West Angelas Deposit A west and Deposit F

Subterranean Fauna Assessment

1. OVERVIEW OF SUBTERRANEAN FAUNA

Subterranean fauna tend to be highly specialised to, and obligate dwellers of, subterranean habitats. Subterranean fauna have been recorded from Western Australia since the 1940s. They are widespread in the Pilbara region and are generally considered to comprise two main categories (Humphreys 2000a in Biota 2004):

- Troglofauna: obligate terrestrial subterranean fauna occurring in underground cavities, fissures and interstitial spaces above the water table. Troglofauna are divided into three groups based on their life histories: troglobites, which are obligate dwellers of subterranean habitats; troglophiles, which are facultative species that live and reproduce underground but that are also found in similar microhabitats on the surface; and trogloxenes, which are principally surface species that regularly inhabit underground caves and cavities for refuge (Sket 2008). A fourth group; accidentals, wander into cave systems but cannot survive there (Howarth 1983 in *ecologia* 2013).

  A species is considered truly troglobitic if it displays morphological characteristics that appear to restrict it to subterranean habitats (Howarth 1983). These include a significant reduction or a complete loss of eyes, pigmentation and wings, as well as development of elongated appendages, slender body form and, in some species, a lower metabolism. Behavioural adaptations such as lack of a circadian rhythm (24-hour biological cycle) are also characteristic of true troglobites (*ecologia* 2013).

- Stygofauna: obligate groundwater-dwelling, aquatic fauna that occupy the interstitial spaces, vugs and fissures in alluvial, karstic or fractured rock aquifers. This environment is devoid of light, may have restricted available space and relatively constant temperature. These species have evolved unique features such as a lack of pigmentation, elongated appendages, filiform body shape (worm like) and reduced or absent eyes (*ecologia* 2013).

  Stygofauna, like troglofauna, are divided into three groups: stygobites which are obligate dwellers of groundwater and complete their entire life in this environment; stygophiles which inhabit both surface and subterranean aquatic environments, but are not necessarily restricted to either; and stygoxenes which are principally surface species with occasional presence in subterranean waters.

Higher levels of endemicity have been found to be characteristic of subterranean fauna (Biota 2004). The high levels of endemism that this fauna exhibit may be due, in part, to poor dispersal capabilities. The dispersal of fauna inhabiting subterranean environs is extremely slow and limited by the geological formation in which they occur (Marmonier et al. 1993; Gibert et al. 1994 in Biota 2004).

It is unclear at present whether the occurrence of subterranean fauna as documented by recent surveys in Western Australia reflect the true distribution of the fauna, and hence potential impact, or whether this is more a function of the current limitations on sampling and understanding of subterranean systems (Biota 2004). It is estimated that over 80% of the subterranean fauna likely to be present in Western Australia have not yet been documented (Guzik *et al*. 2010).

1.1 POTENTIAL IMPACTS

Recent surveys and research have suggested that relatively localised impacts such as mining have the potential to significantly change the conservation status of locally endemic species (Eberhard and Humphreys 1999; Biota 2001 in Biota 2004).

Potential impacts to subterranean fauna include the following:

- **Excavation**. Mining has the potential to reduce subterranean habitat availability.
- **Clearing**. The food resources for subterranean ecosystems are largely allochthonous, transported into subterranean habitats by water, plant roots and animals (Howarth 1983 in *ecologia* 2013). Clearing has the potential to reduce organic inputs to subterranean ecosystems.
- **Dewatering, groundwater abstraction and other aquifer impacts**. Dewatering has the potential to reduce habitat availability for stygofauna. Dewatering below troglofauna habitat may have the potential to impact subterranean humidity and therefore, the quality of troglofauna habitat. The extent to which humidity is affected by depth to the water table is unclear. Given that pockets of residual water probably remain trapped throughout de-watered areas (including within clay rich areas) and keep the overlying substrate saturated with water vapour, de-watering may have minimal impact on the humidity in the unsaturated zone. In addition, troglofauna may be able to avoid undesirable effects of a habitat drying out by moving deeper into the substrate if suitable habitat exists at depth.
- **Changes to surface hydrology**. Artificial landforms may cause localised reduction in rainfall recharge, and the associated input of dissolved organic matter and nutrients, to subterranean habitats. The input of organic matter and nutrients may be further reduced because the absence of surface leaf litter, which is considered to be the main source of carbon and nutrients. Reduced organic matter and nutrients are considered more likely to reduce population densities than cause extinction of species.
- **Vibration effects on subterranean habitats from blasting activities**. Blasting may have indirect effects on troglofauna through altering underground structure (usually via rock fragmentation which may result in either loss of habitat through collapse of voids or creation of habitat through fractures in bedrock).

However, these habitat effects are poorly quantified and their ecological consequences have not been described. Vibration is likely to dissipate rapidly with distance from the pit and blasting is not considered a significant impacting activity beyond the pit boundary.

- **Contamination** (e.g. pollutant spills). Contamination of soil or groundwater has the potential to reduce the quality of subterranean fauna habitat. Any contamination is likely to be localised and is not considered a significant impacting activity.

1.2 GUIDANCE ON ASSESSMENT

Given the considerable scientific interest in subterranean fauna, and the fact that a high proportion of subterranean species are short-range endemics (**SRE**), the Environmental Protection Authority (**EPA**) usually requires that risks to subterranean fauna are considered when assessing proposed mine developments where subterranean fauna are likely to occur (EPA 2003). The EPA has provided three Guidance Statements: Guidance Statement No. 54 - *Consideration of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in Western Australia* (EPA 2003), EPA Technical Appendix to Guidance Statement No. 54: *Sampling Methods and Survey Considerations for Subterranean Fauna in Western Australia* (EPA 2007) and Environmental Assessment Guideline No. 12: *Consideration of Subterranean Fauna in Environmental Impact Assessment in WA* (EPA 2013).

1.3 IMPACT ASSESSMENT APPROACH

The EPA endorses the use of physical habitat as a surrogate for species distributions at a local scale where taxa remain poorly sampled as a result of survey limitations:

> *"Where a reasonable amount of sampling is unlikely to reveal the full range of a species because of demonstrated low capture rates in the habitat sampled, surrogates can be used to estimate whether the habitat is restricted… A physical surrogate is the use of habitat, known to support a particular species, to infer the likely presence of that species in the same habitat beyond the area surveyed. A physical surrogate can be used only where continuity of the presumed habitat can be clearly demonstrated with site-specific data. (Pages 13 and 14, EPA 2013)"*

Development of West Angelas Deposits A west and F are examples where sufficient sampling has occurred but subterranean fauna taxa distributions at the local scale remain poorly resolved as a result of low capture rates. Low specimen capture rates mean it is difficult to assess the impact of the project directly on the subterranean taxa collected. Thus Rio Tinto will infer the impact of the Proposal to subterranean fauna from the impact to the subterranean fauna habitat.

The below sections justify this approach by:

a) outlining the adequacy of current sampling;

b) characterising the habitat; and

c) examining the significance of Proposal related impacts to the identified habitat.

2. SUBTERRANEAN FAUNA SAMPLING

Subterranean fauna surveys have been undertaken over the entire West Angelas area since 1998. The following surveys are applicable to the Proposal;

- a baseline survey was conducted by Ecologia Environmental Consultants (*ecologia*) during 1998;
- a monitoring survey was undertaken by *ecologia* in 2002;
- a monitoring survey was undertaken by Biota in 2003;
- a baseline survey of Deposits E and F was conducted by Biota in 2004;
- a monitoring survey was undertaken by Biota in 2008;
- a monitoring survey was undertaken by Biota in 2012; and
- a subterranean fauna assessment survey was undertaken by *ecologia* in 2013.

A summary of the surveys is included in Sections 2.1 to 2.6.

2.1 BASELINE STYGOFAUNA SAMPLING (ECOLOGIA 1998)

The baseline stygofauna survey in 1998 was carried out by *ecologia* in collaboration with Western Australian Museum staff, and comprised a survey of the West Angelas borefield and the then proposed Turee Creek B borefield (*ecologia* 1998).

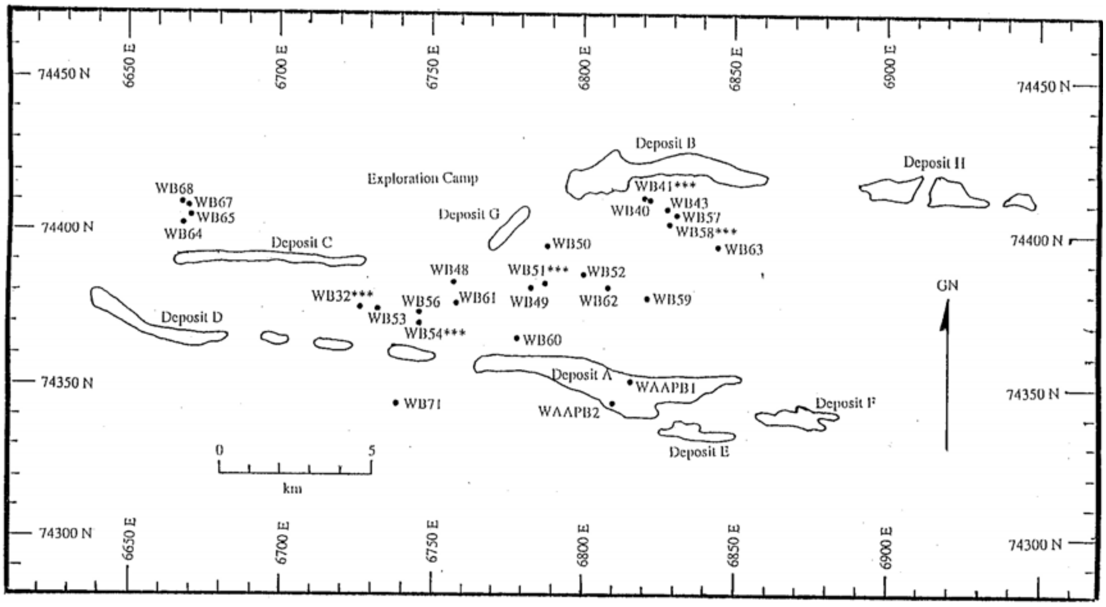
The survey sampled 44 bores in both the West Angelas and Turee Creek B borefields. Methods used include plankton haul nets and baited traps.

The survey resulted in the collection of stygofauna from six of the 44 bores (*ecologia* 1998). No troglofauna by-catch was collected. Analyses of the bore lithology concluded that there was a range of geologies in the area, and while calcrete is well known to be an important habitat for stygofauna (Marmonier et al. 1993, Eberhard 1998), the majority of the calcretes in the area were unsaturated (*ecologia* 1998). Instead, it was proposed that the stygofauna were utilising secondary habitats in other geologies. It was thought that the stygofauna were utilising fractures and weathered zones in the pockets of compact, non-permeable dolerite rocks as habitat. These habitats are patchily distributed, which led to a conclusion that the stygofauna distribution may be patchy within the area (*ecologia* 1998).

2.2 MONITORING SURVEYS (ECOLOGIA 2002, 2003)

Monitoring surveys were carried out in March 2002 and November 2003 and addressed the same areas as the baseline survey but sampled less bores (13 bores and 30 bores respectively) (*ecologia*, 2002).

Stygofauna were recovered from six of the 13 bores sampled in 2002 and six of the 24 bores sampled in 2003 (Figure 1). No troglofauna by-catch was collected.



Stygofauna indicated by ***

Figure 1. Locations of West Angelas Bores (sourced from Eberhard 1998 in Biota 2002).

Accordingly, borehole geology logs were sourced from the hydrogeology reports of Woodward Clyde (1997, 1998) and Aquaterra (1999, 2001). Bore logs were available for nine of the 13 bores that have yielded stygofauna (Table 1).

ecologia (2003) articulated the following conclusions about the presence of stygofauna and stygofauna habitat in the West Angelas and Turee Creek B borefields: stygofauna habitat has been identified previously in calcretes, unconsolidated material such as alluvium (especially coarse gravels) and fractured rock. Of the bores that yielded stygofauna, WB41, WB51 and WB54 in the West Angelas borefield have consistently had the most abundant and diverse collections. These three bores are of the greatest potential significance and sample optimal stygofauna habitat; they are open to similar geology types, consisting primarily of fractured dolerites and shales, with some shallow calcretes. Other bores where stygofauna have been collected included WOB12 (cased with slotting open primarily to alluvial geology); WOB1 and WOB9 (gravelly pisolites and goethite); WOB5 (BIF and jaspilite); and WOB22 (fractured volcanics/dolerite) in the Turee Creek B borefield. Stygofauna abundance was low in these bores however and it is likely that these do not intersect optimal stygofauna habitat compared to the geology intersected by WB41, WB51 and WB54.

Table 1. Borehole geology logs of bores where stygofauna have been recovered during all stygofauna surveys at West Angelas (data from Woodward Clyde (1997, 1998), ecologia (1998) and Aquaterra (1999, 2001) in Biota 2003).

Borefield	Bore	Geological description
Other	Pastoral Bore (Blair's Bore)	Not available
West Angelas	WB32	Not available
West Angelas	WB33	Not available
West Angelas	WB40	Not available
West Angelas	**WB41***	Calcrete (0-12m), dolerite / calcrete (12-22m), dolerite (22-52m), dolerite / black shale (52-66m).
West Angelas	**WB51***	Soil, clay and dolerite (0-10m), dolerite (fractured; 10-28m), dolerite and clay (28-38m), shale (38-70m) and dolerite (65-70m).
West Angelas	**WB54***	Soil (0-5m), calcrete (5-10m), shale (10-22m), dolerite (22-60m) and dolerite / basalt / pyrite (60-85m).
West Angelas	WB58	Soil and clay (0-5m), dolerite with fractures (5-85m).
Turee Creek	WOB1	Scree (0-7m), clays (7-40m), gravelly pisolites and goethites (40-60m), goethite and limonite in a clay matrix, and jaspilite (60-86m).
Turee Creek	WOB12	Recent - Tertiary alluvium (0-83m) above basement rock of BIF and jaspilitic BIF (83-90m).
Turee Creek	WOB22	Sands and gravel (0-10m) underlain by clays (10-38m), basement gravels (38-44m) and fragmented volcanics / dolerite (44-64m).
Turee Creek	WOB5	Alluvium (0-6m), and alluvium with clay (6-22m), gravelly goethites and limonite (22-32m), clays (32-62m), and scree (62-68m) above a basement of weathered jaspilitic BIF (Weeli Wolli).
Turee Creek	WOB9	Alluvium (0-20m), gravelly scree and clay (20-48m), clays (48-74m), gravelly channel iron deposit (74-118m), underlain by clays and basement volcanics.

***** bores have consistently yielded stygofauna

2.3 DEPOSITS E AND F SUBTERRANEAN FAUNA SURVEY (BIOTA 2004)

Stygofauna sampling at Deposits E and F in December 2003 was consistent with the approach outlined in EPA Guidance Statement Number 54 (EPA 2003).

A total of 12 bores were successfully sampled for stygofauna in the Deposit E area, and 8 bores were sampled in the Deposit F area. No stygofauna or troglofauna by-catch were recorded from any of the bores sampled during the survey (Figure 2). Many of the bores showed high turbidity and the geology of the sampled areas was not overly prospective for subterranean fauna (Biota 2004).

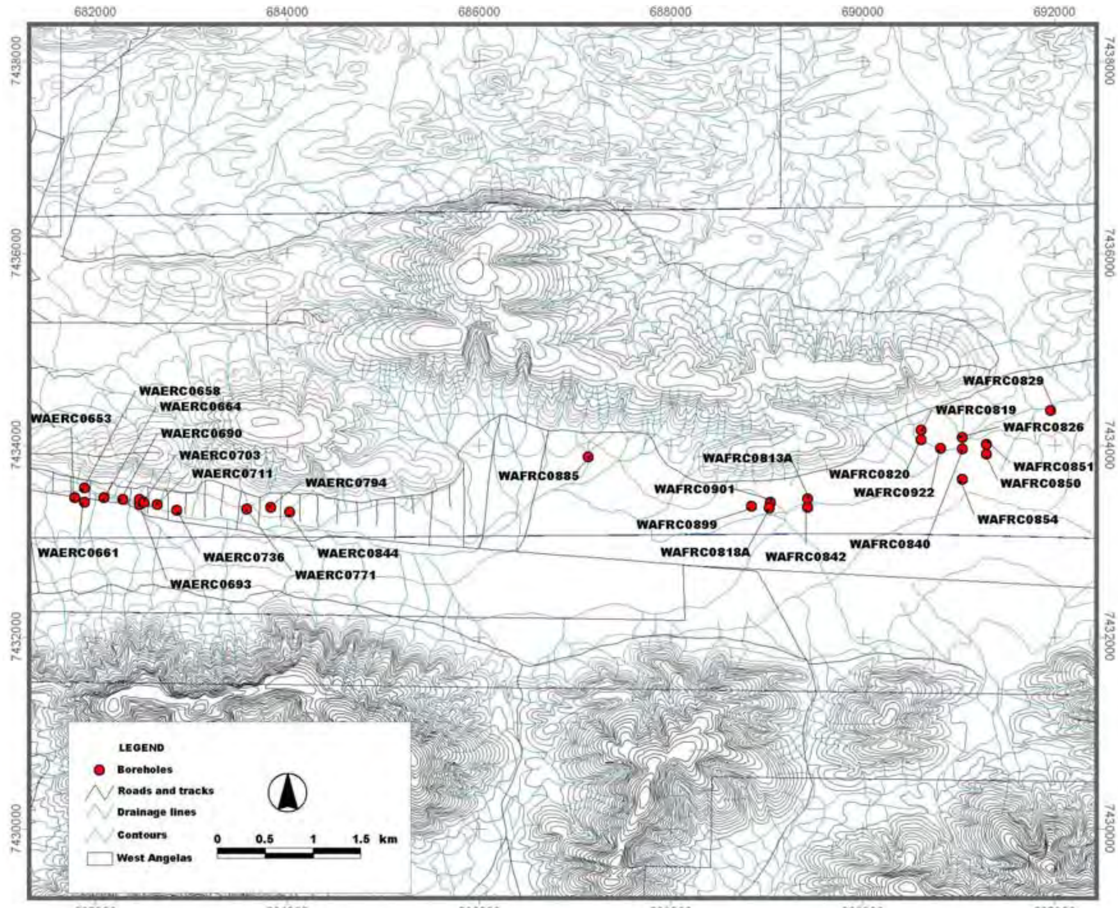


Figure 2. Locations of Bores Sampled for Stygofauna (sourced from Biota 2004).

A review of the geological units present in the valley system containing these deposits suggests that the area is not overly prospective for stygofauna. The strata of boreholes previously sampled in the Deposit E and F area (from surface to end of hole) typically comprised:

1. Alluvials (top ~50 m);
2. Goethite and shales (50 - 100 m);
3. Banded Iron Formation (BIF) (deeper layers, down to 130 m from top of hole).

In the inland Pilbara, the superficial alluvials are the only geological type that appear to consistently provide habitat for stygofauna (Biota unpublished data in Biota 2004). However, at Deposits E and F, this unit is situated above the water table (depth to water table is approximately 100 m below the ground level) and is largely unsaturated. The deeper geological units below the water table in the study area do not typically support stygal communities (Biota unpublished data, Humphreys 2000b in Biota 2004).

The Biota (2004) report did not consider the potential for the unsaturated superficial alluvial strata to contain troglofauna.

2.4 WEST ANGELAS AND DEPOSIT A STYGOFAUNA SURVEY (BIOTA 2008)

A single-phase stygofauna survey was completed in 2008 in accordance with EPA Guidance Statement No. 54 - *Consideration of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in Western Australia* (2003).

A total of 15 bores in the Deposit A aquifer were successfully sampled for stygofauna. No stygofauna or troglofauna by-catch were recorded from any of the bores sampled (Biota 2008a).

The Deposit A aquifer is described by Woodward-Clyde (1998) as variably permeable and is surrounded by low permeability material. The lack of stygofauna collected during the survey was considered consistent with the confined nature of this aquifer (Biota 2008a).

2.5 WEST ANGELAS STYGOFAUNA SURVEY (BIOTA 2012)

A single-phase stygofauna survey was completed in 2012 in accordance with EPA Guidance Statement No. 54 (EPA 2003), and EPA Technical Appendix to Guidance Statement No. 54: *Sampling Methods and Survey Considerations for Subterranean Fauna in Western Australia* (2007).

A total of 12 bores were successfully sampled for stygofauna, including 10 from the Turee Creek B borefield and two from the Deposit A aquifer. No stygofauna or troglofauna by-catch were recorded from either area in 2012 (Biota 2012).

Previous sampling of the Turee Creek B borefield has yielded 30 stygofauna specimens in total. Twenty-two of the total specimens recorded came from a single site (WOB12) during 2002, which later that year yielded no stygofauna (Biota 2003). While no stygofauna were collected during the 2012 phase of sampling, it was impossible to conclusively determine whether this represents a natural fluctuation in stygal populations or a project-induced impact (Biota 2012).

No stygofauna have been collected from within the confined aquifer at Deposit A to date (including prior to dewatering of the deposit). The lack of stygofauna collected was considered consistent with the confined and disconnected nature of this aquifer (Biota 2012), as described in Section 2.4.

2.6 GREATER WEST ANGELAS SUBTERRANEAN FAUNA SURVEY (ECOLOGIA 2013)

The most recent single-phase subterranean fauna (troglofauna and stygofauna) survey was conducted in accordance with EPA Guidance Statement No. 54 (EPA 2003), and EPA Technical Appendix to Guidance Statement No. 54 (EPA 2007).

The subterranean fauna (troglofauna and stygofauna) survey was conducted in July - October 2012, following a drier than average dry season. The previous wet season (November 2011 - March 2012) however, recorded higher than average rainfall.

A total of 91 drill holes were sampled for troglofauna. Only twenty two bores (24%) intercepted ground water, with the remaining holes above the water table. Sample sites are mapped in Figure 4.

The survey yielded 109 invertebrate specimens representing eleven orders. Of these, ten species were identified as troglobitic. These species belong to the orders; Thysanura (silverfish), Psocoptera (booklice), Hemiptera (true bugs), Embioptera (webspinners), Blattodea (cockroaches), Coleoptera (beetles), Araneae (spiders), Isopoda (slaters) and Chilopoda (centipedes). Non-troglobitic specimens included Collembola (springtails), Blattodea, Coleoptera, Araneae and Diplopoda (millipedes). Troglobitic specimens collected are summarised in Table 2 and mapped in Figure 4.

The likelihood of the collected troglobitic species to be considered SRE was determined by expert taxonomists based on the current knowledge of the distribution and biology of each species. Six of the recorded species (*Nocticola* sp. indet., *Prethopalpus* sp. indet., *Pseudodiploexochus* sp. nov., *Cormocephalus* CH1003, *Atelurinae* sp., indet., Anillini sp.indet.) are considered likely to have restricted distribution ranges and four (*Hydrobiomorpha* sp. indet., *Embioptera* sp. indet., Meenoplidae sp. indet., Trogiidae sp. indet.) are potentially restricted. Only spiders of the genus *Prethopalpus* and centipedes from the genus *Cormocephalus* have been recorded previously in the area, with the remaining eight genera/families representing new records. In addition, the spider *Prethopalpus* 'sp indet.' and the isopod *Pseudodiploexochus* 'sp. nov.' (the first ever to be recorded in the Pilbara region at the time of the survey) represent new species. The centipede *Cormocephalus* 'HCI003' was the first eyeless scolopendrid specimen recorded at the time of the survey.

The majority of troglobitic species recorded were collected as singletons and doubletons, with only the Blattodea specimens (*Nocticola* sp. indet.) and Coleoptera specimens (*Anillini* sp. indet.) collected in higher numbers 13 and 26, respectively).

Table 2. Troglobitic specimens recorded (*ecologia* 2013).

Order	Genus/Species	Easting	Northing	Bore ID	No. individuals
Thysanura	*Atelurinae* 'sp. indet.'	667471	7436527	WAD358	1
Psocoptera	*Trogiidae* 'sp. indet.'	691917	7441689	DHRC006	1
Hemiptera	*Meenoplidae* 'sp. indet.'	677142	7439755	WAG307	1
Hemiptera	*Meenoplidae* 'sp. indet.'	690832	7441805	WAH189	1
Embioptera	*Embioptera* 'sp. indet.'	676945	7436109	DExt13	1
Blattodea	*Nocticola* 'sp. indet.'	691491	7441209	DHRC010	2
Blattodea	*Nocticola* 'sp. indet.'	690832	7441805	WAH189	3
Blattodea	*Nocticola* 'sp. indet.'	693430	7441478	WAH048	8
Coleoptera	*Anillini* 'sp. indet'.	672131	7439118	WACRC332	26
Coleoptera	*Hydrobiomorpha*'sp. indet.'	665491	7437029	WAD329	2
Araneae	*Prethopalpus* 'sp indet.'	693112	7441491	WAH017	2
Isopoda	*Pseudodiploexochus* 'sp. nov.'	693112	7441491	WAH017	2
Chilopoda	*Cormocephalus* 'CHI003'	690369	7441601	WAH192	1

There was little commonality of troglofauna species across different geological units, suggesting potentially isolated species assemblages. However, this is considered likely to be an artefact of a small sample size.

Only one of the potentially troglobitic species recorded by *ecologia* in 2013, *Embioptera* sp. indet, is associated with the Proposal. A single juvenile specimen was collected from a bore in Deposit A west. Classification to family level was not possible because only adult males can be taxonomically identified. Little is known about troglobitic *Embioptera*. Generally they have limited distribution due to the flightless nature of the females, and morphologically distinct groups appear to be geographically restricted. This species is thus considered to represent a potential SRE.

Stygofauna sampling was limited to four accessible bores in Deposit F, which yielded no stygofauna specimens.

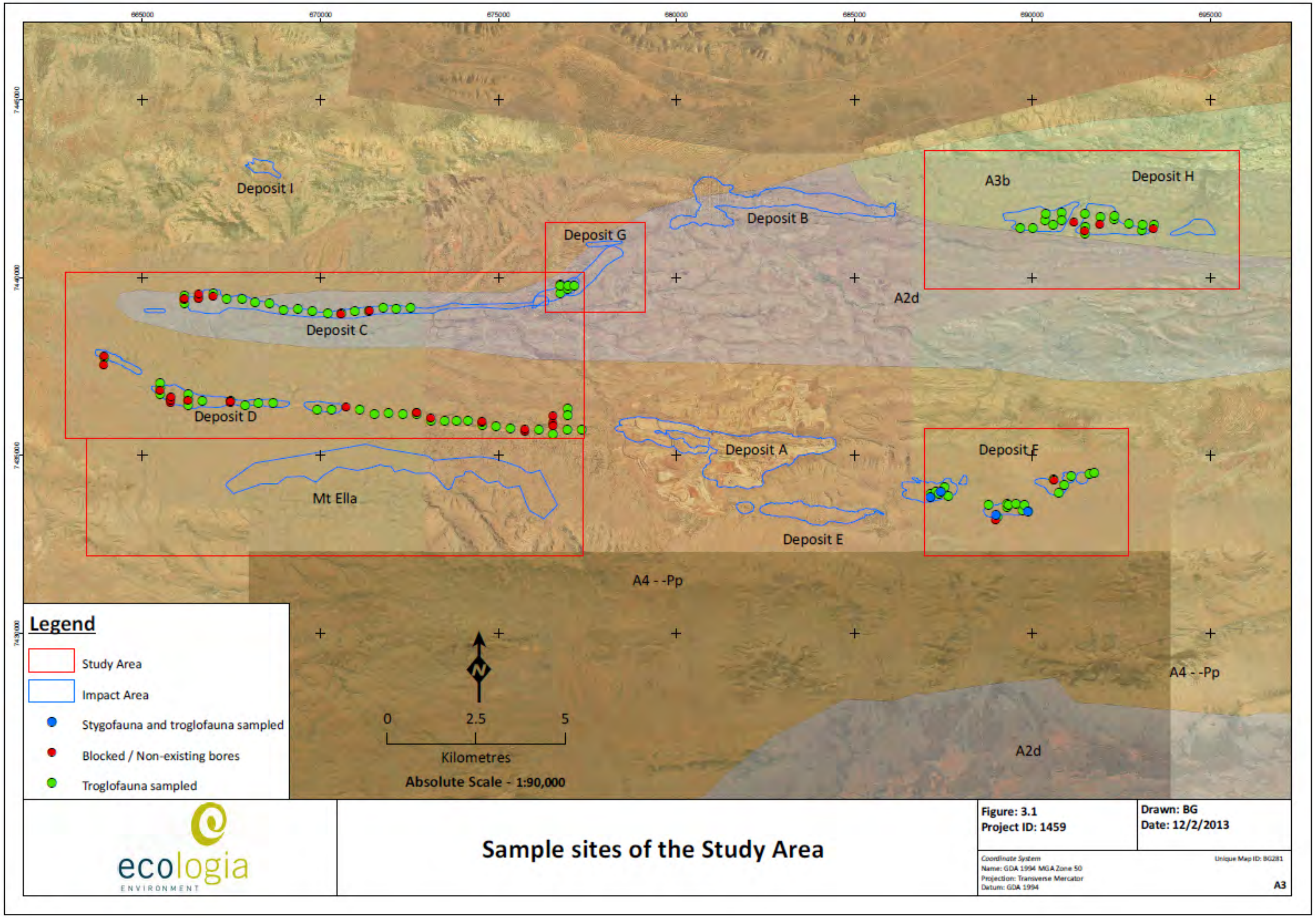


Figure 3. Sample sites (*ecologia* 2013).

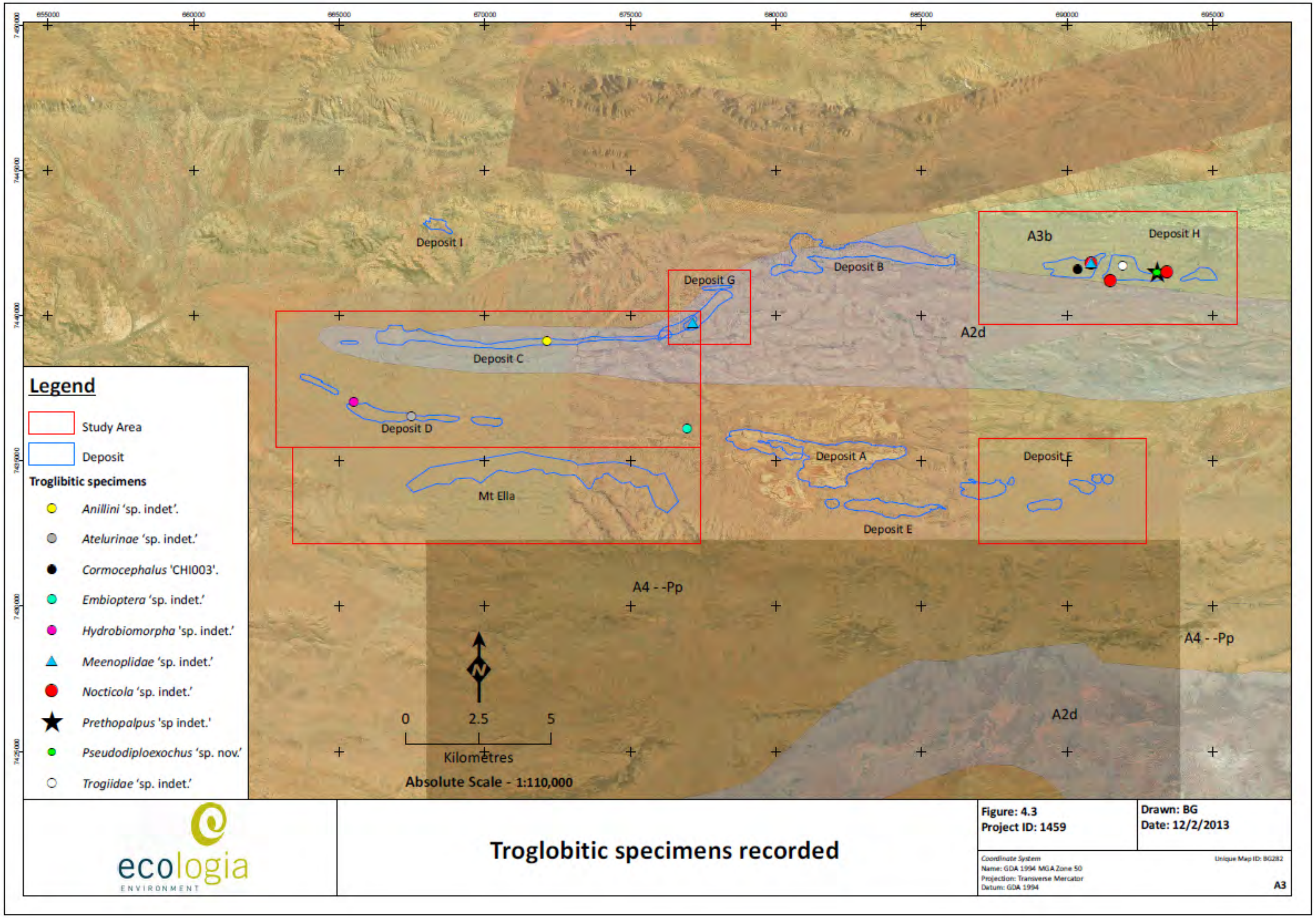


Figure 4. Troglofauna specimens recorded (*ecologia* 2013).

3. SPECIES ASSESSMENT

Over the span of the historical surveys, troglofauna were only recovered in the most recent survey. The majority of potentially troglobitic species recorded were collected as singletons, i.e. known only from a single individual at a single location. Most of the species are therefore known only from within the Proposal Area.

Over the span of the historical surveys stygofauna were recovered from bores within both the Turee Creek B borefield and the West Angelas borefield. The majority of potentially stygobitic species were collected in low abundance.

It is estimated that 70% of Pilbara stygofauna species are SREs (Eberhard *et al*. 2009).The proportion of SRE troglofauna in the Pilbara is likely to be significantly higher, given that the known ranges of many troglofauna are smaller than those of stygofauna (Lamoreux 2004).

However, it is considered unlikely that the species currently known only from a few records do, in fact, have such restricted ranges. The known ranges of most 'restricted' species are thought likely to be an underestimate given that information on the range of subterranean fauna species is limited to the point where they are known occur.

The specific identification, distribution and conservation status of the *Embioptera* sp. indet collected remains undefined. However, it is considered probable that the range of this 'restricted' species extends in continuous habitat. Evidence about the likely distributions of species in continuous habitat at West Angelas is included in the habitat assessment below.

4. HABITAT CHARACTERISATION

The occurrence and distribution of subterranean fauna is influenced or limited by the geological formation in which they occur. The presence of subterranean voids affects the pattern of occurrence, the density and distribution of subterranean fauna. Lateral connectivity of voids is important because it enables animals to move about underground, while vertical connectivity with the surface is important for supplying carbon and nutrients to maintain populations of different species. Geological features such as major faults can either act as barriers or conduits to below-ground dispersal of subterranean fauna.

4.1 GEOLOGY OF THE PILBARA

The geology of the Pilbara region is dominated by the Hamersley Group. The Hamersley Group was formed by chemical sedimentation of minerals in an ocean environment during the late Archean and early Proterozoic (2,500 million years ago). It contains several large units of alternating iron-rich and silica-rich layers called banded iron formation (BIF). The BIF derived ore group contains the largest tonnage of known iron ore resources (Hamersley Iron, 2000).

4.2 GEOLOGY OF THE WEST ANGELAS REGION

The West Angelas deposits are located on the regional Wonmunna Anticline. The geological formations in this local synclinal structure are continuous, extending throughout the region.

The Wonmunna anticline contains a low-lying plateau of Jeerinah Formation in its core. The composition of the Jeerinah Formation includes mudstones, shales, and ultramafic intrusive dolerite sills. The permeability and groundwater storage is generally low in this formation, except where there are local fracture systems associated with regional lineaments. Areas of low relief have been in filled with Tertiary and Quaternary sediments, up to 70 m thick, and include boulder beds and gravel, calcrete and silcrete, mixed sand and gravel and Channel Iron Deposit (Pisolite) (*ecologia* 1998; Hamersley Iron 2000).

The Marra Mamba Iron Formation surrounds the Jeerinah Formation. The Marra Mamba Iron Formation is subdivided into three members. The main unit of interest within the Marra Mamba Iron Formation is the uppermost Mt Newman Member which hosts the majority of mineralisation at West Angelas. The Mt Newman Member comprises banded iron formation (BIF) with interbedded carbonate and discrete shale bands.

Mineralisation consists of a series of discontinuous deposits located on both the north and south limb of the regional anticline. Along the northern limb of the regional anticline (from west to east) are deposits C, G, B and H while the southern limb hosts (from west to east) Deposits D, A, E and F (*ecologia* 1998).

The mineralisation is overlain by a widespread regolith of hydrated material, produced by the secondary alteration process of weathering. This hydrated material, which is commonly intersected in the Mount Newman Member close to the surface, is generally 20 – 50 m thick.

4.2.1 Deposit A west

Deposit A west is a southerly dipping Marra Mamba resource occurring along the southern limb of the regional Wonmunna Anticline. The deposit is east-west trending over a strike length of 9 km, with the eastern end terminating at Deposit A, and is considered a continuation of the mineralisation.

Mineralisation is predominately contained in the Mt Newman Member of the Marra Mamba Iron Formation. There is also minor mineralisation in the MacLeod Member and at the base of the West Angelas Shale Member. Dolerite dykes are present throughout the deposit.

Hydrated detritals cover the resource. These detritals are generally pisolitic or limonitic in lithology.

4.2.2 Deposit F

Deposit F also occurs along the southern limb of the regional Wonmunna Anticline. The deposit is considered a continuation of the Deposit E mineralisation, with an interrupted resource approximately 6 km in strike length. The Deposit F resource includes Marra Mamba and Detrital mineralisation.

Mineralisation is predominately contained in the Mt Newman Member and sometimes into the Macleod Member. Where present, the lower part of the West Angelas Member may also be mineralised. Faults are present throughout the deposit. Detritals intermittently overlay the bedrock, creating continuous, variably thick, mineralisation which transitions down into the mineralised Mount Newman Member.

Alluvials cover the resource, varying from 2 metres in depth in the north to up to 80 metres towards the south.

4.3 LOCAL HABITAT ASSESSMENT

The occurrence and distribution of subterranean fauna is influenced or limited by the geological formation in which they occur. Such dispersal limitations result in extremely small, fragmented species ranges and thus high levels of endemism (EPA 2003). In order to assess the potential for subterranean fauna to occur, it is necessary to identify likely habitats and the extent of those habitats:

4.3.1 Troglofauna

The range of geological formations which troglofauna may habit has yet to be determined, however, surveys have demonstrated that troglofauna occur within various rock-forms of the Pilbara. Troglofauna are most commonly associated with calcrete deposits, likely due to their karstic nature which creates habitat space in the form of caves, together with interconnectivity. More recently they have also been associated with micro-cavities of porous Pisolite Iron Formations and BIF within the Pilbara, which contain cavities of various sizes. The micro-habitats within these lithologies are yet to be characterised but it is inferred they occupy fissures and voids associated with weathering and faulting.

The Marra Mamba Iron Formation is not considered core habitat for the persistence of significant populations of troglofauna. Deposits A west and F are considered ‘typical’ of Marra Mamba Iron Formation. The massive-textured geology of these deposits does not provide suitable interconnected cavities or void spaces, suggesting that the distribution of subterranean fauna is likely to be limited in this formation.

Moreover, this geological formation is well-represented in the region (Figure 5). Even if the sedimentary rocks of the Marra Mamba Iron Formation hosted some troglofauna, the proposed area of Marra Mamba Iron Formation affected by mining is negligible is comparison to the overall area of the formation present in the wider region.

Local fracture systems and weathered zones associated with regional lineaments are one of the only parts of the Marra Mamba Iron Formation which represent potential troglofauna habitat. These fractured and weathered zones exhibit vughy textures. The fracture patterns are not well defined and it is likely that they extend vertically and horizontally outside of the Proposal Area suggesting there is habitat continuity through areas where the species was not recorded. The degree of connectivity of these habitats is important for subterranean fauna dispersal. It may be reasonably expected that if troglofauna were present within are local fracture systems and weathered zones, then they would be well represented across the entire area.

Hydrated, vuggy-textured material has also previously been identified as potential troglofauna habitat elsewhere in the Pilbara. The widespread regolith of hydrated material, which is commonly intersected in the Mount Newman Member close to the surface, is the only other part of the formation which potentially can exhibit micro-vughy textures. Hydrated zones extend beyond the deposits (i.e. they occur both locally and regionally). It is therefore likely that troglofauna habitat extends into continuous habitat in the surrounding strata.

The deeper geological units that are saturated (below the water table) do not support troglofauna communities.

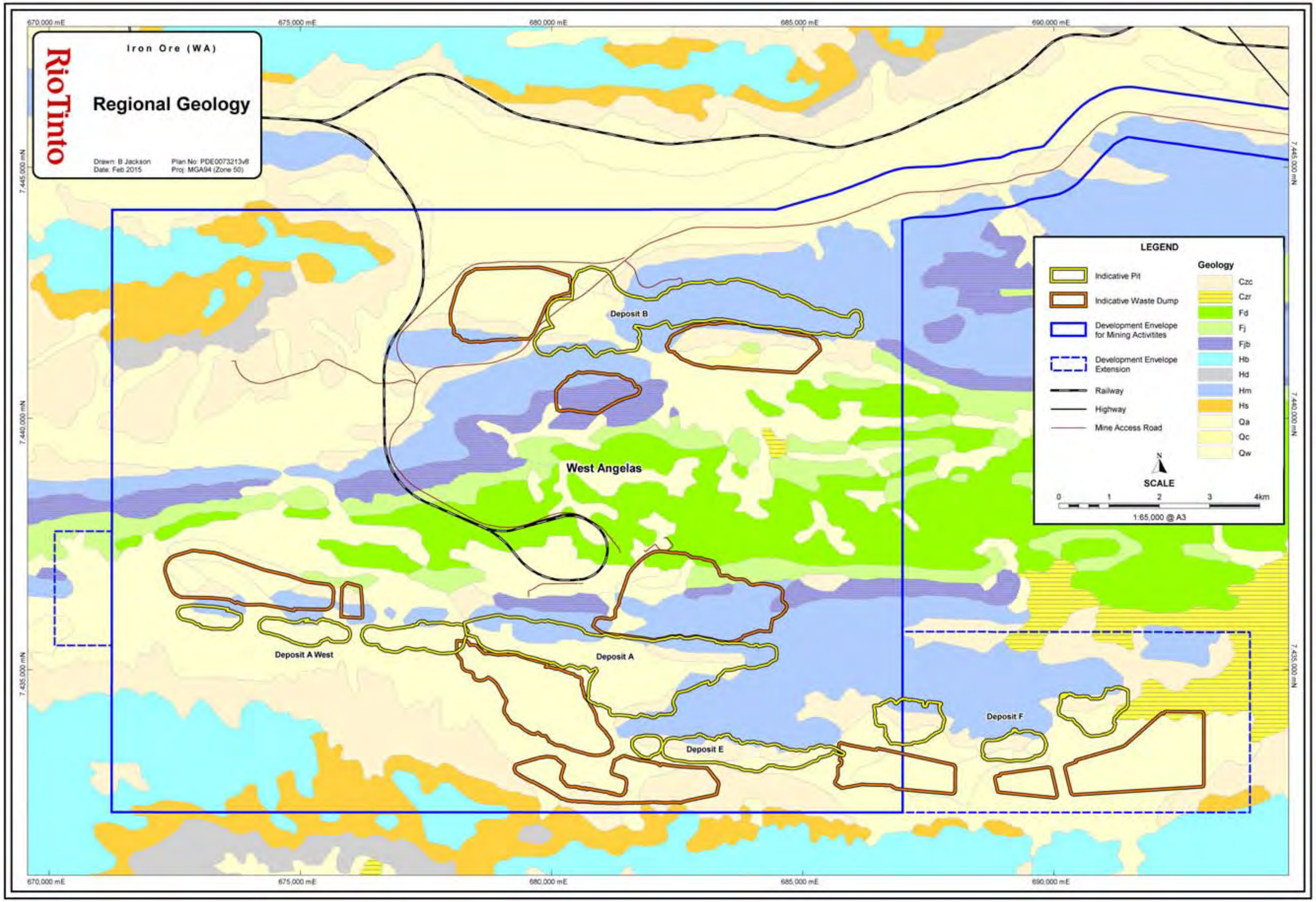


Figure 5. Geology.

Geology Legend

- Czc - Colluvium - partly consolidated valley-fill deposits. Detritals
- Czr - Hematite and geothite - LATERITE
- Fd - Metadolerite sills intruded into Fortescue Group; medium to coarse-grained, usually foliated. Massive grey - green rock
- Fj - Shale, chert, jaspilite, mudstone, quartzite and dolomite. Intruded by dolerite sills
- Fjb - Metabasalt; pillows locally well developed
- Hb - Banded jaspilite and chert with some shale dolomitic with riebeckite and crocidolite at Wittenoom Gorge and Dales Gorge. Contains stromatolites
- Hd - Thin to medium-bedded grey crystalline dolomite, intercalations of chert, dolomitic shale, and metatuff in upper part.
- Hm - Chert, ferruginous chert and banded iron with minor shale; jaspilite with pronounced 'pinch and swell' structures, small occurrences of manganese
- Hs - Pelite, chert and banded iron formation
- Qa - Alluvium - unconsolidated silt, sand, aeolian sand, red loamy sand in drifts and fixed self dunes and gravel.
- Qc - Colluvium - unconsolidated quartz and rock fragments in soil.
- Qw - Alluvium and colluvium - red-brown sandy and clayey soil.

4.3.2 Stygofauna

The presence of stygofauna in Western Australia has been well documented, especially from regions such as the Pilbara and Kimberley, and less so in the Midwest and South West regions of Western Australia (*ecologia* 2013). Stygofauna are known to be present in the groundwater associated with a variety of geologies. These include (but are not limited to) calcrete aquifers associated with palaeochannels, haematite sandstone aquifers, clay-sandstone aquifers on the Swan and Scott Coastal Plains, porous aquifers (e.g. alluvium), fractured-rock aquifers, springs and hyporheic habitats (*ecologia* 2013). These types of aquifers have sufficient interstitial spaces required to support stygofauna.

However, distribution patterns of stygofauna in aquifers are considered to be determined by hydraulic connectivity rather than associated with particular geologies. Stygofauna require adequate hydraulic connectivity to allow food and oxygen to be distributed from the surface to the groundwater.

Open (porous, fractured and karstic) aquifers have abundant interstitial space and at least moderate hydraulic conductivity. There is continuous exchange with surface water for food and oxygen supply, which is why stygofauna communities are often found in this aquifer type (Hahn and Fuchs 2009). Historically, the Turee Creek B borefield, which is located within an open aquifer, has yielded stygofauna (*ecologia* 2013).

Confined and / or compact aquifers have low hydraulic conductivity and are not considered overly prospective habitat for stygofauna according to classifications by the EPA (2013). These types of aquifers have minimal interstitial space and reduced food and oxygen supply, which is why these aquifer types are usually either devoid of stygofauna or have depleted taxonomic richness and abundance (Hahn and Fuchs 2009 in *ecologia* 2013). Historically, the Deposit A aquifer, which is a confined aquifer has returned no stygofauna (Biota 2003, 2008).

Given the depth and hydraulically confined nature of the Deposits A west and F aquifers, these aquifers are considered unlikely to support significant populations of stygofauna. This does not preclude the potential occurrence of stygofauna if the aquifers have secondary hydraulic conductivity in the form of local fractures. However, the historic sampling of the Deposit A, which failed to detect stygofauna, suggests there is a low likelihood of a diverse and abundant stygofauna community being present in these analogous aquifers.

5. SUMMARY

Based on review of potential subterranean habitats, results of published and unpublished studies on subterranean fauna from the region and previous subterranean fauna sampling, the Proposal generally presents a low risk to subterranean fauna:

- No species listed under the EPBC Act, WC Act or by the Department of Parks and Wildlife as critical, endangered or vulnerable have been recorded.
- Stygofauna have not historically been recorded from, and are not expected to be recorded from, within the confined (i.e. low hydraulic connectivity) aquifers associated with the deposits.

- The Proposal has the potential to impact the potentially locally endemic troglofauna *Embioptera* sp. indet which was collected from a bore in Deposit A west however, the known range of 'restricted' species, particularly those represented by a single specimen, is likely to be an underestimate. It is considered probable that the range of this 'restricted' species will extend in continuous habitat.
- Adequate sampling (as per EPA (2013)) has occurred. Low capture rates mean Rio Tinto is using habitat as a surrogate for the distribution of subterranean fauna taxa, as per the approach outlines in EPA (2013).
- The Marra Mamba Iron Formation is not considered core habitat for the persistence of significant populations of troglofauna. Moreover, even if the Marra Mamba Iron Formation hosted some troglofauna, the proposed area of Marra Mamba Iron Formation affected by mining is negligible is comparison to the continuous extent of Marra Mamba formation within the syncline and overall area of the formation present in the wider region.
- Local fracture systems and weathered zones as well as hydrated material, which represent potential troglofauna habitats both connect and extend outside of the deposits suggesting there is habitat continuity through areas where species were not recorded. It may be reasonably expected that if troglofauna were present, then they would be well represented within the local area.

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