

Sorby Management Pty Ltd

Subterranean fauna desktop study and field survey for the Sorby Hills Project

Final Report

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Sorby Management Pty Ltd
by Bennelongia Pty Ltd

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Subterranean fauna desktop study and field survey for the Sorby Hills Project

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EXECUTIVE SUMMARY

Sorby Hills Management Pty Ltd is planning to recommence mining activities at the lead, zinc and silver orebodies located approximately 50 km by road north-east of the Kimberley regional town of Kununurra. The open cut mining and mine pit dewatering techniques proposed have the potential to remove or significantly disrupt the habitats of subterranean invertebrate species with tightly restricted ranges.

A desktop compilation of previous subterranean fauna records was conducted over a 100 km by 100 km area that included the extensive river flood plains on which the proposed Sorby Hills Project is located, as well as low sandstone hills and eroded limestone reefs. The results revealed a moderately rich array of troglofauna species belonging to four higher taxa and seven orders:

- Arachnida were represented by three orders; Araneae (spiders), Opilionida (harvest men) and Pseudoscorpionida (pseudoscorpions);
- Crustaceans were represented by the single order Isopoda (slaters or woodlice);
- Entognatha were represented by the single order Diplura (bristletails); and
- Insects were represented by two orders; Blattodea (cockroaches), and Hemiptera (beetles).

Recorded specimens included five formally described species of which none is listed as specially protected under either Commonwealth or Western Australian legislative or policy frameworks.

Troglofauna specimens were collected almost exclusively from limestone caves, and none was collected from within Sorby Hills mining tenements M80/197 and M80/286, or at other bores located on the river flood plains. The lack of troglofauna records, together with the occurrence of very fine grained alluvial sediments unlikely to contain extensive interconnected voids, and the generally shallow water table and likely seasonal inundation, suggest that significant troglofauna communities are unlikely to occur in the area of proposed mining.

The desktop study showed that a moderately diverse array of stygofauna species occur both in the limestone cave systems and beneath the river flood plains to the west and south-west of the Sorby Hills mining tenements. They include oligochaete annelids and four crustacean orders: Copepoda, Isopoda, Ostracoda and Syncarida. Four stygofauna species were formally described, of which none is listed as specially protected under either Commonwealth or Western Australian legislative or policy frameworks.

A two-phase stygofauna survey was conducted within Sorby Hills mining tenements M80/197 and M80/286 between August and November 2011, with totals of 41 impact and 40 reference samples being collected. At least ten species from six orders or higher level groups were identified from 78 specimens:

- Nematoda or round worms (at least one species);
- the oligochaete worm order Tubificida (one species); and
- four orders of crustaceans – Ostracoda (two species), Copepoda (four species), Syncarida (one species), and Isopoda (one species).

All species are new to science, and therefore none is currently listed as specially protected under either Commonwealth or Western Australian legislative or policy frameworks.

Of the ten species collected during the 2011 stygofauna survey and the syncarid Gen A sp. 5 (probably *Kimberleybathynella*) collected in 2004, all but one species were collected from outside the proposed impact area. It is considered unlikely that the proposed disturbance of stygofauna habitat will result in

a level of impact that could cause the significant downgrading or extinction of species that are known to occur beyond the zone of impact.

The single species known only from the impact area, Ostracoda sp. A, was collected as a single valve and was considered to be a surfacewater species, with a range likely to be orders of magnitude greater than the predicted impact area. Surfacewater species are very unlikely to have ranges restricted to an area the size of the impact area at Sorby Hills. In support of this observation, the more abundant collected Ostracoda sp. B was found both within and outside the impact area. The distribution of Ostracoda sp. B demonstrated ostracod habitat continuity between the impact and reference areas. It is likely that the collection of Ostracoda sp. A only in the impact area is an artefact of it being collected only once. Thus, it is considered that the localised impact of mining in the Sorby Hills Project is unlikely to threaten the persistence of any stygofauna species.

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1. INTRODUCTION

Subterranean fauna are primarily invertebrate species that inhabit caves and the many small voids and tunnels that occur within some unconsolidated and rocky substrates. Species living above the water table are referred to as troglofauna and those within the saturated zone below the water table are called stygofauna. Many subterranean species are dependent on discontinuous habitats and have restricted ranges, and most are characterised by limited dispersal abilities, slow growth rates, and low fecundity (Harvey 2002; Gibert and Deharveng 2002; Eberhard *et al.* 2009). These characteristics make subterranean species vulnerable to extinction as a result of anthropogenic disturbance (Fontaine *et al.* 2007; Ponder and Colgan 2002).

Sorby Hills Management Pty Ltd is planning to recommence mining activities at the lead, zinc and silver orebodies located less than 5 km west of the Northern Territory border in the Kimberley, approximately 50 km north-east of Kununurra (Figure 1). The open cut mining and mine pit dewatering techniques proposed have the potential to remove or significantly disrupt the habitats of subterranean species with ranges encompassed by the area of disturbance.

In recognition of the potential vulnerability of highly restricted species of subterranean fauna, the Environmental Protection Authority (EPA) has prepared guidance statements relating to the requirements for survey of subterranean fauna in environmental impact assessment (EPA 2003, and 2007).

This report provides an assessment of the potential impacts on subterranean fauna of mine recommencement during the Sorby Hills Project through:

- a desktop study that
 - summarises existing information relating to subterranean fauna and habitats within and surrounding the Sorby Hills Project;
 - assesses the likely occurrence of troglofauna at the Sorby Hills Project area;
- results of a field survey of stygofauna; and
- an evaluation of the potential impact of the Sorby Hills Project on subterranean fauna.

2. BACKGROUND INFORMATION ABOUT SUBTERRANEAN FAUNA

Early troglofauna research in Western Australia focussed on caves. However, surveys in other habitats during the past five years have demonstrated that many troglofauna in Western Australia occur outside caves in a variety of substrates. The invertebrate groups containing troglofauna include pseudoscorpions, spiders, paligrads, schizomids, harvestmen, isopods, centipedes, millipedes, pauropods, symphylans, diplurans, silverfish, cockroaches, bugs, beetles and fungus-gnats. While diversity and abundance of troglofauna seem to be greatest in the Pilbara, troglofauna occur in most regions of Western Australia and have previously been recorded from the Kimberley (Harvey 2001), as well as at Cape Range (Harvey *et al.* 1993), Barrow Island (Biota 2005a), the Mid-West (Ecologia 2008) and Yilgarn (Bennelongia 2009), South-West (Biota 2005b) and Nullarbor (Moore 1995).

Intensive surveys for stygofauna in Western Australia began in the Pilbara in the 1990s (Humphreys 1999a), with a rapid increase in knowledge during the last decade (see Eberhard *et al.* 2005, 2009).

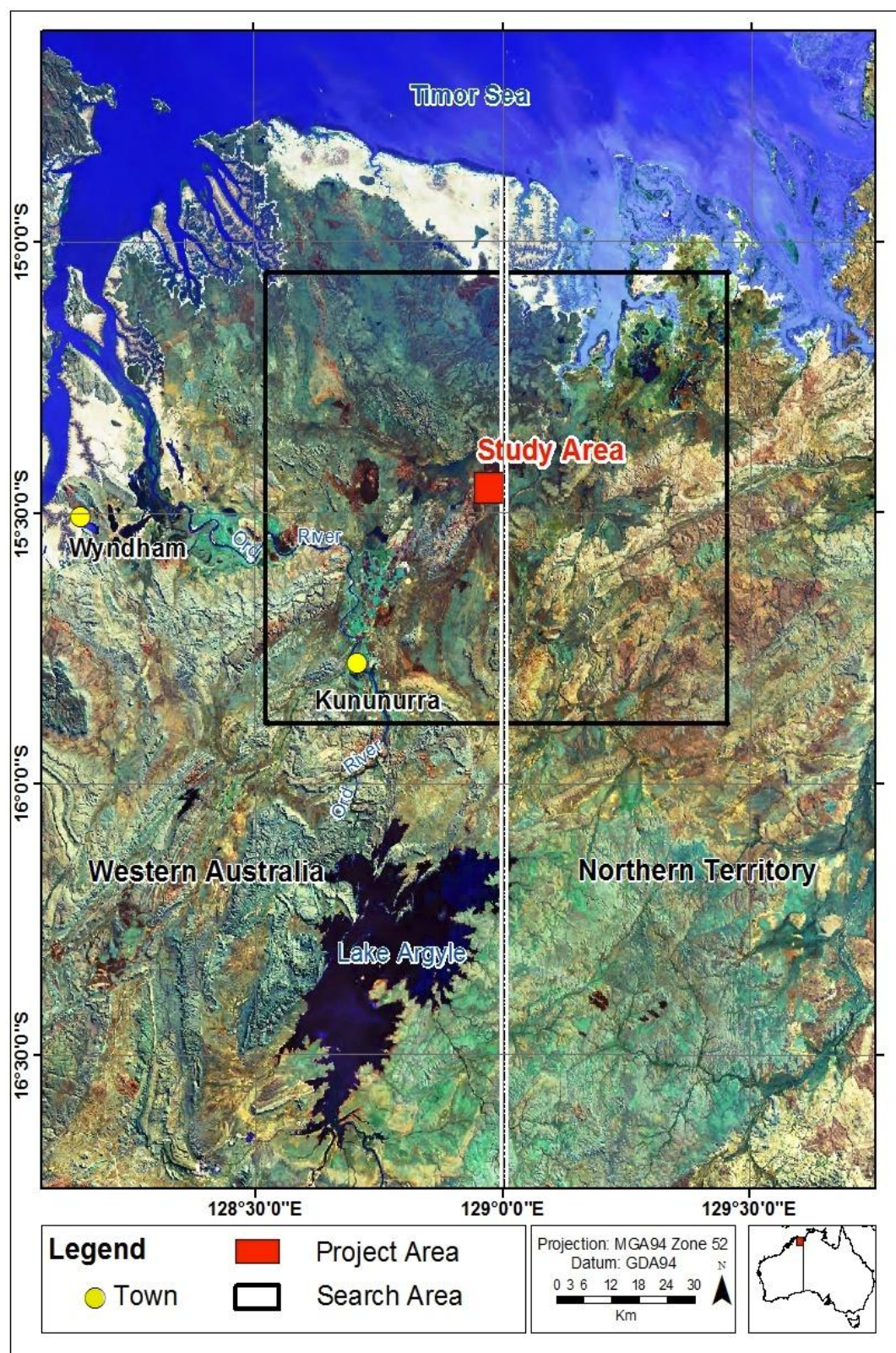


Figure 1. Location of Sorby Hills Project in relation to the desktop search area and regional northern Australia.

Calcrete and alluvium are typically considered to be the most productive habitats for stygofauna, although other fractured and vuggy rock substrata are also known to support rich stygofauna populations (Halse *et al.* in preparation). Australian stygofauna communities are dominated by crustaceans with ostracods, copepods and amphipods contributing most of the animals and species (Eberhard *et al.* 2005; Halse *et al.* in preparation). Stygofauna have been found in fresh to hypersaline groundwater (Humphreys 2008).

3. SORBY HILLS PROJECT

The Sorby Hills silver, lead zinc deposit was discovered in 1971 and explored during the 1970s and 1980s. KBL Mining Limited acquired the Sorby Hills Project in 2008 and entered into a Joint Venture Agreement with Yuguang (Australia) Pty Ltd. The joint venture partners have appointed KBL Mining Limited subsidiary, Sorby Management Pty Ltd, as Manager of the Joint Venture.

The Sorby Hills mining tenements M80/197 and M80/286, cover an area of 1,782.27 hectares, and the ore deposits lie along an 8 km, north-south orientated linear strip. An open cut mining technique will be used, initially focusing on three separate pits that will be contained within one larger pit as mining progresses. In addition to the mine pits, the mine will include a run of mine (ROM) pad, mineral and overburden stock piles, haul roads, a mill and concentrator, tailings dam and road train loading facility. Mining is planned to a depth of 70m and will therefore require dewatering using peripheral dewatering bores and an in-pit sump. Ore will be trucked to the coastal port town of Wyndham for export (Sorby Management 2011).

4. POTENTIAL IMPACTS FROM MINING

Activities that cause direct *habitat loss* are considered to be *primary* impacts that have the potential to lead to extinction of tightly restricted subterranean species. For proposed mining at Sorby Hills these primary impacts are:

1. *Pit excavation.* Removal of overburden and ore in the mining process has the potential to pose a significant risk to restricted troglifauna species.
2. *De-watering.* Drawdown of aquifers to prevent flooding of mine pits has the potential to pose a significant risk to stygofauna species unless the underlying aquifers also provide habitat.

The ecological impacts of activities that *reduce the quality* of subterranean fauna habitat have been little studied in Australia (or elsewhere) but it is considered that these impacts are more likely to reduce population size than cause species extinction (Scarsbrook and Fenwick 2003; Masciopinto *et al.* 2006). These impacts are therefore considered to be of *secondary* importance.

Mining activities at Sorby Hills that may result in secondary impacts to subterranean fauna include:

1. *De-watering below troglifauna habitat.* The impact of a lowered water table on subterranean humidity and therefore the quality of troglifauna habitat is poorly studied, but it may sometimes pose a risk to troglifauna species depending on geology or soil type, the amount of residual humidity and whether there is any suitable habitat in deeper, recently de-watered substrates. However, in line with usual interpretations, de-watering outside the proposed mine pits is not considered to be a significant risk to troglifauna at Sorby Hills.
2. *Run of mine pad and stockpiles.* These artificial landforms may cause localised reduction in rainfall recharge and associated entry of dissolved organic matter and nutrients, because water

runs off compacted pads and stockpiles rather than infiltrating through them and into the underlying ground. The effects of reduced carbon and nutrient input are likely to be expressed over many years and may be greater for troglofauna than stygofauna because lateral movement of groundwater is likely to transport carbon and nutrients from beyond areas covered by stockpiles. The extent of impacts on troglofauna will largely depend on the importance of chemoautotrophy in driving the subterranean system compared with plant roots and infiltration-transported surface energy and nutrients. Stockpiles are unlikely to cause species extinctions, although population densities of species may decrease.

3. *Percussion from blasting.* Impacts on both stygofauna and troglofauna may occur through the physical effect of explosions. Blasting may also have indirect detrimental effects through altering underground structure (usually rock fragmentation and collapse of voids) and transient increases in groundwater turbidity. The effects of blasting are often referred to in grey literature but are poorly quantified and have not been related to ecological impacts. Any effects of blasting are likely to dissipate rapidly with distance from the pit and are not considered to be a significant risk to either stygofauna or troglofauna outside the proposed mine pits.
4. *Aquifer recharge with poor quality water.* Quality of recharge water usually declines during, and after, mining operations as a result of rock break up and soil disturbance (e.g. Gajowiec 1993; McAuley and Kozar 2006). Impacts can be minimised by management of surface water through the installation of drainage channels, and sumps and pumps in the mine pit to prevent recharge through the pit floor.
5. *Contamination of groundwater.* Any change, or contamination of groundwater, either during or after mining could impact subterranean communities. However, the risk of contamination from many sources; e.g. petroleum and tailings spills, can be minimised by engineering and management practices to ensure their containment.

5. DESKTOP STUDY

5.1. Methods

The occurrence of subterranean fauna is dependent on habitat availability. Stygofauna require groundwater and, without the presence of cracks, tunnels and other voids within rocky or unconsolidated substrates, subterranean fauna cannot survive. Hydrogeological characteristics of the Sorby Hills Project area were investigated with reference to the 1:250,000 geological map images (GSWA 2003) and previous reports (O'Boy *et al.* 2001; AGE 2011).

Museum databases and existing reports (Humphreys 1999b; Ecowise 2005) were reviewed to determine the existence of previous subterranean fauna records from the Sorby Hills and surrounding areas. A 100 km square area, defined by the coordinates 15.057°S, 128.529°E in the north-western corner and 15.890°S, 129.453°E in the south-eastern corner (Figure 1), was used to search for records of catalogued subterranean fauna specimens in the Western Australian Museum. A search of arachnid and myriapod specimen collections at the Northern Territory Museum was also made by staff of the Western Australian Museum. The much smaller Study Area immediately surrounding the proposed mine development was defined by the boundaries of tenements M80/197 and M80/286 (Figure 2).

The previously recorded occurrence of specially protected subterranean species in the search area was determined with reference to the EPBC Act Protected Matters database (compiled from a range of data sources including the Western Australian Department of Environment and Conservation, the Australian

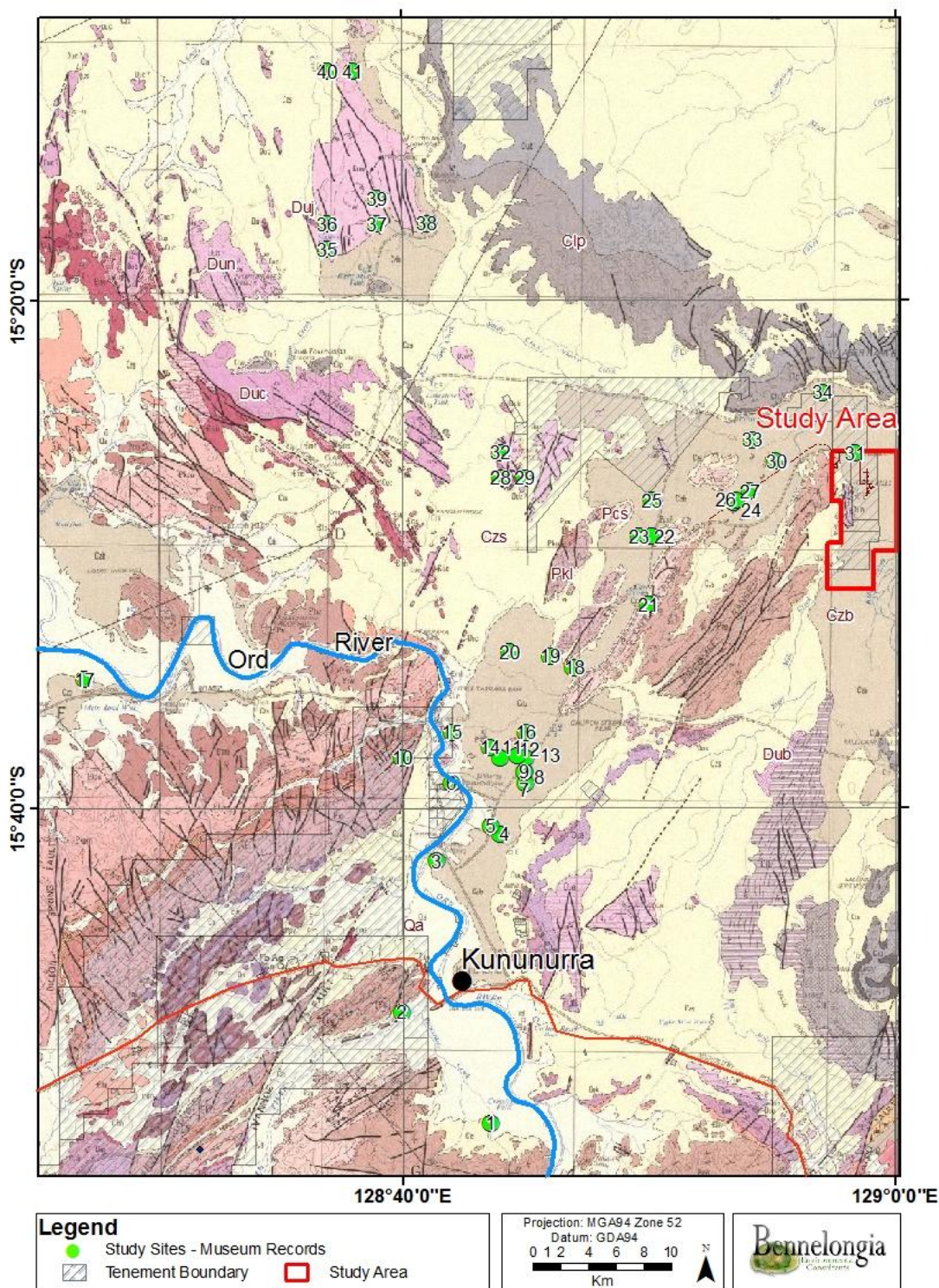


Figure 2. The Study Area and distribution of existing subterranean fauna records in relation to surface geological layers (see key overpage).

Sourced from 1:250,000 geological map images (GSWA 2003).

Key to Figure 2.

Code	Colour	Surface layer geology
Clp	grey	Quartz, sandstone
Czb	fawn	Black soil
Czs	pale yellow	Sand, soil cover, alluvium, travertine
Dub	pink	Sandy and silty limestone
Duc	pink	Uartz sandstone, minor limestone
Duj	pink	Sandy dolomite
Dun	pink	Limestone of reef complex
Qa	cream	alluvium
Pcs	pale brown	Subfriable quartz sandstone, and feldspathic sandstone. Minor granule sandstone, red shale
Pkl	Pale brown	Massive quartz sandstone, feldspathic sandstone, granule sandstone

National Wildlife Collection, the Australian Museum, and Online Zoological Collections of Australian Museums) and NatureMap (a collaborative project between the Department of Environment and Conservation and the Western Australian Museum).

5.2. Results

5.2.1. Hydrogeology

The oldest rocks in the Kimberley were formed from sediments deposited over 1,700 million years ago. At that time, the Kimberley was a separate continent that later collided with the rest of Australia. The ancient landscape still bears witness to a long history of tectonic upheaval, periods of volcanic activity, and to ongoing erosion and deposition during a wide range of climatic conditions, from the formation of reefs in shallow tropical seas, to sculpturing by ice sheets, melt waters and glacial deposits.

The Sorby Hills Project is located in the eastern Kimberley near the northeastern edge of the originally separate Kimberley Block. Proterozoic to Devonian aged basement rocks in this area slope to the east with the oldest layers outcropping on the western edge of the Sorby Hills Project area as the Pincombe Range (AGE 2011). The geology at the proposed mine sites is described as a transgressive sequence of shelf carbonate-clastic rocks that are dominated by Carboniferous aged dolomitic formations which overlie a Devonian basement stratigraphy (CSA 2010 reported in AGE 2011) .

The proposed mine is located on the Knox Creek Plain which is part of the extensive Ord and Keep River plains complex. Today, the plains have a surface layer of unconsolidated sediments up to 40 m thick (O'Boy *et al.* 2001) associated with the infill of Ord and Keep River palaeochannels. The sediments generally fine upwards with basal sands and gravels overlain by sand, silt and topped by fine cracking clays generally referred to as black soils. The region is dominated by two fault/fracture sets. The northeast orientated set is thought to be continuous with the Devonian basement geology. Faults of the second, southeast orientated set occur at intervals of approximately 200 m to 400 m (AGE 2011).

The sandstone Pincombe Range to the west of the Sorby Project area, and Spirit Hill to the northeast dominate the otherwise featureless flood plains in the vicinity of the Sorby Hills Project Area (AGE 2011). Northwest of the Ord and Keep river plains lies the Ningbing Range, which is part of an uplifted Devonian tropical reef that probably stretched over 1000 km around the Kimberley coast between 375 and 350 million years ago. Constructed by millions of lime secreting bacteria and other extinct marine

organisms, this massive limestone structure has been eroded by water to form cave systems. South of the Sorby Hills Project area is the Halls Creek Mobile Zone, which is a fault-bounded belt of highly deformed rocks (O'Boy 2011).

The flat Knox Creek Plain provides a low energy environment for surface water runoff. Border and Knox creeks, 3.5 km to the north and south respectively, and the Keep River 4.6 km to the southeast, provide the major drainage channels in the area (Soil Water 2011). Drainage patterns are seasonal with most creeks and rivers dry between mid-June and the monsoonal rains and cyclones characteristic of the summer and late autumn months. During the wet season, water courses rapidly respond to the intense rain. The clay soils of the floodplain become saturated to a depth of about 0.5 m, but because the soils swell when wet, the surface layers form an effective barrier to further infiltration. Additional runoff then pools over the entire floodplain to depths of 20 to 30 cm under normal conditions, with depths of up to 1 m predicted during exceptionally wet conditions (Soil Water 2011).

Groundwater occurs in both confined and unconfined aquifers. Three layers of dolomite have been identified at the proposed mine site, each supporting a confined aquifer. The deepest, or first, of these confined aquifers lies beneath a second confined aquifer that is associated with the ore-bearing dolomitic layer. This layer is overlaid by an aquiclude, which in turn is located beneath the third dolomite layer and confined aquifer. An unconfined aquifer occurs in the unconsolidated surface sediments, but sediments between these surface layers and the third dolomite layer are generally impermeable (AGE 2011).

Depths to groundwater vary, but groundwater is at its highest at the southern end of mining tenement M8/287 where depths between approximately 6 m to 12 m were recorded in 2010 (AGE 2011). Positive recharge potential associated with an extended period of above average rainfall has resulted in a rising trend in ground water levels since 1999 (AGE 2011). Ground water salinity, ranges from low to very low immediately to the north of proposed mine pits, to moderate in the central and southern portions of the proposed development area (AGE 2011). However, all salinities fall within the range over which stygofauna species occur.

5.2.2. Troglifauna

5.2.2.1. Existing troglifauna records

WA Museum troglifauna specimens collected from within the 100 km by 100 km search area were catalogued in two databases. Three described species and two morphospecies of troglobitic arachnids were downloaded from a specialist arachnid database. However, specimens catalogued in a second more general database, together with those listed in reports of previous subterranean fauna surveys, lacked both taxonomic resolution (many specimens not identified beyond order or class), and information regarding their subfaunal status. Interpretation of the combined specimen list may therefore have underestimated the true number of troglobitic species previously collected in the area.

Given the size of the search area, the number of recorded troglifauna species is low. On the otherhand, survey effort is also relatively low. Therefore, little more can be said than that search results indicate that suitable habitat in the area probably has the potential to support a moderately diverse troglifauna community. The species collected to date belong to four higher groups and seven orders:

- Arachnida were represented by three orders: Araneae (spiders), Opilionida (harvestmen) and Pseudoscorpionida (false scorpions);

Table 1. Described species of troglafauna previously recorded from within the 100 km by 100 km search area.

Higher taxonomic groups	Species	Type location (source of holotype)	Search area locations (Figure 1)
Arachnida			
Araneae			
Filistatidae	<i>Wandella pallida</i> (Gray 1994)	Cave KJ 8 (sites 29 and 32)	Cave complex sites 29 and 32
Oonopidae	<i>Opopaea phineus</i> (Harvey and Edward 2007)	Cave KNI 27 (site 38)	Cave sites 38
Pseudoscorpionida			
Hyidae	<i>Indohya gollum</i> (Harvey and Volschenk 2007)	Cave KNI 41 (site 41)	Cave sites 35 and 41
Entognatha			
Diplura			
Campodeidae	<i>Cocytocampa humphreysi</i> (Condé 1998)	outside search area	Cave site 32
Insecta			
Blattodea			
Nocticolidae	<i>Nocticola brooksi</i> (Roth 1995)	Cave KNI 41 (site 41)	Cave sites 35, 36, 38, 40 and 41.

- Crustaceans were represented by the single order Isopoda (slaters or woodlice);
- Entognatha were represented by the single order Diplura (bristletails); and
- Insects were represented by two orders: Blattodea (cockroaches) and Hemiptera (bugs).

Recorded specimens included five formally described species: two araneids, one pseudoscorpion, a dipluran and a species of blattodea (Table 1). Of these species:

- The filistatid spider *Wandella pallida* is known only from a cave system (in the Jeremiah Hills which are located within the search area, approximately 22 km west of the Sorby Hills Study Area (mapped as sites 29 and 32 in Figure 2).
- The goblin spider *Opopaea phineus* has been described from a single specimen collected from cave KNI 27 (Harvey and Edward 2007), which is mapped as site 38 within the search area (Figure 2). This limestone karst cave is located in the Devonian Reef system of the Ningbing Range, to the north-west of the Sorby Hills Study Area.
- The large troglomorphic pseudoscorpion *Indohya gollum* is known only from caves KNI 19 and KNI 41 in the Ningbing Ranges (Harvey and Volschenk 2007). All species of troglifaunal *Indohya* have restricted distributional ranges (Harvey and Volschenk 2007).
- The dipluran *Cocytocampa humphreysi* has been recorded at a cave located at site 32 (Figure 2). This single specimen is possibly a subspecies of *Cocytocampa humphreysi*, which was described from Cape Range on the North West Cape (Condé 1998). *Cocytocampa humphreysi* has also been recorded from caves north of Katherine in the Northern Territory.
- The cockroach *Nocticola brooksi* has been collected extensively within the search area with more than 20 specimens recorded in combined database and report searches relating to the

search area. *Nocticola brooksi* has also been recorded in the Western Kimberley, over 500 km from the Ningbing Range, and at caves near to Katherine in the Northern Territory (Roth 1995).

None of these described troglofaunal species is listed as specially protected under either Commonwealth or Western Australian legislative or policy frameworks.

Troglofauna species identified to morphospecies included the araneids *Argiope* cf. *dietrichae* (WA Museum arachnid database), *Myrmopopaea* 'sp. nov' (WA Museum general database); the opilionid ?*Anjulus* sp. nov (WA Museum general database), the pseudoscorpionid *Lagynochthonius* sp.; and the hemipterans *Myiophanes* (*Perimyiophanes*) sp. nov., *Ploiaria* sp. 1 and *Centrogus* sp.2 (WA Museum general database).

The troglofauna species and morphospecies listed above, together with other catalogued and reported specimens of potential troglofauna, were collected almost exclusively from caves, with specimens from just one cave spring at site 37 (Figure 2). None were collected from bores located on the river flood plains. The nearest troglofauna specimens to the proposed mining were collected from caves in the Jeremiah Hills, which are approximately 22 km west of the Sorby Hills Study Area.

5.2.2.2. Prospectivity of Sorby Hills Study Area for troglofauna

Although the 100 km by 100 km desktop study search area contains diverse troglofauna communities, there is no direct evidence of troglofauna species occurring within the Sorby Hills Study Area. Hydrogeological conditions within the the Sorby Hills Study Area suggest that significant troglofauna communities are very unlikely to occur at the proposed mine site.

The Sorby Hills Study Area is has very different surface geology from the locations where troglofauna have been collected. The caves and cave spring are all located in areas dominated by limestone or karstic geologies (mapped as pink on Figure 2). Weathered limestone creates a network of interconnected voids. It is therefore not unexpected that the fossil Devonian reefs to the west and north-west of the proposed mines support rich troglofauna communities. The river plains, however, are characterised by alluvial deposits (mapped as fawn, creams and pale yellow on Figure 2). The alluvial layers are fine grained to some depth forming tightly packed cracking clays. It is considered very unlikely that significant interconnected voids occur within these fine grained sediments.

Troglofauna require air for respiration and drown when submerged in water. The water table is as shallow as 6 m in parts of the Sorby Hills Study Area (AGE 2011), and further seasonal shallowing is considered likely. The Knox River Plain floods on a seasonal basis and although the cracking clays expand and generally seal the surface, it is considered likely that groundwater recharge will occur elsewhere and raise the groundwater levels beneath the pooled floodwaters on the surface leaving little or no substrate dry enough to support significant troglofauna during the wet season.

In summary, the probable lack of voids and the seasonally high water table at the Sorby Hills Project Area are interpreted as making the area unlikely to support significant troglofauna communities. Therefore, further troglofauna surveys of the project area is considered to be unnecessary.

5.2.3. Stygofauna

5.2.3.1. Existing stygofauna records

WA Museum stygofauna specimens collected from within the 100 km by 100 km search area were catalogued in two databases. Three described species of stygobitic syncarids were downloaded from a specialist crustacean database. However, as with records of troglofauna, stygofauna specimens catalogued in a second more general database, together with those listed in reports of previous subterranean fauna surveys in the search area, lacked both taxonomic resolution (few were identified beyond order or class) and information about their subfaunal status. Interpretation of the combined specimen list may therefore have underestimated the true number of stygobitic species previously collected in the area.

While recognising the limitations of the data available, it is evident that a moderately diverse assemblage of stygofaunal species have been recorded within the search area. They include oligochaete worms and four crustacean orders: Copepoda, Isopoda, Ostracoda and Syncarida. Syncarids dominate the records with relatively high numbers of potential stygofaunal species, the presence of one or more species recorded at 21 bore sites, and the occurrence of high specimen numbers (up to 56) at individual bores.

Stygofauna specimens included four formally described species of syncarids (Table 2):

- *Kimberleybathynella gigantea* is currently known only from bore WP 1 (Cho *et al.* 2005), which has been mapped as site 22 in Figure 2;
- A total of eight *Kimberleybathynella kimberleyensis* specimens from five river flood plain bore sites have been recorded. One of these, at site 34, is the type location for *Kimberleybathynella kimberleyensis*;
- The type location of *Kimberleybathynella argylensis* is just outside the search area at the Argyle diamond mine. One specimen of this species has been recorded from within the search area mapped as bore site 27 on Figure 2;
- The type location of *Kimberleybathynella hexapoda* is bore WP 6, which is mapped as site 25 on Figure 2. A total of 12 specimens have been recorded at this location and single specimens have been collected at each of bore sites 8, 18, and 23.

Table 2. Described species of stygofauna previously recorded from within the 100 km by 100 km search area.

Higher taxonomic groups	Species	Type location (source of holotype)	Search area locations (Figure 1)
crustacea			
Syncarida			
Bathynellacea	<i>Kimberleybathynella gigantea</i>	Bore WP 1 (site 22)	Bore site 22
	<i>Kimberleybathynella kimberleyensis</i>	Bore WP 19 (site 34)	Bore sites 19, 24, 27, 30, and 34.
	<i>Kimberleybathynella argylensis</i>	Outside the search area	Bore site 27
	<i>Kimberleybathynella hexapoda</i>	Bore WP 6 (site 25)	Bore sites 8, 18, 23, and 25.

None of the formally described syncarid species is listed as specially protected under either Commonwealth or Western Australian legislative or policy frameworks.

Stygofauna morphospecies included the oligochaetes *Pristina* sp. WA2 and *Pristina* sp. WA3 (WA Museum general database); the harpacticoid copepod *Parastenocaris* sp. (WA Museum general database); the isopod *Tainisopus* sp. (Humphreys 1999b); the ostracods *Cypridopsis* cf *Cypridopsis*, and *Strandesia* sp. (WA Museum general database), and a candonid ostracod (called *Merisocandona* sp. by Ecowise 2005 but this is not a valid genus); and the syncarids Bathynellidae sp. A, *Atopobathynella* sp. and *Kimberleybathynella* ?? "hexapoda Cho" n. sp (WA Museum general database), together with five syncarid species referred to as Gen A sp 1 – 5 (Ecowise 2005).

Most of the stygofauna specimens from the search area were collected from the bore sites shown in Figure 2. Very low specimen numbers were collected from the hand dug site 10 and the cave springs at sites 21 and 37, with higher numbers of stygofauna recorded at cave site 35 (Figure 2).

The only hole sampled within the Sorby Hills Study Area was at site 31 on the northern boundary of the Study Area in an area predicted to be undisturbed by mining activities. Site 31 yielded 22 specimens of the syncarid morphospecies Gen A sp. 5 (Ecowise 2005). Based on a photograph of Gen A sp. 4 in Ecowise (2005), it is considered that Gen A sp. 5 belongs to the genus *Kimberleybathynella* and it is probably a species described by Cho et al. 2005.

Of the two stygofauna surveys conducted in the vicinity of the Sorby Hills Study Area, Humphreys (1999b) recorded stygofauna in 32% of sampled bores while Ecowise (2005) recorded stygofauna in 23% of sampled bores.

5.2.3.2. Prospectivity of Sorby Hills Project Area for stygofauna

Complementing the results of stygofauna survey in adjacent areas, the available hydrogeological data suggest that stygofauna occur beneath the Sorby Hills Project Area. The range of salinities recorded across the proposed mining area are within the tolerance levels of stygofauna species and therefore any voids, channels and crevices associated with unconsolidated sediments, rock fractures along fault lines, or larval bubbles and channels associated with mineral formation within the dolomite layers, potentially support stygofauna communities. The fact that previous development of mineral deposits within the Study Area was halted by uncontrollable groundwater flows (AGE 2011) demonstrates the occurrence of interconnected voids and the porous nature of the dolomite layers.

The results of stygofauna surveys within the 100 km by 100 km desktop search area showed moderately diverse stygofauna communities both in the limestone cave systems and beneath the river flood plains to the west and south-west of the Sorby Hills Study Area. The only bore previously sampled within the Sorby Hills Project Area yielded an abundance of a single syncarid species providing direct evidence of stygofauna in the area. However, the absence of stygofauna from bores sampled to the south and north-east of the Sorby Hills Project Area indicate that stygofaunal communities are unlikely to be locally rich or of special conservation significance.

In summary, previous stygofauna surveys have shown one species of stygofauna (a syncarid) occurs within the Study Area). Geological data suggest a richer community may occur. Field surveys are required to define the nature of the Sorby Hills stygofauna community.

6. STYGOFAUNA FIELD SURVEY

6.1. Methods

6.1.1. Survey rationale

The stygofauna field survey was conducted within the 1,782 ha Sorby Hills Study Area defined by the boundaries of tenements M80/197 and M80/286 (Figure 2.).

Existing exploration drill holes were used to sample stygofauna. Those located within proposed mine pit or within the predicted extent of groundwater drawdown were classed as impact sites, while those located beyond the predicted drawdown cone were categorised as reference sites. The allocation of sites to impact and reference categories done by Sorby Hills Management Pty Ltd; inset A in Figure 3 approximately covers the predicted impact area.

6.1.2. Sampling methods

Stygofauna sampling followed the methods recommended by the EPA (2007). At each bore, six net hauls were collected using weighted plankton nets; three hauls with a 50 µm mesh net and three with a 150 µm mesh net. After the net was lowered to the bottom of the bore it was jerked up and down briefly to agitate benthic stygofauna into the water column prior to slowly retrieving the net. Contents of the net were transferred to a 125 ml polycarbonate vial after each haul and preserved in 100% ethanol. Nets were washed between bores to minimise contamination between sites. Each set of six hauls from a single bore made on the same day were combined as a single sample.

6.1.3. Sampling effort

A total of 81 samples were collected during a two phase survey. Twenty samples from within the impact area, and 20 samples from reference areas were sampled between 23 and 25 August 2011, and an additional 20 impact samples and 21 reference samples were collected between 8 and 10 November 2011 (Table 3, Figure 3).

Table 3. Sample numbers at impact and reference bores during the two phase field survey.

Survey date	No. samples within impact area	No. samples outside impact area	Total number of samples
23/08/2011		14	14
24/08/2011	10	6	16
25/08/2011	10		10
8/11/2011	10		10
9/11/2011		14	14
10/11/2011	10	7	17
Totals	40	41	81

6.1.4. Species sorting and identification

Preserved stygofauna samples were elutriated to separate animals from heavier sediment and sieved into size fractions (250, 90 and 53 µm) to remove debris and improve searching efficiency prior to sorting.

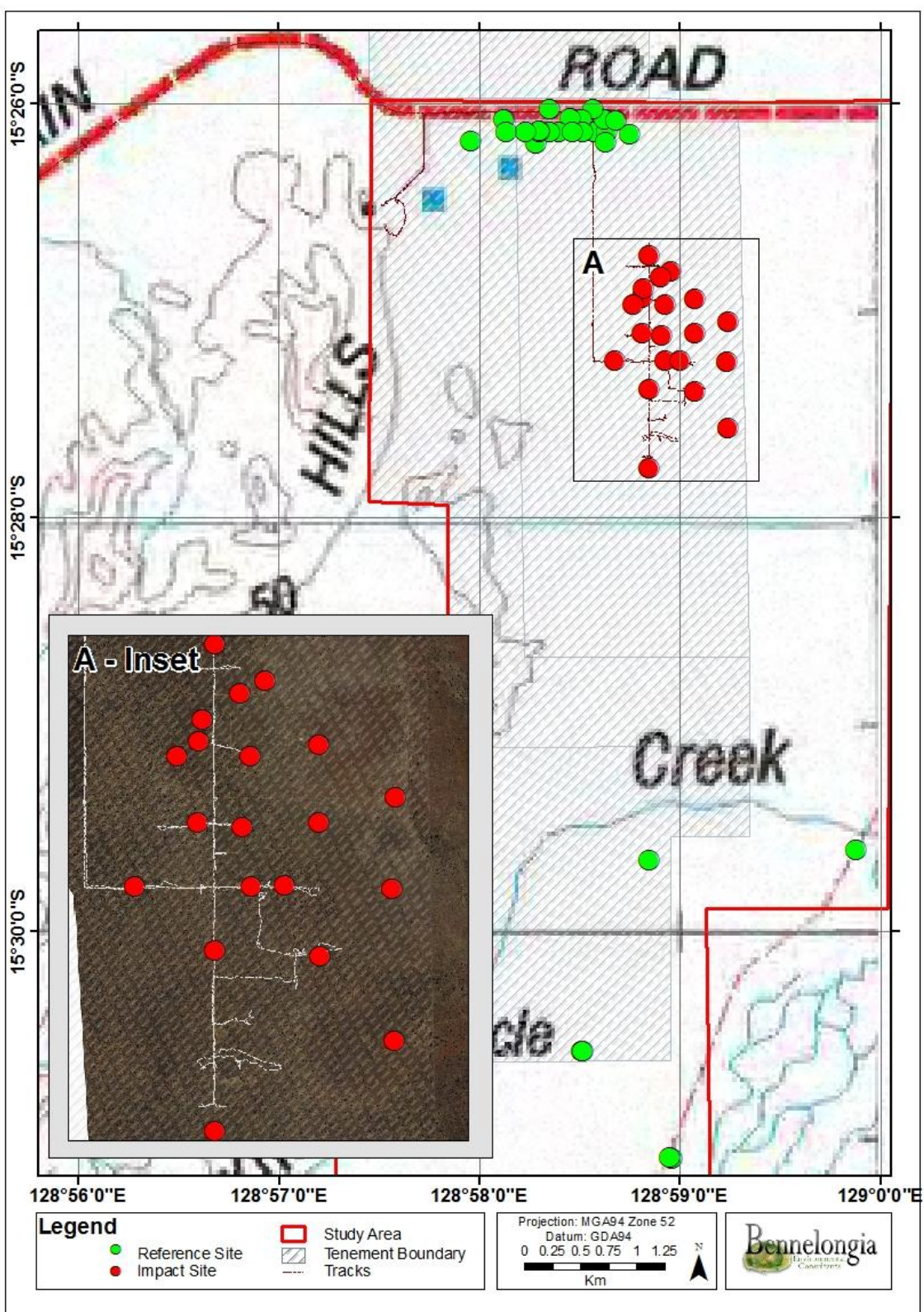


Figure 3. Distribution of impact and reference stygofauna sampling bores.

All samples were sorted under a dissecting microscope and where possible, stygofauna specimens were identified to species or morphospecies level using published and informal keys and reference to voucher collections. Specimens were dissected as required.

Representative specimens will be lodged with the Western Australian Museum after the Sorby Hills Project assessment process has been completed.

6.1.5. Compiling species lists

Stygofauna specimens that could not be identified to species or morphospecies level were included in estimates of species richness only if they could not belong to species already recorded. The purpose of this criterion was to account for all species collected, while preventing higher level identifications falsely inflating estimates of species richness.

6.1.6. Personnel

Sorby Hills surveys and specimen identifications were conducted by Bennelongia staff as follows:

- Field work was undertaken by Dean Main and Michael Curran during phase one, and by Jeremy Quartermaine, and Jim Cocking during phase two;
- Sample sorting was done by Jim Cocking, Michael Curran, Sabrina Cocking, Lucy Gibson, Dean Main, and Jeremy Quartermaine; and
- Identifications were made by Stuart Halse, Jane McRae, and Mike Scanlon.

6.2. Results

6.2.1. Stygofauna occurrence and abundance

At least ten species from six orders or higher level groups were identified from 78 specimens. The following groups were recorded:

- Nematoda or round worms (at least one species);
- the oligochaete worm order Tubificida (one species); and
- four orders of crustaceans – Ostracoda (two species), Copepoda (four species), Syncarida (one species), and Isopoda (one species) (Table 4).

None of the species formally described and, therefore, none are currently listed under State or Commonwealth legislation or had an elevated conservation status.

Ostracoda sp. B, and the copepod Ameiridae (nr *nitocrella*) sp B3 were the most abundant species (22 and 28 specimens, respectively). Six species had an abundance of less than five specimens and three of these were represented by single specimens: the group B tubificid worm, Ostracoda sp. A, and the isopod species *Tainisopus* sp. B2. Copepods were the most speciose order with four species, and the 75 crustacean specimens accounted for 96% of all stygofauna specimens collected (Figure 4).

Twelve, or 25%, of the sampled bores yielded stygofauna: five were in the impact area, and seven were from the reference area (Figure 5). One hole (WBS1112) in the reference area yielded 39 stygofauna specimens or 50% of all specimens collected. The 39 specimens included all of the 28 Ameiridae (nr *nitocrella*) sp B3 specimens. Localised high abundance of copepods is not uncommon and the collection of all nine specimens of *Microcyclops* sp. B1 in a single sample provides another example of patchy distribution (Table 4).

Table 4. Stygofauna species collected during the 2011 field survey of the Sorby Hills Project Area.

Taxonomic classification	Reference	Impact	Total No. of specimens	Recorded occurrence outside Sorby Hills impact area?
Nematoda				
Nematoda.....	2	-	2	Yes - Sorby Hills reference area
Oligochaeta				
Tubificida				
Tubificidae				
Tubificidae group B.....	1	-	1	Yes – Sorby Hills reference area and north-west Kimberley ^(a)
Crustacea				
Ostracoda				
Ostracoda sp. A.....	-	1	1	No
Ostracoda sp. B.....	4 ³	18 ⁵	22	Yes - Sorby Hills reference area
Copepoda				
Ameiridae				
Ameiridae (nr <i>nitocrella</i>) sp B3.	28 ²	-	28	Yes – Sorby Hills reference area
Cyclopidae				
<i>Australocyclops</i> nr <i>similis</i>	6 ²	-	6	Yes – Sorby Hills reference area
<i>Microcyclops</i> sp. B1.....	9	-	9	Yes - Sorby Hills reference area
Parastenocarididae				
<i>Parastenocaris</i> sp. B17.	4	-	4	Yes - Sorby Hills reference area
Syncarida				
Bathynellidae				
<i>Bathynella</i> sp. B6.....	4 ²	-	4	Yes - Sorby Hills reference area
Isopoda				
Tainisopidae				
<i>Tainisopus</i> sp. B2.....	1	-	1	Yes - Sorby Hills reference area
Total specimens	59	19	78	

Superscript numbers represent the number of samples in which specimens were recorded.

^(a) Bennelongia unpublished data.

Other than the B group of tubificid worms which have also been recorded in the north-west of the Kimberley region, none of the species collected has been recorded outside the Sorby Hills Study Area.

6.2.2. Stygofauna distributions in relation to the proposed area of impact

Two ostracod species were the only stygofauna species collected from within the proposed impact area (Figure 6). Both were represented only by valves, which limited the level of identification that could be achieved. One of these, *Ostracoda* sp. A, has not been collected outside the proposed impact area and its known distribution is therefore restricted to the impact area. All of the other stygofauna species were collected from outside the proposed impact area (Table 4).

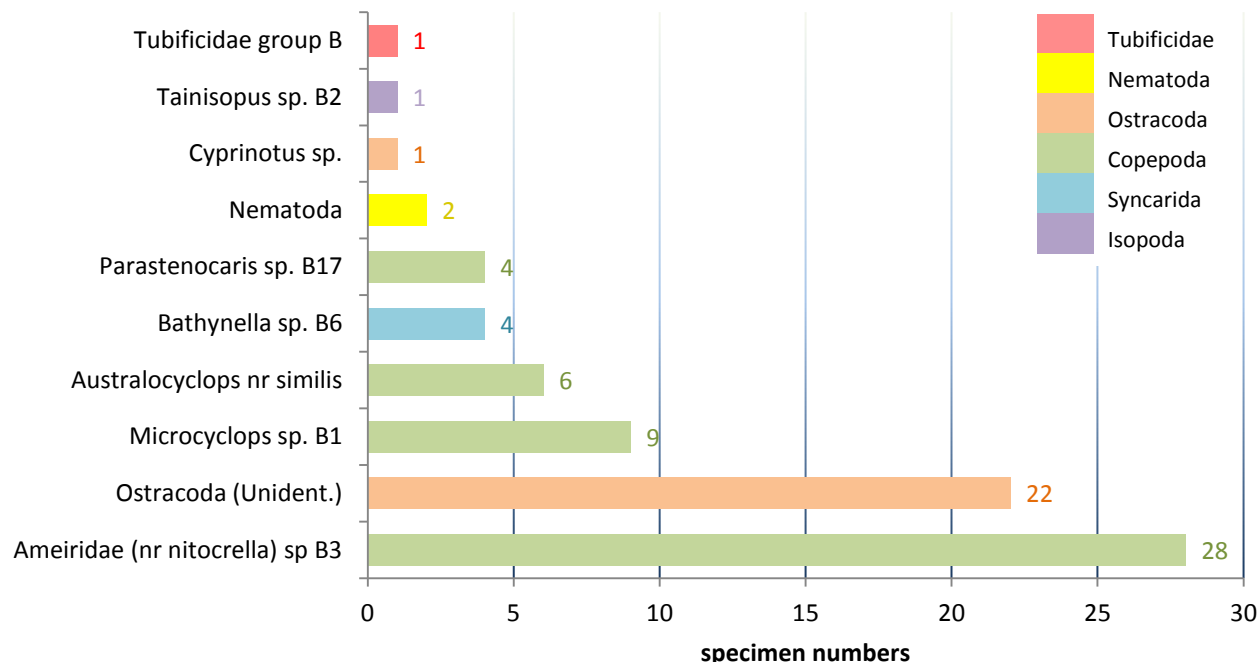


Figure 4. Capture abundance of each stygofauna species within the Sorby Hills Study Area.

6.2.3. Stygofauna species determinations

Tubificid group B is a species complex including several closely related species that are difficult to distinguish. The recorded occurrence of this species complex in north-west Kimberley does not necessarily indicate that it is the same species that occurs across the Kimberley region.

As stated in the section above, all ostracod specimens were represented by valves only. While this limited the extent of identification, it is considered likely that both species are undescribed surface water ostracods. Ostracoda sp. A, which was represented by a single specimen, was more distinctive.

Specimens of *Australocyclops* nr *similis* probably were *Australocyclops similis*, although the identification could not be confirmed. *Australocyclops similis* extends from southern Australia into the southern Kimberley (Atlas of Living Australia, <http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/afd/taxa/Australocyclops%20similis>).

6.3. Discussion

As anticipated from the desktop study, the species collected during surveys within the Sorby Hills Study Area represent a stygofauna community relatively low species richness. Although the 2011 survey collections were not dominated by syncarids, as the desktop study might have predicted, the specimens collected in 2011 generally belonged to the same taxonomic groups as those represented in previous surveys and the proportion of holes yielding stygofauna (25%) was roughly equivalent to the strike rates reported in previous surveys (32% in Humphreys 1999b and 23% in Ecowise 2005). It is reasonable therefore to assume that the 2011 survey adequately sampled the stygofauna community present within the Sorby Hills Study Area.

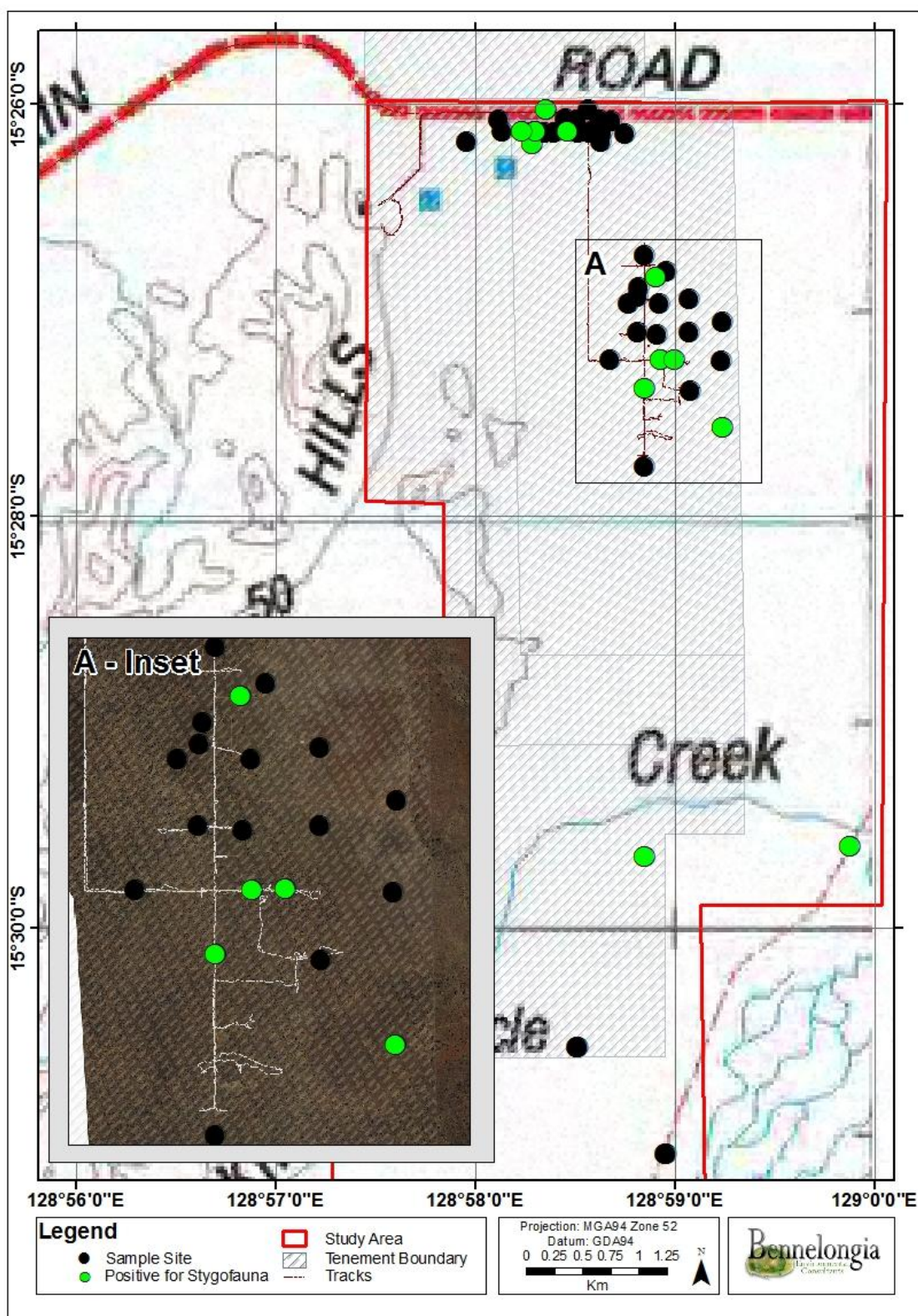


Figure 5. The distribution of sampled holes that yielded stygofauna.

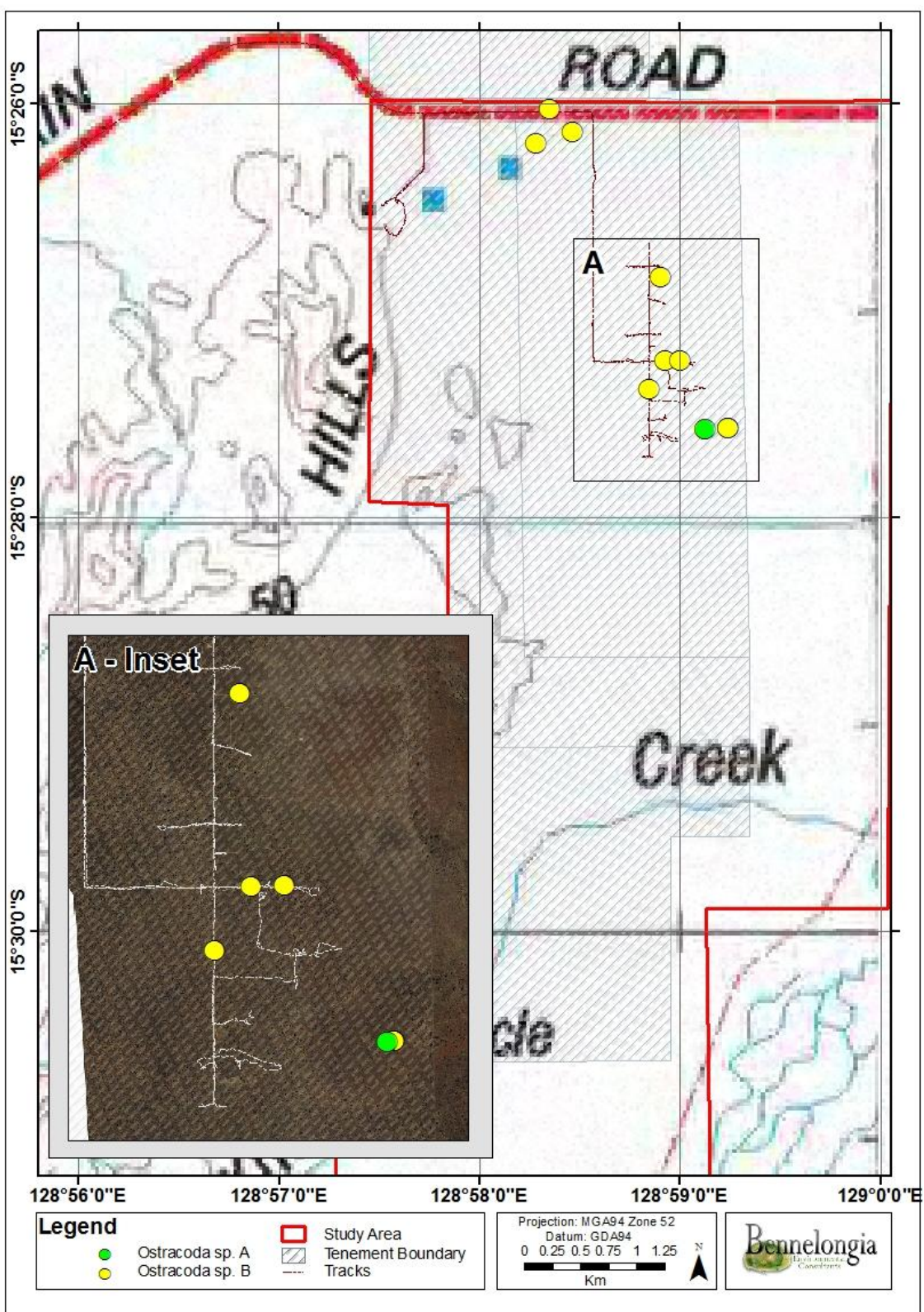


Figure 6. The distribution of two ostracod species collected from within the proposed impact area.

The objective of the EPA in relation to subterranean fauna species is to ensure adequate protection of important habitats used by subterranean species and to make sure that development proposals do not potentially threaten the viability of species causing them to become extinct (EPA 2003).

Of the ten species collected during the 2011 stygofauna survey and the syncarid Gen A sp. 5 (probably *Kimberleybathynella*) collected in 2004, all but one species were collected from outside the proposed impact area. It is considered unlikely that the proposed disturbance of stygofauna habitat will result in a level of impact that could cause the significant downgrading or extinction of species that are known to occur beyond the zone of impact.

The single species known only from the impact area, Ostracoda sp. A, was collected as a single valve (ostracods are bivalved crustaceans that are superficially similar to mussels). Little information can be gathered from the valve of a species unless it has been collected previously, but Ostracoda sp. A was considered to be a surface water species. Surface water species are very unlikely to have ranges restricted to an area the size of the impact area at Sorby Hills; in fact species with Australia-wide ranges are quite common (De Deckker 1981) and most Pilbara ostracod species are widespread (Pinder *et al.* 2010). In support of the prediction that Ostracoda sp. A is widespread, the more abundantly collected Ostracoda sp. B was found both within and outside the impact area (Figure 6). The distribution of Ostracoda sp. B demonstrates that continuity of ostracod habitat exists between the impact and reference areas. It is likely that the collection of Ostracoda sp. A only in the impact area is an artefact of it being collected only once. Thus, it is considered that the localised impact of mining in the Sorby Hills Project is unlikely to threaten the persistence of any stygofauna species.

7. SUMMARY

A desktop compilation of previous subterranean fauna records was conducted over a 100 km by 100 km area that included the extensive river flood plains on which the proposed Sorby Hills Project is located, as well as low sandstone hills and eroded limestone reefs. The results revealed a moderately rich array of troglofauna species belonging to four higher taxa and seven orders:

- Arachnida were represented by three orders; Araneae (spiders), Opilionida (harvest men) and Pseudoscorpionida (pseudoscorpions);
- Crustaceans were represented by the single order Isopoda (slaters or woodlice);
- Entognatha were represented by the single order Diplura (bristletails); and
- Insects were represented by two orders; Blattodea (cockroaches), and Hemiptera (beetles).

Recorded specimens included five formally described species of which none is listed as specially protected under either Commonwealth or Western Australian legislative or policy frameworks.

Troglofauna specimens were collected almost exclusively from limestone caves, and none was collected from within Sorby Hills mining tenements M80/197 and M80/286, or at other bores located on the river flood plains. The lack of troglofauna records, together with the occurrence of very fine grained alluvial sediments unlikely to contain extensive interconnected voids, and the generally shallow water table and likely seasonal inundation, suggest that significant troglofauna communities are unlikely to occur in the area of proposed mining.

The desktop study showed that a moderately diverse array of stygofauna species occur both in the limestone cave systems and beneath the river flood plains to the west and south-west of the Sorby Hills

mining tenements. They include oligochaete annelids and four crustacean orders: Copepoda, Isopoda, Ostracoda and Syncarida. Four stygofauna species were formally described, of which none is listed as specially protected under either Commonwealth or Western Australian legislative or policy frameworks.

A two-phase stygofauna survey was conducted within Sorby Hills mining tenements M80/197 and M80/286 between August and November 2011, with totals of 41 impact and 40 reference samples being collected. At least ten species from six orders or higher level groups were identified from 78 specimens:

- Nematoda or round worms (at least one species);
- the oligochaete worm order Tubificida (one species); and
- four orders of crustaceans – Ostracoda (two species), Copepoda (four species), Syncarida (one species), and Isopoda (one species).

All species are new to science, and therefore none is currently listed as specially protected under either Commonwealth or Western Australian legislative or policy frameworks.

Of the ten species collected during the 2011 stygofauna survey and the syncarid Gen A sp. 5 (probably *Kimberleybathynella*) collected in 2004, all but one species were collected from outside the proposed impact area. It is considered unlikely that the proposed disturbance of stygofauna habitat will result in a level of impact that could cause the significant downgrading or extinction of species that are known to occur beyond the zone of impact.

The single species known only from the impact area, Ostracoda sp. A, was collected as a single valve and was considered to be a surfacewater species, with a range likely to be orders of magnitude greater than the predicted impact area. Surfacewater species are very unlikely to have ranges restricted to an area the size of the impact area at Sorby Hills. In support of this observation, the more abundant collected Ostracoda sp. B was found both within and outside the impact area. The distribution of Ostracoda sp. B demonstrated ostracod habitat continuity between the impact and reference areas. It is likely that the collection of Ostracoda sp. A only in the impact area is an artefact of it being collected only once. Thus, it is considered that the localised impact of mining in the Sorby Hills Project is unlikely to threaten the persistence of any stygofauna species.

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APPENDIX A LOCATIONS OF SAMPLED BORES

Bore code	site type	latitude	longitude
WBS1155	Reference	-15.50963889	128.9751667
WBS1155A	Reference	-15.50966667	128.9752778
WP24	Reference	-15.49344444	128.9979167
KC3PB	Reference	-15.51833333	128.9826389
ORD17	Reference	-15.51827778	128.9824722
KC2	Reference	-15.49427778	128.98075
WBS5088	Reference	-15.43561111	128.9761667
WBS5065	Reference	-15.43561111	128.9772222
WBS1110	Reference	-15.43577778	128.9791667
WBS5084	Reference	-15.43461111	128.9770833
WBS1109	Reference	-15.43469444	128.978
WBS5083	Reference	-15.43375	128.9761389
WBS1108	Reference	-15.43463889	128.9751944
WBS4125	Reference	-15.43455556	128.9741944
WBS5081	Reference	-15.43561111	128.9732778
WBS7029	Reference	-15.43655556	128.9714167
WBS1087	Reference	-15.43638889	128.9659167
WBS1107	Reference	-15.43461111	128.9686667
WBS1112	Reference	-15.43375	128.9725278
WBS5066	Reference	-15.43641667	128.9771667
WBS7007	Impact	-15.45408333	128.9779167
WBS6040	Impact	-15.45405556	128.9821389
WBS7008	Impact	-15.45402778	128.9833333
OB03	Impact	-15.44897222	128.9802222
TPB1	Impact	-15.44822222	128.9803333
WBS4135	Impact	-15.44558333	128.9808056
WBS1153	Impact	-15.44686111	128.9826111
WBS5078	Impact	-15.44730556	128.9817222
WBS5070	Impact	-15.4495	128.9820833
WBS5048	Impact	-15.45094444	128.9873333
WBS7003	Impact	-15.46266667	128.9808056
WBS7005	Impact	-15.45633333	128.9808056
WBS7026	Impact	-15.45416667	128.9872222
WBS7027	Impact	-15.4595	128.9872778
WBS6037	Impact	-15.45652778	128.9846111
WBS7011	Impact	-15.45180556	128.9801944
WBS5074	Impact	-15.452	128.9818056

Bore code	site type	latitude	longitude
WBS6036	Impact	-15.45180556	128.9845556
WBS6035	Impact	-15.44911111	128.9845556
WBS7010	Impact	-15.4495	128.9794444
WBS6044B	Reference	-15.43561111	128.9752778
WBS5090	Reference	-15.43558333	128.9743611
WBS5086	Reference	-15.43561111	128.9725
WBS5043	Reference	-15.43558333	128.9716667
WBSUNK01	Reference	-15.43555556	128.9716389
WBS6044	Reference	-15.43558333	128.9705556
WBS1106	Reference	-15.43558333	128.9688889