TROPICANA GOLD PROJECT: REVIEW OF LOCAL AND REGIONAL REGOLITH TYPES AND DISTRIBUTION AS POTENTIAL TROGLOFAUNA HABITAT

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EXECUTIVE SUMMARY

The Tropicana Gold Project is a Joint Venture between AngloGold Ashanti Australia Limited (70%) and Independence Group NL (30%). AngloGold Ashanti Australia Limited as managers of the Project has undertaken extensive exploration and resource development drilling to define a multi-million ounce gold resource at the Tropicana and Havana deposits which are the focus of the Project. The resource is located in a remote area approximately 330 km east north-east of Kalgoorlie in the eastern Goldfields of the Yilgarn Craton bordering the Great Victoria Desert region of Western Australia. The region has previously not been extensively explored and the proposed Project will be the first major development in the area.

As part of the environmental impact studies undertaken for the Project, AngloGold Ashanti Australia Limited (AngloGold) on behalf of the Tropicana Joint Venture commissioned Louisa Lawrance (of Louisa Lawrance and Associates Pty Ltd) to undertake a review of the local regolith types, their regional distribution and their potential to provide suitable habitat for Troglofauna. The review provides evidence that the type and distribution of regolith within the Project's Operational Area (pit (s), waste landform and supporting infrastructure excluding an access road, communications corridor and water supply borefield) that does provide suitable Troglofauna habitat also occurs throughout the region.

Troglofauna are subterranean organisms that inhabit caves and small voids. They derive air, moisture, and food from their immediate environment. They require habitat cavities that are constantly moist and humid but not saturated, are connected to the surface via interconnecting voids and fractures which serve as conduits of organic matter (food) from the surface and air, and are within the active sub-surface biozone where root growth, microorganisms and their decay products provide food. Troglofauna have been located within a range of porous near-surface regolith materials and geological formations in Western Australia, including nodular calcrete, karst formations, pisolitic mesa formations, and Banded Ironstone Formations. The presence of Troglofauna at the Project has been confirmed by the identification of three species in drill holes within the Operational Area, but to date their actual habitat has not been clearly defined.

The regolith of the Operational Area and surrounds is the product of a long weathering history. Highly metamorphosed basement rocks of the Albany-Frazer Belt on the south-eastern margin of the Yilgarn Craton, have weathered to a flat undulating landscape in which the oldest regolith sequences are exposed as elevated landforms, such as ferricrete and silcrete mesas, butts, rubble mounds, and breakaways on the margin of ridges. Calcrete occurs in lower stratigraphic positions and is partially buried. These duricrust materials are predominantly multigenerational palaeo-valley-fill sequences, remnant of regional palaeo-drainage systems, but also include sediment from a period of marine incursion. They have been preserved through silicification, relief inversion, up-lift and erosion. Less consolidated regolith materials, have been reworked into sand, clay and gravel colluvial and alluvial soils in the intervening areas. Recent aeolian sand dune deposits have encroached into the landscape along low-lying corridors from the north-east Great Victoria Desert. These deposits abutt and overlap the duricrust exposures. Gypsiferous saline ephemeral lakes and clay pans, and associated marginal dunes, mark topographic low areas in the landscape. With the exception of some dune tops and salt lake surfaces, all units are now stabilised by vegetation. Present-day quiescent weathering processes largely involve minor reworking of surface soils, and sediment in shallow drainage channels and floodplains.

The climate at Tropicana is semi-arid to arid. Temperatures range between -3°C and 48°C and the mean average annual rainfall, 150 to 190 mm, and is grossly exceeded by evaporation of an estimated 2,750 mm. This net movement of water causes excessive surface moisture loss from regolith above the water table (located at 30 to 40 m below ground level). Biota at the land surface is specifically adapted to cope with low levels of soil moisture and elevated temperatures. Without surface protection, such conditions are likely to be prohibitive to troglofauna habitation.

Areas of soil cover within low-lying zones are subject to seasonal water infiltration, sub-surface dehydration, and to sediment reworking by wind and water erosion. Cavities that form are likely to be temporary. Hence, these environments are unsuitable for troglofauna habitat.

In contrast, the duricrust is typically elevated in the landscape, structurally stable, and resistant to further weathering and erosion. Impermeable slabs or pavements, from a few centimeters up to three meters thick, commonly cap the top. Underneath the duricrust is less indurated, with interconnected cavities, such as interstitial voids, solution pipes, and root casts, inherent at the time of formation. Deeper fractures, and other zones of palaeo-water access, such as root canals and previously unconsolidated gravel materials, are preferentially silicified during silcrete formation and provide subterranean support to the duricrust. Between these supports, the regolith is commonly moist and friable, and is thus prone to disaggregation and reworking by biological activity and contains roots and organic debris. The sub-surface duricrust is most cavernous adjacent to zones of lithostatic unloading, such as exposure at breakaways.

The duricrust exposures therefore provide stable, highly favourable cavities for subterranean troglofauna habitation in the Operational Area. They are elevated in the landscape and perched well above the watertable. They protect the sub-surface profile from water and sediment inundation, and flooding during episodes of high rainfall. The sub-surface environment is porous and protected from dehydration and extreme fluctuations in external temperature and thus, maintains a moist, uniform humid ambient environment in an otherwise hot-dry climate. The environment is well ventilated especially at breakaways; and fractures and interconnected voids provide access to plant roots, water, oxygen, and animals, thus providing an allochthonous food resource for the subterranean ecosystems.

The Operational Area is near the juncture of three regionally extensive bio domains, the Great Victoria Desert, the Eucla Basin-Nullarbor Plain, and the Yilgarn Craton (including the eastern Goldfields, Murchison and the Coolgardie biogeographic regions). Individually these domains cover a vast area of many hundreds of square kilometres with only slight variations in climate, biogeography, landform and regolith expression. With the exception of the Great Victoria Desert proper where sand dune cover is extensive, remnant regolith duricrust similar to those described at the Operational Area are exposed throughout these regions and represents approximately 15 to 25 percent of the cover throughout these regions. Thus, similar Troglofauna habitat as that found within the Operational Area is present over large proportions of the Great Victoria Desert, the Eucla Basin-Nullarbor Plain, and the Yilgarn Craton bio domains. It is therefore probable that all three Troglofauna species recorded within the Operational Area are also located in areas not affected by the proposed Tropicana Gold Project.

1.0 INTRODUCTION

1.1 PROJECT OVERVIEW

The Tropicana Gold Project (the Project) is located 330 km east northeast of Kalgoorlie on the western margin of the Great Victoria Desert, Western Australia (Figure 1). Drilling to date suggests that the deposit represents a multi-million ounce discovery within a new and relatively unexplored greenfields gold province. Tropicana was the first deposit discovered in this remote part of Western Australia, closely followed by the Havana deposit, and hence, base line studies have been required to be conducted by the Tropicana Joint Venture to understand the geology, regolith, groundwater, and biological profiles of the area.

The Tropicana Gold Project is a Joint Venture between AngloGold Ashanti Australia Limited (70%) and Independence Group NL (30%). In 2007 the Joint Venture commenced a pre-feasibility study investigating the potential establishment of the Project; the Project has now entered the feasibility stage and is progressing through the environmental approvals process. The proposed Project includes the development of:

- An Operational Area - This area contains the mine (one or more pits, up to 420 m deep); a carbon in leach processing plant, a tailings storage facility, aerodrome, village and other associated infrastructure;
- A Water Supply Area - Two basins have been investigated, the Minigwal Trough and Officer Basin; the Minigwal Trough is the selected water source; and
- An Infrastructure Corridor - Two options are under consideration, the Tropicana- Transline and Pinjin Corridors.

The Project aims to established an open-cut mine and processing plant with a production rate of 7Mt per annum over approximately 15 years.

As part of the assessment process, the impact of the Project on the local and regional natural environment, hydrology, and biodiversity must be considered and must pass through the Western Australian and Federal Government approval processes. This report on regolith and potential troglofauna habitat forms part of the environmental impact assessment and will input into the approval process.

Subterranean fauna are protected at a State level under the *Wildlife Conservation Act 1950* (WC Act) and their environment is protected under both the *Environmental Protection Act 1986* (EP Act) and the Federal *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Guidance on environmental management with respect to subterranean fauna is provided by EPA Guidance Statement 54: *Consideration of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in Western Australia 2003.*

In general, subterranean faunal habitat can be impacted by:

- Lowering the water table sufficiently to dry out the zone in which some species live, or otherwise artificially changing water tables; or
- Changing water quality (e.g. increasing salinity levels or altering haloclines, increasing nutrient levels or the availability of organic matter, or introducing other pollutants); or• Destroying or damaging caves (including changing their air temperatures and humidity).

Projects undertaken as part of the Environmental Impact Assessment (EIA) process are required to address guidelines produced by the EPA, in this case Guidance Statement 56: *Terrestrial Fauna Surveys for Environmental Impact in Western Australia* (EPA 2004), Guidance Statement 54: *Consideration of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in Western Australia* (EPA 2003), and principles outlined in the EPA's Position Statement No. 3 *Terrestrial Biological Surveys as an element of Biodiversity Protection* (EPA 2002). Additionally, a requirement to protect subterranean fauna, and to prevent or manage activities that may cause a decline in subterranean fauna populations is now written into the License to Operate for most mining and industrial activities.

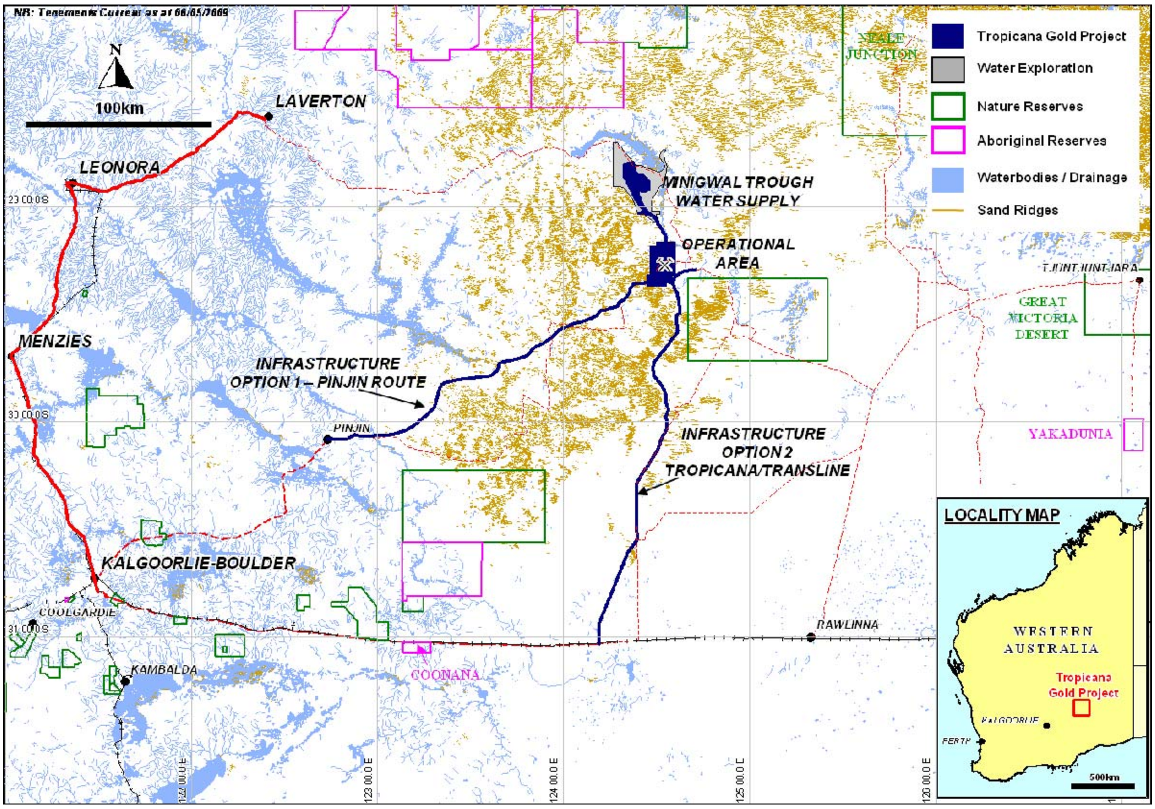

Figure 1 Location map of the Tropicana Gold Project area.

1.2 REVIEW OBJECTIVES

The aim of this review is to provide documentation on the type and distribution of surface regolith materials at Tropicana, and their regional continuity, as potential habitat for Troglofauna. This information is provided to assist in the formal public review process to assess the potential environmental impact of the proposed Project on the local and regional troglofauna population.

The presence of troglofauna at Tropicana has been confirmed by the identification of three troglobitic species, a dipluran, a centipede and several isopods (Figure 2), in drill holes within the Operational Area, but to date their actual habitat has not been clearly defined.

This report made use of the following information by Belinda Bastow, Environmental Manager - Tropicana and Exploration AngloGold Ashanti Australia Ltd:

- *ecologia* Environment (2007a): Goldfields Troglofauna Desktop Review.
- *ecologia* Environment (2009a): Flora and Vegetation Assessment of the Proposed Operational Area and its Surroundings.
- *ecologia* Environment (2009b): Tropicana Gold Project - Operational Area Troglofauna Survey.
- Pennington Scott (2009): Operational Area Groundwater Assessment.
- Previously undocumented maps, information and field photographs prepared and provided by Ben McCormack, Senior Project Geologist, AngloGold Ashanti Australia Ltd.
- The author's published and unpublished data sources, including unpublished field notes and regolith knowledge of the area.

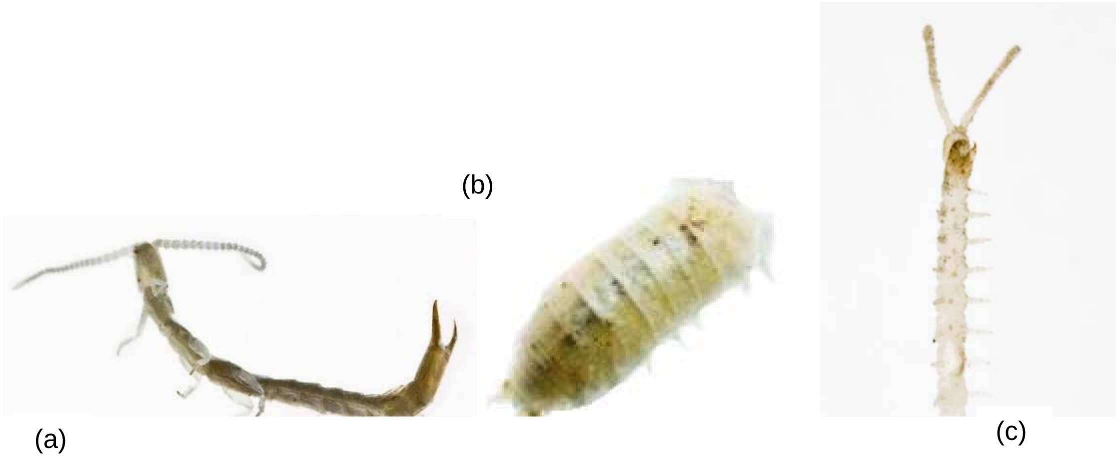

Figure 2 Troglofauna species located at the Operational Area; (a) Dipluran, (b) Isopod, and (c) Centipede.

2.0 BACKGROUND

2.1 DEFINITION OF TROGLOFAUNA

Subterranean fauna that colonise regolith environments comprise two main groups, troglofauna (terrestrial subterranean fauna) and stygofauna (aquatic subterranean fauna). Troglofauna inhabit air chambers in underground caves or other smaller voids in sub-surface regolith above the watertable, and stygofauna dwell in groundwater held in underground cavities.

Troglofauna are further divided into three ecological categories (Howarth 1983):

(a) troglobites - obligate cave species that are unable to survive outside of the subterranean environment,

(b) troglofiles - facultative species that live and reproduce in caves but that are also found in similar dark, humid microhabitat on surface; and

(c) trogloxenes - species that regularly inhabit caves for refuge but normally return to surface environment to feed.

A fourth group, accidentals, wander into cave systems but cannot survive there.

A species is considered truly troglobitic if it displays morphological characters that appear to restrict it to subterranean habitats. These include a significant reduction or a complete loss of eyes, pigmentation and wings, and a circadian rhythm (24-hour biological cycle), as well as development of elongated appendages, slender body form and, in some species, a lower metabolism. Troglobitic faunal assemblages are dominated by arthropods such as schizomids, pseudoscorpions, spiders, harvestmen, centipedes, millipedes, diplurans and mites (Howarth 1983). The three troglobitic species, a dipluran, a centipede and several isopods (Figure 2) that have been recovered from drill holes within the Tropicana Operational Area are thus considered true troglobites.

Although some troglofauna may disperse under the cover of darkness, at night or under transient deposits of leaf litter and rubble, true troglobites are incapable of dispersing on the surface and are subject to dispersal barriers due to the geological structure of their habitat and availability of life sustaining environmental conditions. For these troglobites dispersal limitations can result in extremely small, fragmented species ranges, where organisms occupying different systems of voids appear to be sufficiently physically isolated for speciation to have occurred. Study of these populations can provide an insight into evolutionary processes (EPA 2003). In contrast, genetic analyses of some troglobitic mites from Pilbara provide evidence that these microscopic organisms can have a wide-ranging distribution, suggesting that they use other means of dispersal, possibly on vertebrates inhabiting the surface (Biota 2006).

Many troglobitic species are relicts from previous tropical climate eras and often include relict forms of surface-dwelling organisms that have since become extinct. Thus, troglofauna are important for providing information about past environmental and zoogeographical conditions.

2.2 HABITAT REQUIREMENTS

True troglobites are permanently confined to, and dependent on their immediate subterranean environment from which they must derive air, moisture, and food.

The food resources for the subterranean ecosystems are largely allochthonous (not formed in the region where found) and carried into caves and cavities by plant roots, water and animals (Howarth 1983). Although troglofauna have been recorded from a range of geological types, they are most abundant in highly porous rock habitats, which facilitate movement of animals among void systems (Biota, 2006).

Thus environments suitable to sustained troglofauna habitation require constant:

- Tectonic stability – where habitation can be maintained without structural disturbance;
- Adequate sized voids - must contain voids, pits and cavities that are sufficiently large for the organism to inhabit without restricting movement;
- Air access – the subterranean environment must be well ventilated to the surface via interconnecting voids and fractures;
- Humidity and moisture – environment must remain above the water table or drainage sump, but not be wet and not be allowed to dry out; and
- Biological activity – the environment must be an active sub-surface biozone where root growth, microorganisms and their decay products provide sufficient food to supplement allochthonous suppliers that infiltrate from the surface.

Due to their specific habitat requirements and restricted range, sustained troglofauna habitation in a particular regolith environment requires the continuous maintenance of suitable conditions since colonisation, in some cases over millions of years. Thus geologically old and stable terrain provide the best possibility of supporting the continuous presence of troglofauna. With regolith and landform development over a long period of time under evolving climates, habitat environments are also likely to evolve and isolated populations with varied evolutionary trajectories may coexist, some isolated in remnant habitat formed in earlier eras and other populations evolved by successively colonising new environments.

Troglofauna are relatively understudied compared to terrestrial fauna and their distribution is currently poorly documented. Strategic trapping programs undertaken as part of environmental impact reviews for other developments have been successful in locating troglofauna in a range of geologies within Western Australia. Such programs indicate that their distribution is potentially widespread.

Examples of the geologies where troglofauna have been located and the representative troglobitic assemblages are summarised below.

(1) Pisolite Ores within Mesa Formations at Robe River, in the Robe Valley.

The pisolite palaeo-valley-fill deposits of lateritic gravel formed in the Robe Valley approximately 20-30 million years ago, and are now exposed in the present landscape through up-lift and erosion, as a series of flat topped mesas (Robe, 2003). The bulk of the pisolite is cemented ferruginous pisolithic gravel, with minor clay and silica.

Several troglobitic groups have been recorded in the Mesa A formation, including two arachnid orders (Schizomida and Pseudoscorpionida), two insect orders, (Thysanura and Coleoptera), two orders of myriapods (Scolopendrida and Polydesmida) and the order Diplura. Thus, the Mesa A formation represents a significant area of troglobitic diversity unmatched to date in the mainland Pilbara region of Western Australia. Ongoing research and monitoring is still underway.

(2) Cape Range in the Exmouth sub-basin of the Carnarvon Basin.

Cape Range forms part of the Exmouth sub-basin of the Carnarvon Basin and the Province is underlain by about 10 km of sedimentary rocks. The actual Range is predominantly carbonate sediments of the

Palaeocene – Miocene period and are about 500 m thick. Shallow water marine, alluvial, littoral and aeolian sediments of recent age form coastal plains on each side of the range. The Cape Range Anticline has been rising intermittently since the late Cretaceous. The upper calcareous sedimentary rocks about 100 m thick have karstified and extensively eroded (Allen 1993). Both troglofauna and stygofauna have been recorded in the karst formations. Both of these subterranean faunal groups are important because of their species richness, evolutionary history and adaptations, and the evidence they can provide for continental drift.

To date, 67 subterranean species have been recorded at Cape Range, of which 41 are terrestrial and 26 are aquatic. As such, the cave fauna is the richest and most diverse troglobite community yet discovered in Australia, and probably in the world (Hamilton-Smith and Eberhard, 2000). There are distinct eastern and western assemblages due to isolation. Such relics may occur elsewhere, for example in the boulder beds underneath major rivers of the north west of Western Australia.

(3) Nullarbor Plain Caves of the Eucla Basin.

The Nullarbor bioregion occurs to the south east of the Operational Area and extends over the majority of the Eucla Basin of Cretaceous and Tertiary sediments on an irregular basement of Precambrian granite and metamorphic rocks. The Nullarbor Plain forms a central tertiary limestone plain of shallow calcareous soils overlying a massive (the world's largest) limestone karst system. Surface features include the shallow surface depressions, collapse dolines, blowholes, drip pits, rillenkarren, rundkarren, pavements, solution pans and rock holes. The plain is known for endemic reptiles, birds, plants and vegetation associations.

The Nullarbor caves within the subterranean karst system provide refuge for many evolutionarily relictual invertebrates and two vertebrates. The caves also contain sub-fossil remains that have been very useful in reconstructing lists of the original vertebrate fauna assemblages and relictual invertebrate assemblages (Anonymous, 2000). The endemic invertebrates known from the Nullarbor caves include numerous troglobites and troglophiles many of which have previously not been described.

It is unknown whether these species are capable of inhabiting troglobitic habitats outside of the Nullarbor caves system. However, cave dwelling organisms are often much larger and less modified than their cousins inhabiting voids or cavities from non-karst environments (e.g. there is often no need for the filiform body shape seen in subterranean stygofauna and troglofauna because the voids are much larger or cavernous). The taxa most likely to be able to inhabit non-karst environments in the region would include the araneomorph (new-world) spiders, pseudoscorpions and the isopods (slaters). The beetle species might also have limited success in colonising non-karst environments.

(4) Midwest Banded Ironstone formations at Blue Hills near Morawa in the Midwest region.

Recent troglofauna sampling at Blue Hills near Morawa in the Midwest region of Western Australia has revealed a single troglobitic pseudoscorpion specimen (Biota 2007) and an araneomorph spider species (ecologia Environment 2007b). Expanded sampling is being conducted at this location at present. Drill cores into Banded Ironstone Formations (BIF) from Weld Range, near Cue, under investigation for haematite and magnetite resources appear to contain the necessary deep pitting and cavities near surface to facilitate troglofauna presence. BIFs are one of the oldest known rock formations on earth and have, therefore, undergone a long weathering history.

3.0 REVIEW LOCAL ENVIRONMENT

3.1 CLIMATE

The climate of the region around the Operational Area (the Great Victoria Desert) is semi-arid to arid, with summer and winter rainfall ranging from 150 to 190 mm per year (Beard, 1974; Beard, 1975; Barton and Cowan, 2001). The climate trends to arid towards the north-east into the interior Great Victoria Desert and to wetter, temperate conditions towards the southern coast.

The Operational Area falls between the 178 and 203 mm rainfall isohyet range on the Bureau of Meteorology rainfall map of this region, receiving approximately 200 mm annually (Beard, 1974). Temperatures may range between -3°C and 48°C, with the highest temperatures in January and February and the lowest in July and August.

There are no long-term climate records for the Operational Area or its vicinity and the closest current Bureau of Meteorology weather stations with current records are located at Laverton, approximately 220 km north-west, and Balgair, approximately 250 km south-east. Climatic conditions for the Tropicana Project area can be extrapolated from climatic data from these two locations are summarised in Table 1.

The mean annual rainfall for Balgair is 277.8 mm, and for Laverton 233.4 mm. The majority of rainfall for these stations occurs during the late summer months and early winter. Summer rainfall is generally associated with cyclonic rainfall extending into the interior, and this may result in isolated heavy rainfall between January and April (Laverton received 233.6 mm in February 1995). Conversely, the region may not receive any significant rainfall during any months of the year. The lowest annual rainfall received in the area was 65.6 mm at Laverton (1928) and 140.7 mm at Balgair (1991).

Temperature extremes are also experienced in the region, with the highest maxima at Laverton and Balgair being 46.1°C (1957) and 47.6°C (1991) respectively. Temperatures may fall below 0°C during the winter months, with the lowest minimum reaching -2.4°C at Laverton (1969) and -5.0°C at Balgair (2006).

Table 1 Summary of climatic data for Laverton and Balgair weather stations (Appendix 16-9: ecologia Environment, 2009b).

Statistic	J	F	M	A	M	J	J	A	S	O	N	D
Laverton												
Mean max (°C)	35.8	34.8	31.9	27.2	22.1	18.5	17.8	20.0	24.5	28.0	32.1	34.9
Mean min (°C)	20.5	20.0	18.0	13.9	9.5	6.6	5.2	6.4	9.5	12.8	16.6	19.3
Mean rainfall (mm)	24.3	30.1	30.7	22.6	24.1	24.4	16.4	13.7	8.2	8.5	13.6	17.1
Balgair												
Mean max (°C)	32.8	31.9	29.5	26.3	22.3	19.1	18.7	20.6	24.2	26.7	29.2	30.9
Mean min (°C)	16.3	16.7	14.8	11.9	9.0	6.1	5.2	5.9	8.3	10.5	12.8	14.7
Mean rainfall (mm)	21.1	27.7	30.8	21.3	24.0	24.8	17.2	19.1	17.3	15.6	23.6	36.4

Laverton: 28.63 °S 122.41°E. Records from 1899 – 2007.
Balgair: 31.09 °S 125.66°E. Records from 1982 – 2007.
(Source: Bureau of Meteorology, 2007).

3.2 REGOLITH TYPES AND DISTRIBUTION

The Tropicana Joint Venture tenements lie over the eastern edge of the Yilgarn Craton and its transition zone into the Albany-Fraser Province. The Tropicana and Havana gold deposits are hosted within rocks that are strongly altered (metamorphosed) within an ancient collision zone between the Yilgarn Craton and Albany-Fraser Orogen. Further information on the geology of the area is provided by van de Graff and Bunting (1977).

The Yilgarn Craton is an ancient landmass, large areas of which are considered to have been tectonically stable and continually exposed to weathering since the Archaean Epoch (4.0-3.2 Ga). During this long exposure, the original land surface of probable considerable relief, has undergone continuous chemical weathering and physical reworking, accelerated during periods of glacial activity, tectonic up-lift and rejuvenated drainage, to produce the present-day planted landscape of low relief and a quiescent weathering environment.

As highlighted in regional drilling, the present land surface conceals a complex and highly variable subsurface regolith profile. Over most of the Operational Area, the basement rock is weathered to a general depth of 65 m and is buried by a complex subsurface regolith remnant of earlier phases of localised erosion and sediment deposition to a depth of several meters. The palaeo-transported cover sequences principally comprise weathering products that have resisted chemical alteration and physical transport similar to those accumulated on the land surface today. Figure 3 provide an indication on the known regolith geology previously mapped in the Tropicana Region

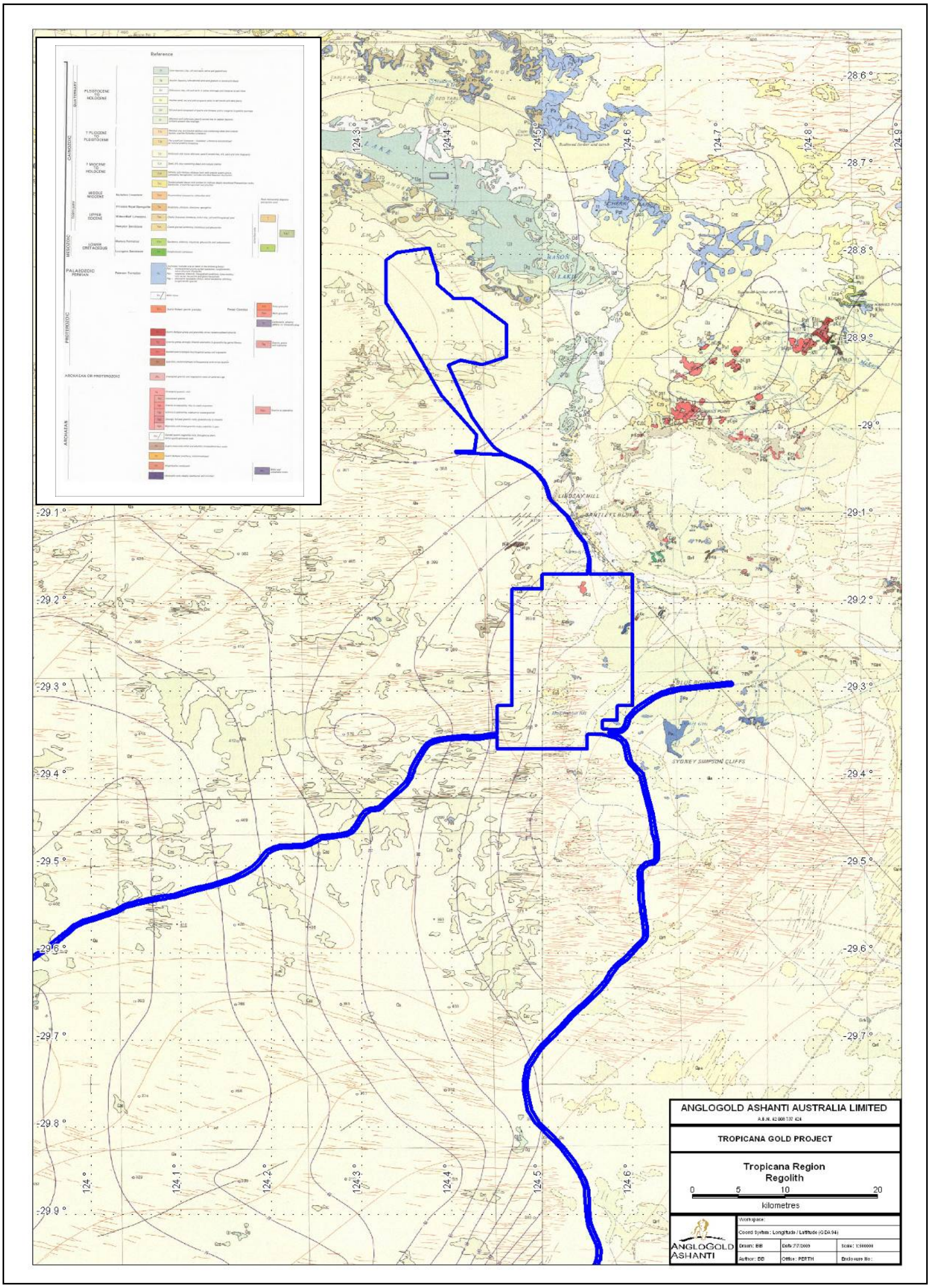

Figure 3 Tropicana Region mapped Regolith Geology
(refer to Appendix 1 for a more detail legend)

Small, localized outcrops of the weathered crystalline and sedimentary basement rocks are exposed at the surface (Plate 1). These exposures include rock types resistant to weathering, such as banded quartz magnetite rock and banded chert; saprolitic exposures of ademellite to gabbro; metamorphosed layered mafic intrusive rocks, such as garnetiferous gabbro, hornblendite; and granitic gneiss rocks; and *in situ* white, indurated kaolinised saprolite of indeterminable bedrock origin.

Plate 1. Outcropping weathered crystalline and sedimentary basement rock exposed on a ridge with locally derived coarse angular scree in sand colluvium. The basement rocks outcrops are generally only sparsely vegetated with stunted *Casuarina* sp., *Eremophila* sp., Sandalwood trees and *Acacia* sp. (Photograph and field information supplied by Ben McCormack).

The regolith cover sequences have been separated into four main groups, namely colluvial and alluvial soils, duricrust, aeolian deposits, and lake deposits. The materials grade into one another and exact boundaries are difficult to demarcate in mapping. A generalized map of the surface regolith is shown in Figure 3. A type description and landform expression of the cover sequences is provided below.

(1) Colluvial and Alluvial Soils

Unconsolidated colluvial and alluvial soils are the most extensive cover sequence. They predominantly comprise ferruginous sands, mixed with aeolian quartz sand, with locally abundant accumulations of clay, silt, and gravel (Plate 2a).

The soils are deposited on broad plains of present-day drainage valleys where they are most deeply accumulated in depressions and at the base of breakaways. A common feature of the soils is a distinct red-brown ferruginous clay layer exposed as a clay pan soil or up to 500 mm depth into the sub-surface profile (Plate 2b). This zone is probably formed by the redistribution and accumulation of colloidal components (predominantly clay and iron oxides) with groundwater run-off, shallow infiltration, and subsurface drainage in the profile during rain events. Areas of clay-pan soil have a noticeable absence of spinifex grass (Plate 3).

During heavy rain events, the soils are locally re-deposited along drainage centers and adjacent to duricrust outcrops to define major zones of run-off usually with separation of fines and coarser gravel fragments into drifts. The gravel component of the drifts is usually fine-grained and highly polished ferruginous pebbles referred to buckshot gravel. Wind and water erosion has locally exposed course alluvial float of ferruginous pisolithic laterite gravel and rounded ferricrete and silcrete fragments (Plate 4), and indurated sub-surface desert pavements of silcrete and calcrete. The soils become saline and capped with a fragile crust marginal to trunk valleys and ephemeral salt lakes.

Plate 2. Mixed clay-rich aeolian quartz-sand and colluvial soil cover (a) characteristically vegetated with Spinifex and Mallee species with occasional Mulga, other *Acacia* sp. and smaller shrubs. (b) A red-brown ferruginous clay horizon has formed at 500 mm into the sub-surface profile (Photographs and field information supplied by Ben McCormack).

Plate 3. Ferruginous clay-pan soil formation in colluvial soil cover (a) characterised by the absence of Spinifex compared to the colluvial sand cover shown in Plate 2. (b) A scrapping showing the abundant accumulation of red-brown ferruginous clay in the sub-surface soil profile (Photographs and field information supplied by Ben McCormack).

Plate 4. Dark red-brown ferruginous clay-rich soil profile washed to expose rounded ferricrete and quartz alluvial fragments (illuvial float) accumulated at the surface. Lenses of similar material are buried within a few metres of surface indicating multiple depositional and erosional events (Photographs and field information supplied by Ben McCormack).

(2) Duricrust

Three forms of duricrust, namely laterite, silcrete (including ferricrete), and calcrete (including pedogenic calcrete) are present in the Operational Area. The duricrust units are most prominently exposed as sub-horizontal indurated flat-topped layers on rises where they resist weathering and erosion to form steep-sided mesas, and breakaways. At the exposed edge, the units commonly develop overhangs resulting in shallow caves and voids, and have rubble scree slopes at their base.

Lateritic material is characterised by aggregated reddish yellow-brown pisolithic gravels that have a distinctive concentric ferruginous surface coating. The laterite is generally spatially associated with areas underlain by ferruginous basement rocks and is less widespread in the Operational Area compared to the other duricrust units. The material occurs as coarse (usually conglomeritic) aggregated gravel sediment, in which some zones are strongly silicified and others are more friable, either within, or just above indurated, sub-horizontal Permo-Cretaceous sediments. These units form the upper leading edge of many breakaway escarpments (Plate 5), and weathering creates significant porosity and voids. Overhangs are common, and shallow caves develop underneath where less consolidated sediments are eroded out. Eventually this process leads to failure of the escarpment edge and lateritic rubble and boulders are redistributed on colluvial slopes to the breakaways. Finer lateritic gravel is more distally transported and interspersed in the soil colluvium and alluvium away from the escarpments.

Plate 5. Laterite duricrust exposed at a breakaway (Photograph and field information supplied by Ben McCormack).

Silcrete is the most abundant, well-preserved, and regionally widespread duricrust material in the Operational Area. Landform expressions range from prominent silcrete-capped mesas, with breakaway of several meters (Plate 6), to low rubble mounds, and scree slopes (Plate 7). These occurrences mark multigenerational palaeo-drainage systems (Plate 8) that were narrower and centered on smaller catchments than exhibited by the board drainage systems of the present landscape. The silcrete comprises a range of silicified palaeo-colluvial and alluvial sediments.

The silcrete characteristically has a massive siliceous cap underlain by less strongly silicified cavernous regolith. Scattered rounded silcrete fragments are also common as float in colluvial and alluvial soils and as gravel accumulations in present drainages valleys.

Plate 6. Massive silcrete duricrust exposed at a breakaway (Photograph and field information supplied by Ben McCormack).

Plate 7. Massive ferruginous silcrete duricrust exposed (a) on a ridge, and (b) in detail showing a less silicified subsurface cavernous zone (Photograph and field information supplied by Ben McCormack).

Plate 8. Silcrete-capped mesas mark palaeo-drainage channels and are eroded to expose a friable white kaolinitic horizon of previously reduced palaeochannel–fill clay beneath the duricrust (Photograph and field information supplied by Ben McCormack).

Calcrete duricrust is largely confined to low-lying areas, associated with flanks of palaeo-channels, even where the palaeo-channel is almost unidentifiable in modern environment, and marginal to modern trunk valleys and ephemeral salt lakes. An almost continuous layer (up to 1.5 m thick) of calcrete occurs in clay-dominated soil within 200 mm of surface (Plates 9 and 10). Surface exposures of the calcrete horizon and widespread float of calcrete pieces are common. Pedogenic carbonate nodules and layers are up-lifted and exposed around the base of large trees.

Plate 9. Exposure of partially degraded calcrete duricrust surface where (a) extensive stands of large *Casuarina* trees with Blue Bush, and very little other grass or vegetation, are indicative of calcrete duricrust in the subsurface. (b) Detail of the surface showing *in situ* calcrete fragments (Photographs and field information supplied by Ben McCormack).

Plate 10. Buried calcrete duricrust within sand-dominated soil colluvial cover (a) exposed at the edge of an aeolian sand dune, and (b) exposed at the surface by rehabilitation (ripping) of drill pads in the Havana area (Photographs and field information supplied by Ben McCormack).

(3) Aeolian Deposits

Aeolian dunes of unconsolidated ferruginous red-brown quartz sand are common in the area (Plate 10a). The dunes are gently undulating and formed into sub-parallel, east-west trending seif dunes, longitudinal dunes and sand ridges some up to 5-20 m high and 10 km long, with well-defined interdunal corridors. The sands are ferruginous, predominantly well-sorted, well-rounded quartz grains. The quartz is highly polished probably due to multiple transport and deposition events that could suggest a distal origin for the sediment. About ten percent of the dune material comprises other sand-sized particles, silt, and clay fractions of mixed regolith material probably locally derived from the exposed surrounding landscape. The dunes are strongly gypsiferous and saline where they border ephemeral lakes. The sand cover is predominantly deposited in topographically lower areas marginal to silcreted zones. The dunes butt onto the eastern margin of silcrete exposures. The dunes are presently inactive and are well vegetated, some with mature Eucalypt trees, presumably because the dunes act as water catchments. Interdunal areas contain patches of clayey colluvium and small soaks.

(4) Lake Deposits

Lake deposits (Plate 11) comprise surficial accumulations of clay and fine sand with abundant soluble salts, mainly gypsum and halite within ephemeral lakes and their catchments. The fine sediments and salts are deposited in trunk valleys and lakes that fill up temporarily with runoff after heavy rains. Profile is often saturated with hypersaline water from 100 mm below the surface with standing water after heavy rainfall. The salts are preferentially accumulated within the surface sediment during dry periods. Water evaporation results in a characteristic friable surface saline crust and desiccation cracks. During extended dry periods wind erosion redeposits the fine saline sediment to the margins of the lakes to form crescentic or lunette lacustrine dunes predominantly on the eastern sides of salt lakes. Lake deposits are mainly confined to the lowest topographic areas corresponding to the major relict drainage system. These sediments are presently activily forming. The surfaces of salt lakes are commonly devoid of vegetation.

Plate 11. Margin of a salt lake showing a saline (gypsum and halite) crusted dune surface (Photographs and field information supplied by Ben McCormack).

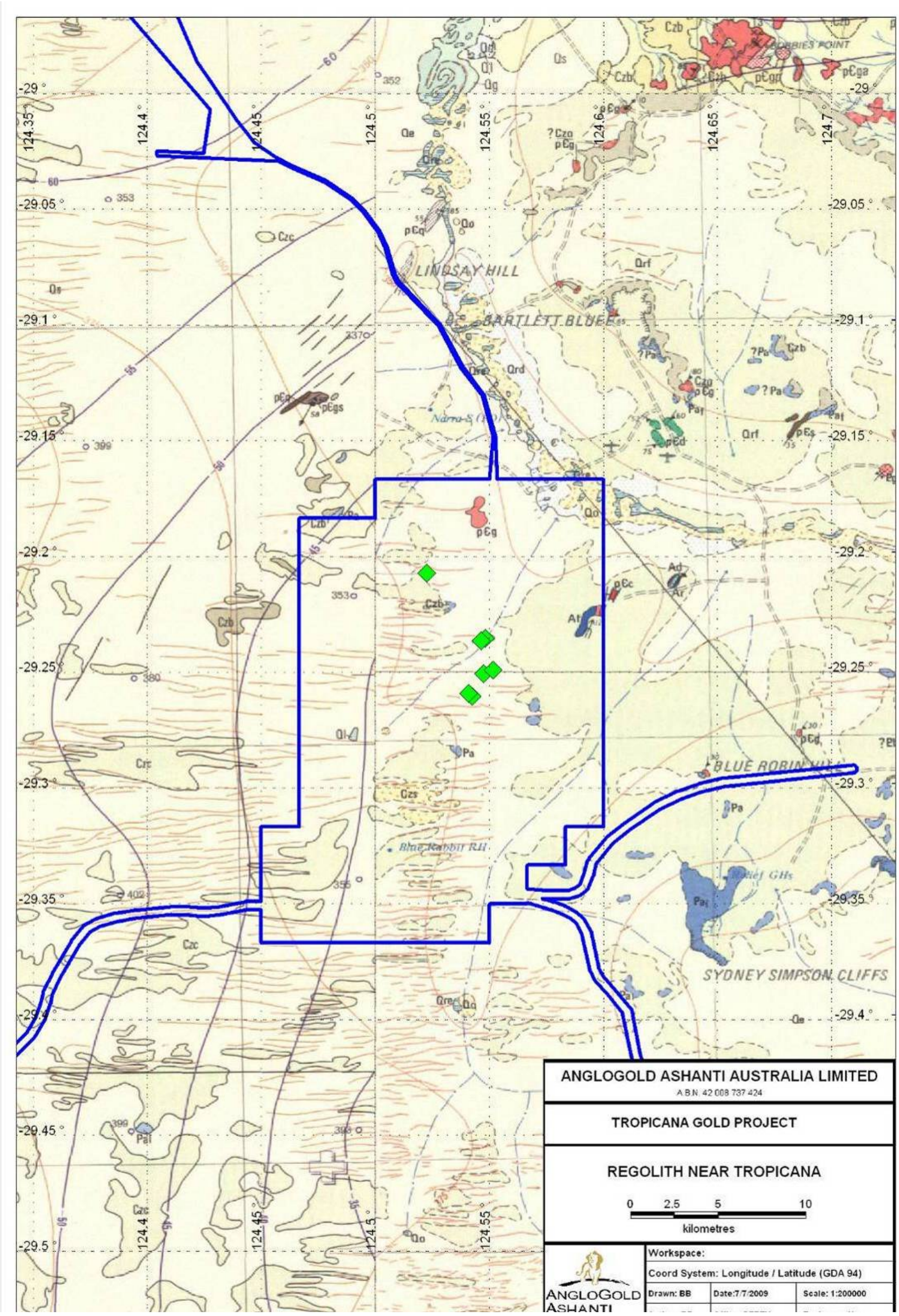

Figure 4. Distribution of prominent regolith units at Tropicana.
Green diamonds are the locations where Troglofauna have been obtained.
(refer to Appendix 1 for the legend)

3.3 BIOGEOGRAPHY

A tree steppe of *Eucalyptus gongylocarpa* and mallee (*Eucalyptus kingsmillii*, *E. youngiana*) over hummock grassland dominated by *Triodia basedowii* occur on aeolian sands, with *Acacia aneura* (mulga) and *Eremophila* and *Santalum* spp. occurring on the colluvial and residual soils. Scattered marble gum (*E. gongylocarpa*) and native pine (*Callitris*) occur on the deeper sands of the sand plains. Halophytes such as salt bush (*Atriplex*), Bluebush (*Kochia*), and samphire (*Arthrocnemum*) occur on margins of salt lakes and in saline drainage areas.

The above vegetative assemblages reflect the present-day arid climatic conditions and are well adapted to cope with extremes in temperature and low moisture conditions. With the exception of salt lake surfaces and the tops of large dunes, their growth has stabilised the surface alluvial and colluvial cover sequences against further erosion.

3.4 LANDSCAPE EVOLUTION

The regolith of the Operational Area is the product of a long weathering history. Although the present-day soil cover is the result of sediment reworking under recent arid-phase quiescent weathering conditions, the well-developed sub-surface regolith and the distinctive landform features in the landscape are the products of much earlier weathering events, formed under wetter, more humid and higher energy conditions. This complex regolith has been preserved because it has formed over old (Precambrian) basement rocks of the Albany-Frazer Belt at the margin of a landmass that has been stable over millions of years, and because there has been a general trend to aridity and the regolith has dried out causing retardation in weathering processes.

Most regolith materials are vulnerable to reworking as the landscape evolves and they become exposed at the near surface. However, an inherent process of rock weathering is the release and redistribution of silica that commonly results in the overprinting, and local silicification and induration of surface regolith materials, particularly in topographic low environments. The silicified horizon is subsequently preserved as duricrust in the regolith and preserves evidence of the materials and processes at the time of formation. The prominence of a range of multigenerational duricrust materials at the Operational Area is indicative of extensive periods of alternating seasonally wet-dry palaeo-climatic weathering conditions.

Wet-dry climatic weathering conditions are those with an extended hot-dry period during which the land surface becomes dehydrated under low rainfall, alternating with seasonal short periods of high rainfall, during which weathering processes and groundwater and sediment flux conditions in the regolith can be extreme. Under these weathering conditions, regolith within, and at the margins of drainage valleys become silicified into duricrust with repeated seasonal wetting and drying out in the near surface. The overprinted and silicified regolith is usually accumulated depositional materials (alluvium and colluvium), and the upper residual regolith where the cover is thin and sufficiently permeable to be infiltrated by groundwater. Due to surface induration, torrential rainfall experienced under seasonal wet conditions does not fully access the profile but is mostly drained by run-off resulting in aggressive surface erosion and accumulation of sheet wash regolith detritus in drainage beds and valleys.

As the water evaporates during seasonal drying of the land surface, silica causes irreversible cementation and hardening to form laterite, ferricrete, and silcrete duricrusts. The sub-surface of these laterite-ferricrete zones is usually partially water-saturated and mottled due to local groundwater accumulation.

Once formed, the duricrust valley-crete material is resistant to further weathering and erosion, and as the more vulnerable surrounding landscape is weathered and eroded down over time, the silicified rock becomes progressively elevated in the landscape and may ultimately become a topographic high feature. This mode of landscape evolution results in terrain that is referred to have undergone "relief inversion", where topographic "lows" become "highs" interspersed by erosional plains (Figure 5).

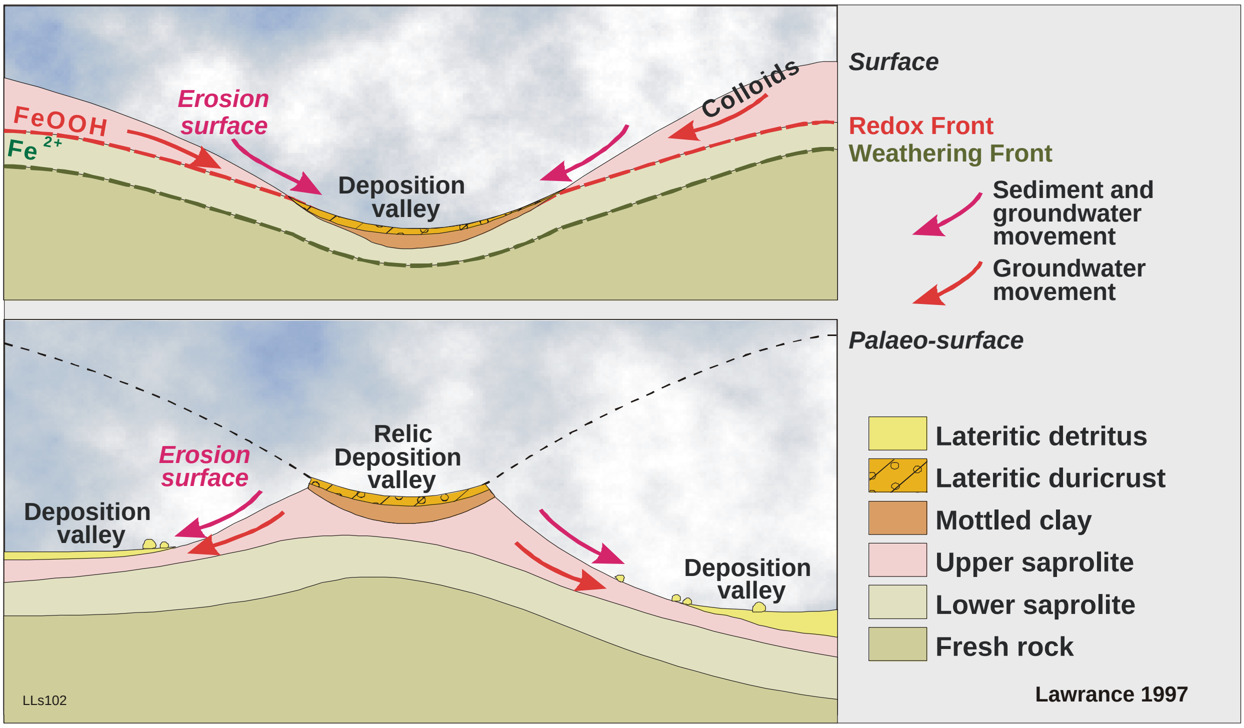

Figure 5 Schematic representation of duricrust formation and relief inversion under wet-dry climates.

Three forms of duricrust are present in the Operational Area and are indicative of a progressive evolution in climate from wet-humid conditions to the present semi-arid environment. Each duricrust exposure thus represents a relict palaeo-drainage surface with potentially millions of years separating there period of formation. The composition of duricrust materials reflects regional weathering conditions at the time of formation. Abundant coarse rounded alluvial gravels and sands are relict of high-energy regional palaeo-drainage systems formed under a wet climate and reflect a period of abundant sediment and groundwater movement in the landscape. These exposures include prominent ferricrete and silcrete outcrop, and less commonly laterite, as remnant mesas, butts, rubble mounds, and breakaways on the margin of ridges. Some of the duricrust sequences are underlain by friable white clay-rich and mottled-clay profiles, remnant of poorly drained and reduced sub-surface regolith within the palaeo-drainage channel.

The presence of lateritic duricrust (characterised by pisoliths) indicates a period of low energy drainage under wet-humid conditions. And while sediment within the laterite duricrust is likely to be younger than that deposited in major channels active under wetter conditions, the laterite are possibly the oldest duricrust formed in the area. Unlike the alluvial channel sequences that are silicified post deposition under dry climates, laterite is cemented as it is laid down. Most lateritic surfaces are now partially degraded and their sediment redistributed in sheet wash scree and as colluvial gravels.

Duricrust at the Operational Area comprise multigenerational palaeo-valley-fill that has been preserved through silicification, relief inversion, up-lift and erosion probably during post-Miocene seasonally wet-dry climatic weathering conditions. Due to ongoing weathering and erosion, the oldest regolith sequences are now preserved and exposed as elevated landforms at higher stratigraphic positions in the landscape.

The most recently formed duricrust sequences are less dramatically exposed at low stratigraphic positions in the landscape where they are partially buried by more recent, relatively unconsolidated, colluvial, alluvial, and aeolian sedimentary sequences. The exposure of these duricrust materials at small breakaways, as pavements at the margins of present day drainage creeks and floodplains, within inter-dunal corridors, and at the margins of salt lakes; and the exposure of pedogenic calcrete, locally uplifted as calcrete nodules at the base of large trees and as float within the colluvial cover, indicates that they are wide-spread under the present-day shallow cover sequences. Thus, they are likely to be well preserved as regionally extensive sub-surface pavements, particularly in broad drainage catchments.

These duricrust include intermixed silicified laminar alluvial gravel and palaeo-sols, and calcrete. They comprise alluvial and colluvial regolith materials, including fragments of the older duricrust surfaces reworked under low energy erosional and depositional conditions. Because the duricrust horizons formed under periods of more quiescent weathering conditions, and sediment and groundwater movement, they tend to comprise soluble minerals, particularly abundant carbonates and indurated soil colluvium or palaeo-sols. The upper sequences are the most calcareous, and indicate a trend towards extended dry climatic conditions. The calcrete horizons are formed as soluble carbonate is retained and accumulated in the near-surface soil with low rainfall and an excess of evaporation, similar to the present-day climate at the Operational Area. As such, calcrete is a young-end member duricrust and is likely to be the most recently formed.

Under extended dry (arid) environments, weathering is impeded due to low rainfall and restricted groundwater movement. Soluble weathering products are retained in the groundwater, increasing its salinity. In addition, sodium chloride and other salts, derived largely from rainfall, accumulate in the upper regolith. With run-off these soluble components eventually accumulate in topographic low areas in the landscape (usually associated with palaeo-drainage basins and channels) to form playa deposits by the local accumulation and evaporative deposition of salts.

Dehydration and soluble salt accumulation leads to alkaline conditions in the upper profile. Under these conditions, hydrous goethite in the near-surface profile dehydrates to hematite. Soils and ferricretes become characteristically red-brown. Both goethite and hematite are converted to maghemite under elevated temperatures at the land surface. Indurated components and hematitic weathering products are resistant to weathering and their preservation in the regolith is a permanent record of dehydration during extended dry periods.

A general lowering of the water table results in the progressive exposure and dehydration of the upper horizons. The lower profile can retain moisture in pore fluid for a long period of time, even after extended aridity. With an excess of evaporation over precipitation, the net movement of water is up through the profile due to capillarity. Dissolved substances are drawn up in groundwater into the near-surface from the lower profile. The interaction of soluble cations (e.g. Ca^{2+} and Mg^{2+}) and carbon dioxide from the atmosphere results in the formation of pedogenic carbonate. The upper profile becomes overprinted and cemented by soluble salts.

In topographic low parts of the landscape, groundwater accumulation and low flux may result in reduced zones in the sub-surface regolith. In these poorly drained profiles, water within the zone of saturation commonly remains static for months at a time. Under these conditions, organo-reduction processes may result in the local destruction of regolith materials by the reduction of iron oxides and the dissolution ferruginous minerals (in particular lateritic materials).

The present-day soil cover is largely unconsolidated and permeable, but with the exception of some barren dune tops and salt lake surfaces, the cover sequences are now stabilised by vegetation. Under the present-day quiescent weathering environment most weathering involves erosion and redistribution by wind and by occasional wash following heavy rains and hence, largely involves minor reworking of surface soils and sediment in shallow drainage channels and floodplains. Run-off, subsurface water penetration and drainage have redistributed colloidal minerals and resulted in a prominent clay layer at generally less than a metre into the soil cover. Clay has a high water absorbency and retention capacity, and thus, the clay horizon largely protects the underlying profile from water inundation and dehydration. However, during periodic extreme weather events, mainly storms associated with cyclonic activity, the soil cover is vulnerable to water infiltration and flooding, particularly in low-lying areas, and to sediment reworking by wind and water erosion, to dehydration during extended dry periods.

3.5 POTENTIAL TROGLOFAUNA HABITAT WITHIN THE WIDER OPERATIONAL AREA

The dominant surface regolith cover sequences within the Operational Area are unconsolidated to semi-consolidated colluvial and alluvial soils, dune and lake deposits (Section 3.2). Not only are these materials unlikely to maintain stable subterranean cavities capable of supporting troglofauna habitation, they are prone to strong surface dehydration with elevated surface temperatures (up to 48°C), and to water inundation during high rainfall events (up to 25 mm) and are therefore, unsuitable for troglofauna persistence.

In contrast, duricrust within the landscape is structurally stable and characteristically porous. The duricrust occurs as remnant mesas, butts, and rubble mounds that define palaeo-drainage systems. The duricrust once formed is resistant to further weathering and erosion, and is typically elevated in the landscape and exposed in breakaways. Strongly indurated silcrete slabs or pavements, from a few centimeters, up to three meters thick, cap the duricrust surface. The silcrete cap is underlain by a porous less indurated regolith, in which interconnected voids and cavities, such as interstitial voids, solution pipes, root casts, and are inherent at the time of duricrust formation. Deeper fractures, and other zones of palaeo-water access, such as root canals, and previously unconsolidated gravel materials, are also preferentially silicified during silcrete formation and provide subterranean support to the duricrust. Between these supports, the regolith is less consolidated. The material is commonly clay-rich and friable, and is thus prone to disaggregation and reworking by present-day biological activity. These processes commonly result in a sub-surface cavernous environment particularly adjacent to zones of lithostatic unloading, such as exposure at breakaways. Therefore, the duricrust provides highly favourable cavities for subterranean troglofauna habitation.

Other factors that make duricrust suitable for troglofauna habitat in the present arid landscape include:

- Perched well above the watertable (30 to 40 m below ground level);
- Elevated in the landscape on topographic ridges mesa butts and mounds and therefore are less likely to experience water inundation and flooding during episodes of high rainfall, such as associated with cyclonic activity;
- Raised and well-ventilated;
- Protected from dehydration and hence, maintain a moist, constantly humid sub-surface environment in an otherwise hot-dry climate;
- Protected from extreme fluctuations in external temperature (-3°C and 48°C) and therefore provide a uniform ambient environment; and
- Fractured and porous, providing access to plant roots, water, oxygen, and troglofauna. The fractures and crevices support vegetative root growth and the accumulation of organic debris, thus providing an allochthonous food resource for the subterranean ecosystems.

Silcrete is the most abundant, well-preserved, and regionally widespread duricrust material in the Tropicana area (is there a reference source for this statement? How large an area around the TGP footprint does this statement refer?). The overall distribution of these silcrete materials mark multigenerational palaeo-drainage systems that were narrower and centered on smaller catchments than exhibited by the board drainage systems of the present landscape. In addition, the progressive development and evolution of these duricrust with the evolving landscape in response to climate and drainage evolution since the post Miocene period, allows the potential for continuous troglofauna habitation in the Operational Area from an early wet-humid environment to present arid conditions.

4.0 REVIEW REGIONAL REGOLITH AND BIOGEOGRAPHICAL ENVIRONMENTS

Regolith development and landscape evolution are the cumulative result of past and present-day regional weathering processes predominantly controlled by climate. Thus, regolith and landform features are generally regionally consistent over areas subject to the same environmental conditions. Because vegetation and landforms are the most readily identifiable reflection of landscape and climatic conditions these features are used to define areas into biogeographical zones based on the regional extent of similar climatic conditions, geology, regolith, landform, vegetation, and fauna.

The Interim Biogeographic Regionalisation for Australia places the Tropicana Gold Project area within the Great Victoria Desert bioregion (Thackway and Cresswell, 1995) (Figure 6). At a finer scale, the Tropicana and Havan deposits and the entire Operational Area are located in the Southern Great Victoria Desert Zone within the Gunbarrel Province of the Sandy Desert Region located in the southern Arid Interior between Lake Minigwal and the South Australian border (Tille, 2006). This zone has an area of 87,550 km^2 in which regolith and landform expressions are regionally uniform.

The area is described as an active sand-ridge desert of deep Quarternary Aeolian sands with a tree steppe of *Eucalyptus gongylocarpa*, *Mulga* and *E. youngiana* over hummock grassland dominated by *Triodia* *basedowii* (McKenzie et al., 2002) due to its most prominent landform feature but in detail the area is much more variable.

The underlying basement rock geology of the area varies from an older (Archaean) stable volcanic-sedimentary suite in the west to younger (Eocene-Miocene) basin sedimentary rocks to the east. The western end of the Great Victoria Desert is underlain by the Yilgarn Craton, containing some of the oldest rocks of the Western Australian Shield, and dominated by granite with belts of greenstone rocks. Adjoining the Yilgarn Craton is the Albany-Fraser Province and its transition zone, in which Archaean rocks have been metamorphosed and intruded by granite during the Proterozoic period (van de Graff and Bunting, 1977). To the east of the transition zone lie the Gunbarrel and Officer Basins. The sedimentary rocks of the Gunbarrel Basin include sandstone, glacigene, marine and continental siliclastic and arenite, and overlie conglomerate, sandstone and arenite rocks of the Officer Basin, a former marine trough, which comes to the surface in the north-east of the Great Victoria Desert. In the south west of the Great Victoria Desert are the meso-Proterozoic granite, dolerite, gabbro and ultrabasic intrusions, and Archaean gneiss of an outlier of the Biranup Complex (Albany-Fraser Orogen) (Tille, 2006).

The desert landscape is dominated by sand plains, ring dunes, and patches of longitudinal seif dunes, with a predominant east-west orientation separated by inter-dune corridors (or swales) (van de Graff and Bunting, 1977). These sand plains have moderate relief of 350-500 m AHD30, dropping to less than 300 m in the south. They contain outcrops of sandstones, laterite and silcrete duricrust, exposed as scarpland plateaus and breakaways, cuestas, mesas, buttes, and stony hillocks, usually surrounded by stone and gravel scree pavements (Barton and Cowan, 2001; Tille, 2006). Calcareous duricrust is generally less well exposed as mounds, and occasionally at the margin of saltpans. The floors of major shallow valleys with salt lakes and lake derived sand dunes, claypans, saltpans, calcrete platforms, kopi dunes and calcareous dunes are usually a relatively minor component of the landscape.

The western part of the Great Victoria Desert is underlain by a moderately well-preserved lateritic and ferruginous silcrete duricrust pavements, typically exposed as mesa and butte topography, with flat tops and breakaways. Pediments are formed in front of the breakaways and are often covered by a veneer of alluvial and colluvial sediments. Saltpans and lakes increase to the south.

The proportion of sand plains with extensive seif dunes running east-west, increases to the east south-east into the Great Victoria Desert proper which is an arid active sand-ridge desert with extensive dune fields of deep Quaternary aeolian sands overlying the Gunbarrel Basin. Occasional outcropping (breakaways) and quartzite hills and major valley floors with salt lakes and lake-derived dunes provide minor relief (Barton and Cowan, 2001).

As such, the broader regional environment shows similar regolith and landform features and distributions as described in the Operational Area (Section 3.2).

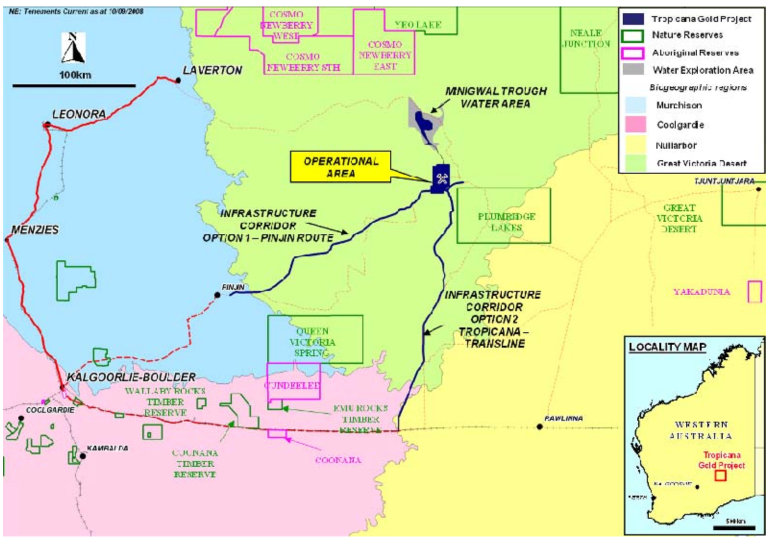

Figure 6 Location Map of the Tropicana Gold Project with respect to distinct bioregions as classified by Interim Biogeographic Regionalisation for Australia.

5.0 DISCUSSION AND CONCLUSIONS

The regolith of the Operational Area is the product of a long weathering history. Although the soil cover is presently being reworked under the prevailing arid quiescent weathering conditions, the well-developed sub-surface regolith and the distinctive landform features in the landscape were formed under a much wetter period of higher energy weathering conditions. This complex regolith has been preserved because it has formed over old (Precambrian) basement rocks of the Albany-Frazer Belt at the margin of a landmass that has been stable over millions of years and because there has been a general trend to aridity and the regolith has dried out causing retardation in weathering processes.

Cumulative weathering processes and landscape evolution have resulted in the preservation and exposure of the oldest regolith materials as elevated landforms in the landscape that are relict of high-energy regional palaeo-drainage systems formed under a wetter climate. These exposures include prominent ferricrete, silcrete, and less commonly laterite, outcrop as remnant mesas, butts, rubble mounds, and breakaways on the margin of ridges. These regolith sequences have been preserved through silicification, relief inversion, up-lift and erosion that probably occurred during post-Miocene seasonally wet-dry climatic weathering conditions.

Younger duricrust sequences are less dramatically exposed at low stratigraphic positions in the landscape where they are partially buried by more recent, relatively unconsolidated, colluvial, alluvial, and aeolian sedimentary sequences. These duricrust include intermixed silicified laminar alluvial gravels and palaeo-sols, and calcrete. They largely comprise alluvial and colluvial regolith materials reworked under low energy erosional and depositional conditions that have undergone multiphase seasonal drying and silicification, and preservation as pedogenic valley-crete in broad drainage catchments. The upper sequences tend to be the most calcareous, and indicate a trend towards extended dry climatic conditions. The exposure of these duricrust materials at small breakaways, as pavements at the margins of present day drainage creeks and floodplains, within inter-dunal corridors, and at the margins of salt lakes; and the exposure of pedogenic calcrete, locally uplifted as calcrete nodules at the base of large trees and as float within the colluvial cover, indicates that they are wide-spread under the present-day shallow cover sequences and probably form regionally extensive sub-surface pavements.

The exposed duricrust is capped by massive strongly indurated silcrete slabs and pavements from a few centimeters up to three meters thick, and is geologically stable and resistant to further weathering and erosion. These early-formed duricrust materials, are now preserved at elevated positions in the landscape, well above the watertable, are well drained, and protected from water and sediment inundation, and flooding during episodes of high rainfall. The indurated caprock also protects the sub-surface regolith from environmental disturbance, from dehydration during extended dry periods and provides insulation to the sub-surface profile from extreme fluctuations in external temperature and thus, maintains a uniform ambient sub-surface environment. Furthermore, the caprock duricrust is a barrier to capillarity rise and serves to keep the sub-surface environment constantly moist and humid in an otherwise hot-dry climate.

Underneath the duricrust caprock, the regolith is inherently porous. Interconnecting cavities or voids are common and are linked by fractures and root canals. Although the duricrust caprock is largely impermeable, root canals and solution pipes between slabs, fractures, and other zones of structural weakness, especially near breakaways, allow local water access and exchange of air to the surface. These features allow the profile to be well ventilated and provide access of water and oxygen and an allochthonous food supply for subterranean ecosystems. Thus the sub-surface duricrust provides a stable, moist. humid zone for root growth and microorganisms, and highly favourable conditions necessary to sustain subterranean troglofauna habitation in the Operational Area.

The buried duricrust has similar attributes to the exposed duricrust and provides an equally favourable environment for troglofauna habitat but being under soil cover, access of water, air and food is potentially moderated. However, the soil cover sequences are generally shallow (commonly < 1 m deep) and unconsolidated sand colluvium. Apart from clay-rich horizons that mark the extent of present-day water penetration and sub-surface drainage, the sand is permeable to water and oxygen. The clay horizon is likely to act in a similar capacity to silcrete caprock, and hence, is a barrier to flooding and dehydration but is still sufficiently permeable to allow moisture access into the subsurface. In addition, the clay adsorbs and retains moisture in the soil and is a barrier to capillarity rise and thus, keeps the sub-surface environment constantly moist and humid.

Other regolith environments in the landscape are likely to be less favourable for troglofauna habitat. Silcrete, laterite, and calcrete scree and gravels, and pedogenic carbonate nodules exposed around the base of large trees, potentially provide short-term protection where organisms may seek refuge in interstitial voids between fragments, but they are generally loose or poorly consolidated and thus, lack long-term stability, and are susceptible to sediment and water inundation.

With the extensive preservation of multiple generations and forms of duricrust within the landscape at the Operational Area, there is the potential for a long period of continuous habitation of troglofauna. Suitable troglofauna habitat formed as early as the post Miocene humid-wet period with the formation of laterite and silcrete duricrusts. Subsequently, there has been a progressive evolution in duricrust formation through to the present-day arid conditions. Given the low mobility of troglofauna between discrete areas of habitat, there is also the potential for multiple isolated populations within the landscape, with varied evolutionary trajectories, some isolated in remnant habitat formed in earlier eras, and other populations evolved by successively colonising new environments. The elevated, most prominent silcrete and laterite exposures are the oldest forms of duricrust in the landscape of the Operational Area and are potential hosts to troglofauna since their formation under wet-humid climates. In contrast, the more recently formed pedogenic valley silcrete-calcrete duricrust, typically buried under soil cover and largely invisible in the landscape, affords the most widespread habitat for troglofauna in the Operational Area regolith.

The Operational Area is at the juncture of three regionally extensive bio domains, the Great Victoria Desert, the Eucla Basin-Nullarbor Plain, and the Yilgarn Craton (including the eastern Goldfields, Murchison and the Coolgardie biogeographic regions) that are also the product of wet-humid to semi-arid to arid weathering regimes. Individually these domains cover a vast area of many hundred's of square kilometres with only slight variations in climate, biogeography, and landform and regolith expression. With the exception of the Great Victoria Desert proper where sand dune cover is extensive, remnant regolith duricrust similar to those described at the Operational Area are exposed, and represents about 15 to 25 percent of the cover throughout these regions (How is this determined? Can a map showing the location of the duricrust in the region be included?). It is probably that a further 25 to 30 percent of the area is underlain by pedogenic valley silcrete-calcrete duricrust.

In conclusion, the presence of troglofauna at the Operational Area has been confirmed by the location of three species in drill holes. Although to date their actual habitat has not been clearly defined, the area has regolith highly favourable to the formation of stable subterranean troglofauna habitat and thus, potentially supports their regional presence in the area. Due to the broad range of similar climate, biogeography, landform and regolith settings, with similar potential troglofauna habitat, covering many hundreds of square kilometres of the surrounding Great Victoria Desert, the Eucla Basin-Nullarbor Plain, and the Yilgarn Craton, it is probable that all three Troglofauna species recorded within the Operational Area are also located in areas not affected by the proposed Tropicana Gold Project.

6.0 REFERENCES

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Appendix 1 Regolith Geology Codes