes us confident it is a contaminated sequence. We excluded it from all downstream analysis.

The contaminated *Prethopalpus* sequence (746862) was unexpected, as Bennelongia (2024) reported this sequence as "Best BENN hit: 96.73% to *Prethopalpus* B27 (#621023). Best Genbank hit: 87.0 % to Cf. *Prethopalpus* sp. Biologic-ARAN014 (#MT373795)". We directly compared 746862 to MT373795, and these sequences were unable to be aligned. It is possible that we were provided with an older, contaminated sequence, rather than the sequence reported in Bennelongia (2024).

All remaining sequences matched Cytochrome Oxidase subunit 1, a mitochondrial gene commonly used in phylogenetic studies and used as a DNA barcode to identify species. Most sequences had some sequence data trimmed, as 5-10bp flanking regions matched universal COI primers routinely used in barcoding. These priming regions are not used in downstream analysis, necessitating their removal. One sequence (747336, *Atopobathynella* sp. B07`) had a region that was poorly aligned at the 3` end, which was removed. Some indels were also detected which caused frameshifts and stop codons to be detected and were cleaned up. The final sequence lengths can be found in Table 2.

3.2 BLAST Results

The remaining 27 sequences formed 20 distinct operational taxonomic units (OTUs), consistent with the identifications provided in the fasta file. The BLAST results are detailed in Table 2. Fourteen sequences (10 OTUs) matches sequences from Biologic's sequence database or GenBank. *Cryptops* `sp. BSCOL091` and *Cryptops* `sp. BSCOL111` did match sequences on GenBank (PP759357- PP759359), but identical voucher IDs, location data, and Bennelongia being the sequence authors, confirmed they were the GenBank uploads of 735805, 746840, and 749071.

Table 2: Summary of BLAST results. Taxa in red are those of interest to E8 Assessment

Specimen Number	Bennelongia ID	Site	New length	Match BLAST databases	OTU Match (Biologic/GenBank Name)
747336	*Atopobathynella* `sp. B07`	YC3601R	474	Yes	*Atopobathynella* `sp. Biologic-PBAT019`
746985	*Atopobathynella* `sp. B07`	YW3907DG	802	Yes	*Atopobathynella* `sp. Biologic-PBAT019`
746983	*Candonopsis* `sp. BOS1831`	YW3907DG	657	No Match	
748960	*Chydaekata* `sp. MJ1-UM1`	HMJ0005	658	Yes	*Chydaekata* `sp. MJ1-UM1`
735805	*Cryptops* `sp. BSCOL091`	YE2029R	658	No Match	
746840	*Cryptops* `sp. BSCOL091`	YE2033R	658	No Match	
749071	*Cryptops* `sp. BSCOL111`	YW3955DG	658	No Match	

Specimen Number	Bennelongia ID	Site	New length	Match BLAST databases	OTU Match (Biologic/GenBank Name)
743230	*Draculoides* `sp. SCH071`	YC3637R	658	Yes	*Draculoides* `sp. WAM-SCH071`
747022	*Elaphoidella* `sp. BHA342`	HYE1511	658	Yes	cf. *Australocamptus* `sp. Biologic-HARP064`
742001	*Elaphoidella* `sp. BHA342`	YE2070R	658	Yes	cf. *Australocamptus* `sp. Biologic-HARP064`
749102	Japygidae `sp. BDP155/DPL002`	YW3933D	658	Yes	Japygidae `sp. BDP155`
747019	*Meridiescandona lucerna*	HYE1511	802	Yes	*Meridiescandona* `sp. Biologic-OSTR074`
736435	*Meridiescandona lucerna*	YW3540D	658	Yes	*Meridiescandona* `sp. Biologic-OSTR074`
742152	*Nocticola* `sp. BBL038/B10 cockingi sl`	YC0020R	802	Yes	*Nocticola* `sp. Biologic-BLAT021`/cockingi?
743074	*Nocticola* `sp. BBL044 quartermainei gp`	YC3633R	658	Yes	*Nocticola quartermainei*
747102	Paramelitidae `sp. B16`	YE2088R	658	Yes	Paramelitidae `sp. Helix-WWA3`
741990	Paramelitidae `sp. B16`	YW3539D	464	Yes	Paramelitidae `sp. Helix-WWA3`
747330	Paramelitidae `sp. Genus 2 B02`	YW3932D	802	Yes	Paramelitidae `sp. Biologic-AMPH045`
735824	*Pilbaranella* `sp. BSY372`	YC3601R	658	No Match	
747338	*Pilbaranella* `sp. BSY372`	YC3601R	802	No Match	
746862	*Prethopalpus* `sp. B27`	YW3956D	-	N/A	Contamination
735837	*Symphylella* `sp. BSYM120`	YC3615R	658	No Match	
746877	*Symphylella* `sp. BSYM121`	YW3914D	658	No Match	
743129	Trigoniulidae `sp. BDI075`	YC0020R	615	No Match	
743059	Trigoniulidae `sp. BDI075`	YE2055R	802	No Match	
746839	Trigoniulidae `sp. BDI079`	YE2033R	469	No Match	
738145	*Trinemura* `sp. BZY105`	YC0020R	740	No Match	
748700	*Trinemura* `sp. BZY105`	YC0025R	802	No Match	

New linear ranges and distributions were calculated based on matches and spatial data available to Biologic. These results can be found in Table 3, comparing the original distributional information from Bennelongia (2024) to the distribution based on OTU matches available to Biologic. It is important to note that Bennelongia and Biologic have access to different datasets, which largely explains disparity in calculated distributions.

Of note, was the OTU *Atopobathynella* `sp. Biologic-PBAT019` (*Atopobathynella* `sp. B07`). This OTU comprised sequences from an unusually large geographic distribution for *Atopobathynella*. The OTU inhabits Turee Ck East subcatchment (flowing south west into the Ashburton), the Weeli Wolli subcatchment, and the Fortescue River catchment. These sequences have an intraspecific genetic distance of up to 7.8% (data not shown).

There is some residual uncertainty about OTU designations within the 'PBAT019' lineage, with two main hypotheses based on data available at the time of writing:

- These sequences could represent a single OTU with a potential geographic range across three subcatchments (linear range 79.6 km).
- There could be four distinct OTUs within the PBAT019 lineage.
    - Note: These OTUs would have intraspecific genetic distances of less than 4.7%, and interspecific distances of more than 6%. In this scenario one OTU would also still exhibit an unusual distribution across two regional subcatchments at Turee Creek/Weeli Wolli Creek.

At this point we are cautiously grouping these sequences into a single OTU based on intraspecific genetic distances and the phylogenetic branching pattern with a grade of short internode distances and poor bootstrap support. Further analysis, including morphology, is ongoing to resolve this OTU, being undertaken by Dr. Giulia Perina.

Additionally, *Nocticola* `sp. Biologic-BLAT021` (*Nocticola* `sp. BBL038/B10 cockingi sl`) revealed an interesting result. Before the comparison to 742152, *Nocticola* `sp. Biologic-BLAT021` was only recorded from the Jinidi and East Packsaddle project areas. This was based on COI sequencing using the Folmer primers (Folmer *et al.*, 1994), which are routinely used for DNA barcoding (Herbert *et al.*, 2003). These primers amplify ~560bp at the upstream end of COI (5`). Three species of Pilbara *Nocticola* were described in 2017 using morphology and DNA seq data (Trotter *et al.*, 2017). The COI gene was amplified in Trotter *et al.* (2017), but a region downstream of the Folmer region, with no overlap between them (Yamauchi *et al.*, 2004). As such, both Folmer and Yamauchi regions need to be sequenced to compare between datasets. To date, *Nocticola* `sp. Biologic-BLAT021` has only been sequenced at the Folmer region of COI, not allowing comparison to *N. cockingi*, except via morphology. However, this identification is consistent with the known distribution of the species, and ongoing sequencing work will hopefully confirm this identification. We are currently working on the assumption *Nocticola* `sp. Biologic-BLAT021` may be *N. cockingi* and will confirm that with sequencing soon.

Specimens identified as *Meridiescandona lucerna* by Bennelongia matched sequences previously sequenced and named *Meridiescandona* `sp. Biologic-OSTR074` by Biologic. The linear range of 280 km provided in Bennelongia (2024) is based on this morphological identification (and possibly non-publicly available sequenced material), whereas the 15.0km linear range provided in Table 3 is based only on sequenced material available for comparison to Biologic. We cannot comment on the accuracy of the morphological identification as the types, or other reliably identified material for this species have not been sequenced.

Specimens identified as *Elaphoidella* `sp. BHA342` by Bennelongia matched sequences previously sequenced and named cf. *Australocamptus* `sp. Biologic-HARP064` by Biologic. This match extended the known LR beyond Jugari E8. The differing genus level identifications for these taxa is likely due to the unresolved taxonomy of this family. A COI phylogeny of available canthocamptids from GenBank reveals that specimens identified as *Elaphoidella* and *Australocamptus* do not form reciprocally monophyletic lineages (i.e., they are not all more closely related to themselves than to the other genus), suggesting that more work is required to resolve the generic level classification in this family.

Table 3: Linear ranges for OTUs with BLAST matches. Taxa in red are those of interest to E8 Assessment

Bennelongia ID	Distribution comment from Bennelongia (2024)	OTU Match (Biologic/ GenBank Name)	Linear Range	Range comment
Atopobathynella `sp. B07`	Known distribution of ca. 220 km²; linear distribution 28 km.	*Atopobathynella* `sp. Biologic-PBAT019`	78.6 km	Widespread species, currently being described by Dr. Giulia Perina. Distributed throughout Weeli Wolli subcatchment, southern margin of Fortescue Marsh, and Turee Ck. Match expands known LR.
Chydaekata `sp. MJ1-UM1`	Known distribution of ca. 60 km²; linear distribution 14 km.	*Chydaekata* `sp. MJ1-UM1`	12.8 km	Match does not expand LR. Likely due to differing datasets available for comparison.
Draculoides `sp. SCH071`	Known linear range 16 km.	*Draculoides* `sp. WAM-SCH071`	17.2 km	Found on southern margin of Fortescue Marsh. Match expands known LR.
Elaphoidella `sp. BHA342`	Known linear distribution 620 m. Known only from the Survey Area.	cf. *Australocamptus* `sp. Biologic-HARP064`	4.6 km	Found in Jugaricoogina Ck from Aquatic/ Hyporheic samples. Match expands known LR beyond Jugari E8.
Japygidae `sp. BDP155/DPL002`	Known distribution of ca. 1,800 km²; known linear range 95 km	Japygidae `sp. BDP155`	37.8 km	Found in "headwaters" of Weeli Wolli Ck. Match does not expand LR. Likely due to differing datasets available for comparison.
Meridiescandona lucerna	Known distribution of ca. 10,300 km²; linear distribution 280 km.	*Meridiescandona* `sp. Biologic-OSTR074`	15.0 km	Found in Jugaricoogina Ck from Aquatic/ Hyporheic samples. LR is based on sequenced individuals, not Bennelongia morphological ID.
Nocticola `sp. BBL038/B10 cockingi sl`	Known distribution of ca. 100 km²; known linear range 15 km.	Nocticola `sp. Biologic-BLAT021`/cockingi?	39.3 km	This is based on matches to BLAT021, in EP and Jinidi project areas. This species' type location is Jirrpalpur Range (MAC). Match expands known LR.
Nocticola `sp. BBL044 quartermainei gp`	Widespread in northern Western Australia	*Nocticola quartermainei*	>400 km	Distributed throughout southern Pilbara
Paramelitidae `sp. B16`	Known distribution of ca. 900 km²; linear distribution 53 km.	Paramelitidae `sp. Helix-WWA3`	14.8 km	Found downstream along Marillana Ck. Match does not expand LR. Likely due to differing datasets available for comparison.
Paramelitidae `sp. Genus 2 B02`	Known distribution of ca. 4,000 km²; linear distribution 85 km	Paramelitidae `sp. Biologic-AMPH045`	57.4 km	Found throughout Weeli Wolli subcatchment, plus southern edge of Fortescue Marsh. Match does not expand LR. Likely due to differing datasets available for comparison.

4 Conclusions

We compared 28 COI DNA sequences from the Jugari E8 survey (Bennelongia, 2024) to Biologic's DNA sequence libraries, and to GenBank. One sequence was removed due to contamination. The remaining 27 sequences formed 20 OTUs. Ten OTUs matched sequence data available in Biologic's sequence libraries and GenBank, and updated distributions were provided.

5 References

Bennelongia. (2024). *Yandi Operations Subterranean Fauna Survey Report. April 2024, Final Report*. Jolimont, WA:

Folmer, O., Black, M., Hoeh, W., Lutz, R., & Vrijenhoek, R. (1994). DNA primers for amplification of mitochondrial cytochrome c oxidase subunit I from diverse metazoan invertebrates. *Molecular Marine Biology and Biotechnology, 3*(5), 294-299.

Hebert, P. D., Cywinska, A., Ball, S. L., & deWaard, J. R. (2003). Biological identifications through DNA barcodes. *Proceedings of the Royal Society B, 270*(1512), 313-321.

Herbert, P. D. N., Ratnasingham, S., & deWaard, J. R. (2003). Barcoding animal life: cytochrome c oxidase subunit I divergences among closely related species. *Proceedings of the Royal Society B, 270*, S96-S99.

Trotter, A. J., McRae, J. M., Main, D. C., & Finston, T. L. (2017). Speciation in fractured rock landforms: towards understanding the diversity of subterranean cockroaches (Dictyoptera: Nocticolidae: Nocticola) in Western Australia. *Zootaxa, 4250*(2), 143-170.

Yamauchi, M. M., Miya, M. U., & Nishida, M. (2004). Use of a PCR-based approach for sequencing whole mitochondrial genomes of insects: two examples (cockroach and dragonfly) based on the method developed for decapod crustaceans. *Insect Molecular Biology, 13*(4), 435-442.