Stygofauna investigation of the Roy-Valais and Korong North Borefields and the Windarra Calcrete Quarry

Murrin Murrin Nickel Cobalt Project
Anaconda Operations Pty Ltd.

DRAFT REPORT

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Executive summary

An examination for specialized subterranean fauna was made of the Roy-Valais Borefield, the Korong North Borefield and the Windarra Calcrete Quarry associated with the Murrin Murrin Nickel Cobalt Project run by Anaconda Operations Pty Ltd.

No stygofauna were recorded in the aquifers associated with the Roy-Valais or Korong North borefields.

Stygofauna is present in the Windarra Calcrete Quarry aquifer. It comprises, *inter alia*, two previously unknown species of eyeless water beetles, amphipods and several microcrustaceans. The community is known from no other location. The fauna is undoubtedly richer than was recorded from the very limited sampling access.

From the known distribution of the fauna the mining operations are likely to have an adverse impact on the stygofauna.

It is recommended that the taxonomic status of the macrofauna be investigated and that the broader distribution of the stygofauna be ascertained to ensure that it is present in areas outside the impact of proposed or projected mining operations.

An early integration of the requirements for stygofaunal monitoring with resource assessment and geotechnical investigations is recommended for future operations.

Introduction

Anaconda Operations Pty Ltd. is commissioning the Murrin Murrin Nickel Cobalt Project and in so doing are developing water abstraction borefields and a calcrete mine in the region. This report examines the potential for subterranean aquatic fauna only from the Roy-Valais Borefield, the Korong North Borefield and the Windarra Calcrete Quarry and discusses the implications of the project to this fauna.

Background

The presence in both fresh and brackish waters of communities of animals living in subterranean water bodies is well known (Botosaneau 1986; Marmonier et al. 1993), but the presence of rich subterranean faunas, both aquatic and terrestrial, in arid Australia has only recently been established (Humphreys 1993a, 1993b, 1993c, in press a), and their derivation debatable (Humphreys in press c).

The aquatic system comprise essentially a fauna of marine derivation inhabiting anchialine waters (Humphreys 1993b, in press a, in press c; Yager and Humphreys 1996; Poore and Humphreys, 1992; Bruce and Humphreys, 1993; Bradbury and Williams 1997), while a freshwater fauna inhabits the groundwaters in the cratons or shield regions (Poore and Humphreys, 1998; Humphreys in press c; Wilson and Keable in press). The fauna respectively appear to be associated with those of the Tethys and Gondwana (perhaps Pangea).

Definitions

Organisms have many pathways of interaction with subterranean spaces (Gibert et al., 1994); those only found underground are termed **troglobites** in the Schiner—Racovitza classification system (Schiner, 1854; Racovitza, 1907), a term sometimes restricted to the obligate inhabitants of air-filled subterranean voids, in which case the term **stygofauna** (comprising **stygobites**) is used to describe the obligate inhabitants of water-filled subterranean spaces. **Troglophiles** (or **stygophiles**) may live and reproduce underground as well as in the surface environment.

The lack of detailed ecological information for most cave-inhabiting species leads to ambiguity, and this is to some extent overcome by the concept of **troglomorphy** (Christiansen, 1962), which permits classification of the cave inhabitants using a less ambiguous morphological definition (troglomorphic/non-troglomorphic species) rather than the ecological one (troglobitic/ troglophilic/ trogloxenic species).

Many species found living underground display certain characteristic traits that are thought to be adaptive to underground life. These include both the reduction or loss of characters (regressive evolution) and the enhancement of others (constructive evolution), which together produce the convergence, characteristic of cave-adapted animals, that is termed troglomorphy. These adaptations include morphological, ecological, physiological and behavioural characteristics (table 1).

Table 1: Characteristics of cave organisms relative to surface organisms — troglomorphies. From Culver et al. (1995), after Christiansen (1992).

Morphological
Specialisation of sensory organs (chemo-, hygro- thermo- and baro-receptors)
Elongation of appendages
Reduction of eyes, pigments and wings
Cuticle thinning (in arthropods)
Foot modification (in Collembola and planthoppers)
Scale reduction (in fish).

Ecological and behavioural
Slowing metabolisms
Starvation resistance
Relaxation and degeneration of circadian rhythms
Lowered fecundity
Increased egg volume
Increased life span

Behavioural
Decreased aggregation (in Collembola)
Reduced reaction to alarm substances (in fish)
Increased sensitivity to vibration
Reduced intraspecific aggression

Methods

During three days in the field a total of 49 sites was sampled, 25 in the Roy-Valais Borefield, 14 in the Korong North Borefield, eight in the Windarra Calcrete Quarry (that is, all the available sites), and two wells (table 2). The sites included pastoral wells, exploration bores, failed (uncased) production bores, production bores yet to be equipped, old de-equipped production bores, groundwater monitoring bores and piezometers. A number of bores examined were dry but these were also sampled in the same manner.

The sites were sampled by plankton nets hauled through the entire length of the bore. In deep bores the initial sample was taken through the upper part of the water column and a subsequent sampled drawn from the entire water column. Time constraints limited trapping — using miniature craypot-like traps — to the Windarra Calcrete Quarry.

All samples were sorted under a dissecting microscope having been maintained for such time and under such conditions that any contained fauna would be expected still to be mobile and thus more easily located. Specimens were transferred to appropriate preservatives and lodged with the Western Australian Museum of Natural Sciences.

Table 2: Locations sampled from 17/11/98 to 19/11/98.

Region	Sample site	Latitude	Longitude	
Roy-Valais Borefield	MMX 140? @ MMP1	28.73954	121.90188	
Roy-Valais Borefield	MMO 7 75 mm PVC constriction at top	28.47700	121.90870	
Roy-Valais Borefield	MMT56 @ MMP1	28.47246	121.89999	
Roy-Valais Borefield	MMO 6	28.46540	121.88710	
Roy-Valais Borefield	MMPO 6	28.46555	121.90244	
Roy-Valais Borefield	MMT 43 @ MMP 2	28.44802	121.91344	
Roy-Valais Borefield	MMO 10	28.44364	121.90117	
Roy-Valais Borefield	MMO 16	28.44990	121.91896	
Roy-Valais Borefield	SB 6 65 mm pvc	28.45433	122.01785	Dry
Roy-Valais Borefield	PBIR @ MMP 58 200 mm steel old PB	28.45847	122.02692	
Roy-Valais Borefield	BIA @ P 58 50 mm pvc	28.45833	122.02662	
Roy-Valais Borefield	B1 @ P 58 65 mm pvc	28.45817	122.02660	Dry
Roy-Valais Borefield	No Id @ PB 58 65 mm pvc	28.45770	122.02624	
Roy-Valais Borefield	No Id @ PB 58 65 mm pvc	28.45129	122.01900	Dry
Roy-Valais Borefield	Valais Well dry	28.46562	122.01918	
Roy-Valais Borefield	next to Valais Wll 65 mm pvc	28.46573	122.01876	
Roy-Valais Borefield	C2 65 mm pvc	28.46530	122.06958	
Roy-Valais Borefield	? Well	28.43196	122.08083	
Roy-Valais Borefield	near well above 55 mm pvc	28.43113	122.08208	
Roy-Valais Borefield	MMT 24 110 mm pvc	28.43112	122.08147	
Roy-Valais Borefield	D3 65 mm pvc	28.48080	122.04926	
Roy-Valais Borefield	MMT 4 110 mm pvc	28.47684	122.05032	
Roy-Valais Borefield	SB 2 @ MMP 10 65 MM pvc	28.47085	122.02860	
Roy-Valais Borefield	PB 10 @ MMP 53 210 mm steel	28.47371	122.03249	
Roy-Valais Borefield	MMP 21 @ ?PBX8] old PB	28.45139	122.02425	
	?Well	28.61864	122.01904	Dry
	Well at start of Kurong Borefield road	28.59067	122.03700	
Windarra Calcrete Quarry	OP 113	28.49084	122.11840	
Windarra Calcrete Quarry	OP 114	28.49233	122.12489	Dry
Windarra Calcrete Quarry	OP 115	28.49421	122.13146	Dry
Windarra Calcrete Quarry	OP 117	28.48643	122.12774	Dry
Windarra Calcrete Quarry	OP 118	28.48529	122.12178	
Windarra Calcrete Quarry	OP 124	28.47552	122.12421	
Windarra Calcrete Quarry	OP 122	28.47670	122.12943	
Windarra Calcrete Quarry	OP 123	28.47824	122.13719	
Korong North Borefield	no id @ PBK 7 65 mm pvc	28.56854	122.03596	
Korong North Borefield	no id @ PBK 7 200 mm steel	28.56862	122.03606	
Korong North Borefield	PBK 6 @ PBK 6 65 mm pvc	28.55940	122.03597	
Korong North Borefield	MMT 18 110 mm pvc	28.56069	122.02357	
Korong North Borefield	MM 11 @ PBK3 200 mm steel	28.56328	122.01680	
Korong North Borefield	no id @ PBK 3 65 mm pvc	28.56378	122.01667	
Korong North Borefield	MMT 17 @ PBK1 110 mm pvc	28.57018	122.00654	

Korong North Borefield	MMX 24 50 mm pvc	28.57116	122.00576
Korong North Borefield	K12 65 mm pvc	28.56812	122.00633
Korong North Borefield	PBK 4 50 mm pvc	28.56024	122.02360
Korong North Borefield	MMT 19 @ PBK2 110 mm pvc	28.55607	122.05127
Korong North Borefield	MMT 20	28.55910	122.05168
Korong North Borefield	TPK9	28.55871	122.04588
Korong North Borefield	MMT22	28.56309	122.03623

Provisos

Access

The utility of various types of access to the groundwater for monitoring or collecting stygofauna depends upon many factors, amongst them the nature of the lithography intersected by the bore at and below the water table, and the characteristics of the bore itself. Attributes related to the construction of the bore include the time since drilling, whether the bore has been developed, the type of casing and slotting, whether the bore has been packed and the interval over which the water column is accessible for sampling. Of less consideration is the diameter of the bore as this limits the volume of water that can easily be sampled. Factors related to the lithology and structure include whether calcrete, gravels or karst regions are intercepted by the bore and the impact of the lithology on the groundwater quality.

While the smaller elements of the stygofauna may penetrate into well established bores, depending on the size of the packing materials, the macro-stygofauna are likely to be absent. Similarly, newly established bores are less likely to have stygofauna owing to the drilling process occluding the matrices in the rock, the high silt load in the water and the addition of drilling fluids, sterilizing fluids, solvents and other substances added to the bore during its establishment.

A survey that relied entirely on samples from completed production bores or new, well established groundwater monitoring bores, would provide a low level of confidence that stygofauna was absent from the area. Surveys including samples from old established wells, and uncased or unpacked boreholes, or bores constructed for the purpose of monitoring stygofauna, provide much greater confidence that a representative sample of the groundwater inclusions has been sampled.

Subterranean fauna

Troglobites: In the absence of direct access to the subterranean realm, as for example in a cave sufficiently large for a person to enter, and sufficiently deep to contain a micro-environment adequately buffered from the surface environment, it is generally not possible to sample troglobites in a one-off visit as it normally requirs some sore of baiting or environmental modification to concentrate the fauna in an area where they can be sampled, such as a bore hole. Subterranean aquatic fauna (stygofauna) are more readily sampled as their habitat can be sampled remotely down boreholes. If a stygofauna is present it would seem likely that a troglofauna may also be present in the area.

Borefield characteristics

Roy-Valais Borefield

The borefield (fig. 1) is developed in palaeovalley deposits and is mainly targeting the aquifer in the basal palaeosands, which are 2-10 m in thickness. Bore completion reports show substantial layers of clays overlying the palaeosands e.g. MMP6 has c. 24 m of clay overlying the lower sands and sandy gravels of the main aquifer (drawing No. MMP6 2/10/97).

Drilling of the production bores in the Roy-Valais Borefield was conducted from 14/9/1997 to 30/4/1998. Machine slotted (1 or 1.5 mm) casing was installed adjacent to the permeable zones and 200 mm stainless steel screens were located adjacent to highly permeable zones. The boreholes were developed by water jetting. Mean TDS for all production bores is 1570 mg L^{-1} with the salinity increasing downgradient towards the salinas, as is typical of such systems.

Korong North Borefield

The Korong North Borefield (fig. 1) is developed in palaeovalley deposits and are mainly targeting the aquifer in ... TO BE ADDED WHEN INFORMATION AVAILABLE

Windarra Calcrete Quarry

Calcretes are carbonate deposits forming near the water table in arid lands as a result of concentration processes by near-surface evaporation (Jacobson and Arakel 1986). Groundwater calcretes (Arakel 1996) often develop typical karst features (Barnett and Commander 1985) which are suitable for stygofauna sampling (Poore and Humphreys 1998).

The calcrete deposits at Windarra (fig. 1), which has a 'cherty' appearance at depth, reaches a maximum thickness of about six metres — it is overlain by c. 1 m of ferriginous, clayey, unconsolidated sand — and it typical of the groundwater calcretes widely occurring in the Australian arid zone. There are well developed karst features within the area covered by the piezometric field that are typical of those found elsewhere in calcrete (Sanders, 1973) and in those supporting stygofauna (Poore and Humphreys, 1998; W.F. Humphreys, unpublished). In addition the resource assessment bore logs from the calcrete contain mention of solution channels, vugs and cavities. In the quarry area the water table is shallow (3.34 m [s.d. 0.89 range 1.90-4.15 below the natural surface] at the time of sampling). As such the calcrete comprises a highly permeable aquifer with limited saturation thickness. The groundwater is reported to flow to the north-northwest with a hydraulic gradient of c. 1: 2,000. The calcrete deposits are adjacent to the lower reaches of the Lake Way-Lake Carey palaeodrainage system at depth.

Sampling results

Borefields

No subterranean fauna was recovered from either the Roy-Valais Borefield or the Korong North Borefield.

While there is little precedent for sampling aquifers of this type for stygofauna in Australia, it seems unremarkable that aquifers in sand beneath thick bands of clay lack stygofauna. The clay layers, if continuous, would likely prevent the downwards percolation of organic detritus and dissolved inorganic carbon believed to be needed to fuel most stygal ecosystems. However, there are circumstances whereby the groundwater flow may transport sufficient energy to fuel stygal ecosystems, but this would appear not to be the case here.

Some of the bores sampled were old and uncased and would have provided no impediment to any stygofauna entering the bore. In addition, the influx of organic matter down the bores is likely to have provided a localized concentration of energy attractive to some stygofauna. The variety and intensity of sampling of these borefield is considered to have provided an adequate representation of the contents of the aquifer (figs 2 and 3).

Calcrete Quarry

The Windarra Calcrete Quarry area (fig. 4) has a stygofauna community of specialized subterranean animals that includes two previously unknown species of dytiscid water beetles, amphipod crustaceans, cyclopoid and harpacticoid copepods (table 3). Given that the entire volume of water accessible for sampling totalled only c. 4.4 L, a richer stygofauna can be expected to occur at this site.

Sampling of the Windarra Calcrete Quarry area is considered to have been inadequate owing to extremely restricted access to the aquifer and the small spacial scale of the sampling.

Table 3: Fauna in the Windarra Calcrete Quarry (WCQ) piezometric field.

Location	Amphipoda	Copepoda Cyclopoidea	Copepoda Harpacticoidea	Coleoptera Dytiscidae	Oligochaeta
WCQ: OP 113		•	•		∘
WCQ: OP 118	•				
WCQ: OP 122	•	•		•	•
WCQ: OP 123	•	•		•	
WCQ: OP 124	•			∘	

Stygofauna

Crustacea: Amphipoda

The amphipods belong to the family Ceinidae (Dr J. Bradbury, pers. comm. 8/12/1998), a family of marine ancestry (Barnard and Karaman, 1984). The family is widely represented in Australia by two surface or troglophilic species belonging to the genus *Afrochiltonia* in southeast and southwest Australia (Williams, 1986), an eyeless, possibly troglobitic species *Phreatochiltonia anopthalma* Zeidler. *Austrochiltonia subtenuis* (Sayce)(Sayce) is associated with tree-root mats in groundwater in karst areas of the southwest of Western Australia, Leeuwin Naturaliste ridge and Yanchep (Jasinska et al., 1996). No clear genetic separation exists between surface and subterranean populations of *Austrochiltonia*, unlike the considerable genetic diversity that occurs in *Gammarus minus* in the Appalachian Mountains of North America (Culver et al., 1995), a well researched species found in cave and epigean waters.

The specific status of the species from Windarra Calcrete Quarry is unknown at present and requires research work. Dr Bradbury, expects them to align with those found in Mound Springs and other underground regions such as Cutta Cutta, Northern Territory, and Mt. Lindsay in northern South Australia.

The stygofauna in the Paroo aquifer, a calcrete aquifer near Wiluna, also contains amphipods and blind dytiscids, but the amphipods there are unrelated to those at Windarra, being crangonyctoid amphipods — a freshwater lineage — which are very different from anything known to date (J. Bradbury, personal communication).

Insecta: Coleoptera: Dytiscidae

The eyeless water beetles belong to the family Dytiscidae and represent two undescribed sister species distinct from those found in the Paroo calcrete aquifer (C.H.S. Watts, personal communication, 9/12/1998), in the northern part of the Lake Way-Lake Carey palaeodrainage system.

Beetles of the family Dytiscidae are carnivorous beetles with a world wide distribution containing about 3000 species distributed amongst 147 genera (Spangler 1996). Worldwide only nine other species of troglobitic dytiscids are known outside Australia belonging to eight genera from Japan, New Zealand, France, Mexico, USA, Upper Volta [Burkina Fasso] and Venezuela. The only other subterranean dytiscids known in Australia are from the Paroo aquifer, a calcrete aquifer near Wiluna where they were found in 1998. In the Paroo calcrete three species belonging to three different genera are represented (C.H.S. Watts, personal communication) and they occur in the same bores, a remarkable occurrence.

Dytiscids may occur in flowing or still water ranging from fresh to markedly saline; an adult has been taken from water with a salinity nearly three times sea water. However, they are most abundant in small freshwater pools (Williams, 1980).

The salinity in the Windarra Calcrete Quarry area ranged from c. 1500-3200 mg L^{-1} TDS at the time of sampling but has been reported as high as 4100 mg L^{-1} TDS in places (Dames and Moore). The current salinity in the Paroo calcrete is unknown but the total salinities ranged from 710-1330 mg L^{-1} TDS when the borefield characteristics were established (Sanders 1973) but was not much stratified within boreholes. There is a general increase in salinity downstream up to 4400 mg L^{-1} TDS where it eventually drains to the saltlakes in the Lake Way system which act as evaporation basins.

Groundwater monitoring in the Windarra Calcrete Quarry

The eight piezometers examined are on average 0.7 m shallower than their nominal drilled depth (table 4: mean 0.69; s.d. 0.77 range -0.25 to 1.9 m), and some are much shallower, up to 1.9 m. At the time of sampling the water table in OP123 was 1.9 m below the natural ground surface (table 4), substantially closer to the surface than suggested by the statement that the 'water table lies between 2.5 and 4.5 m below the natural ground surface'.

Table 4: The piezometer characteristics, water depth and conductivity in the Windarra Calcrete Quarry.

Bore	Water	Fauna	Bore depth	Water depth	Cond. mS cm^{-1}	°C	Bore depth BGS	Depth to water BGS`	Drilled m
OP113	√	√	4.40	0.05	2.36	23.80	4.20	4.15	5
OP114	x	-	3.15	-	-	-	2.85	-	4
OP115	x	-	3.90	-	-	-	3.56	-	5
OP117	x	-	3.35	-	-	-	3.10	-	5
OP118	√	√	5.50	1.55	4.73	24.00	5.25	3.70	5
OP122	√	√	3.70	0.40	4.85	23.90	3.50	3.10	4
OP123	√	√	2.30	0.15	-	-	2.05	1.90	2
OP124	√	√	4.15	0.10	-	-	3.95	3.85	4

Potential impacts of mining on the stygofauna

The planned mining operations (Dames and Moore, 1998: fig. 3d) will probably affect all the sites where this stygofauna is known to occur (fig. 5), either directly or through changes at the surface and in the water level and quality.

Physical removal of habitat: self evident.

Removal of food source: troglobites, in the broad sense, usually depend on the energy provided by the downward percolation of photosynthetically fixed organic detritus. Removal of the vegetation cover will remove this pathway for the provision of food energy to the system. Chemoautotrophic energy fixation has been demonstrated in few places, often associated with sharp changes in the salinity profile, but, *a priori* , such a process would seem unlikely in this system.

Lowering of the water table and changes in salinity: removal of the overburden and calcrete to the water table will enhance evaporation potentially affecting both the level and salinity of the groundwater both during the mining operation and on the restored site.

In addition the projected drawdown in Windarra area (Dames and Moore, 1998: fig. E-7) of perhaps 1 m may be significant if the stygofauna is restricted to the calcrete layer. As the calcretes overlie clay there is only slight likelihood of a refuge further down in the profile.

These factors could well be addressed further as there appears to be rather little room for error in some parameters. For example, it is stated that the 'pits will be backfilled so that the average final depth of the pits will be up to approximately 3m (depending on the depth of the water table).' This would leave an average of only 0.34 m of calcrete above the water table to be removed as, at the time of stygofaunal sampling, the water table in the quarry area was on average 3.34 m below the natural surface. Recorded variation in the level of the groundwater are quite large relative to these figures (fig. 6).

The salinity tolerance of the fauna is unknown and there are insufficient data available for this newly discovered fauna from other areas to make a prediction. However, the fauna comprises lineages with a freshwater ancestry and, as the salinity at Windarra is, perhaps, 2-3 times greater than that found with an analogous fauna at Paroo, further up the palaeodrainage system, it may be reaching its limit of salt tolerance. However, some surface species have been collected in waters of high salinity, at least as adults (Williams 1980).

Previous studies have shown that local surface water drainage converges on the quarry area to form a localized recharge area. Hence, the disruption of the surface drainage resulting from the mining operations and their associated works are likely to have implications to the quality and quantity of water in the calcrete.

Other changes in water quality: ammonium nitrate and fuel oil in the explosive could directly affect the stygofauna through nutrient enrichment, toxicity and the deposition of an impermeable film on the groundwater surface — it is unknown at this stage whether the dytiscid species present need to surface in air pockets to breath. The effect of percussion at the planned magnitude at close range is unknown.

Broad scale distribution of the stygofauna

The stygofauna communities in the separate calcrete areas, even within the same major drainage basin, are substantially different from each other (Poore and Humphreys 1998; W.F. Humphreys, unpublished). This is confirmed by the differences between the communities at Paroo and Windarra which occur in the same palaeodrainage system and contain structurally similar communities but which, nonetheless, have a very different taxonomic composition.

The Windarra stygofaunal community is known only from the Windarra Calcrete Quarry. While the uniformity of the groundwater level suggests that the calcrete comprises a single, unconfined aquifer, the stygofaunal community cannot be assumed to occur throughout a single calcrete aquifer, nor even in a single additional location (Poore and Humphreys 1998).

The 1996 COAG agreement includes provision of water for the environment, although this is poorly defined in the context of groundwater (Hatton and Evans, 1998). Past COAG agreements pertain to the maintenance of biodiversity and hence the protection of species from extinction.

Recommendations

To demonstrate that no fauna shall be made extinct by the mining operations it is recommended that:

- The broader distribution of stygofauna in the calcrete be determined as a matter of priority.
- The specific taxonomic status of the macrofauna be determined so that its existence outside the areas of likely future mining impacted can be demonstrated.

Numerous, 756, boreholes were drilled to assess the calcrete resource in the Windarra area. Most were shallow (c. 5 m) and the piezometers were established in such holes. However, a number of holes were drilled to 10 m (ERC51 to ERC99), and even up to 30 m (ERC1 to ERC11: Maczurad and Murphy, 1997), that would have provided useful sampling points for stygofauna. They could have provided valuable data on the distribution of the stygofauna and the characteristics of the aquifer, especially in terms of salinity profile as calcretes frequently have freshwater overlying much more saline waters. These data would have enabled a better assessment of the likely impacts of the mining operation on the stygofauna.

Recommendation

- In general an early integration of the requirements of stygofauna surveys into the resource assessment and geotechnical drilling programmes would be cost effective and streamline the development of management plans and environmental approvals.

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Figure captions

Figure 1: Project layout showing the location of the sampling areas considered in this report. Base map from Dames and Moore Fig. E-2.

Figure 2: Approximate location of sampling points in the Roy-Valais Borefield; some points denote multiple samples.

Figure 3 NEED: Approximate location of sampling points in the Korong North Borefield; some points denote multiple samples.

Figure 4: The location of fauna sampling points in relation to the resource assessment bore array in the Windarra Calcrete Quarry area. The large points denote the sampling points with the piezometer number (e.g. OP124) and the apparent water table (AHD - 410.0 m) at the time of sampling (e.g. 4.10). Piezometers without an AHD number were dry.

Figure 5: The conceptual project layout at the Windarra Calcrete Quarry showing the approximate location of the piezometers sampled. Solid and open circles denote respectively piezometers with and without water. All piezometers that penetrated the water table contained stygofauna. Base map from Dames and Moore Fig. E-3d.

Figure 6: Variation from the mean level of the water in each monitored bore in the Windarra Calcrete Quarry over a period of 20 months to 28 August 1998.

Figure 1

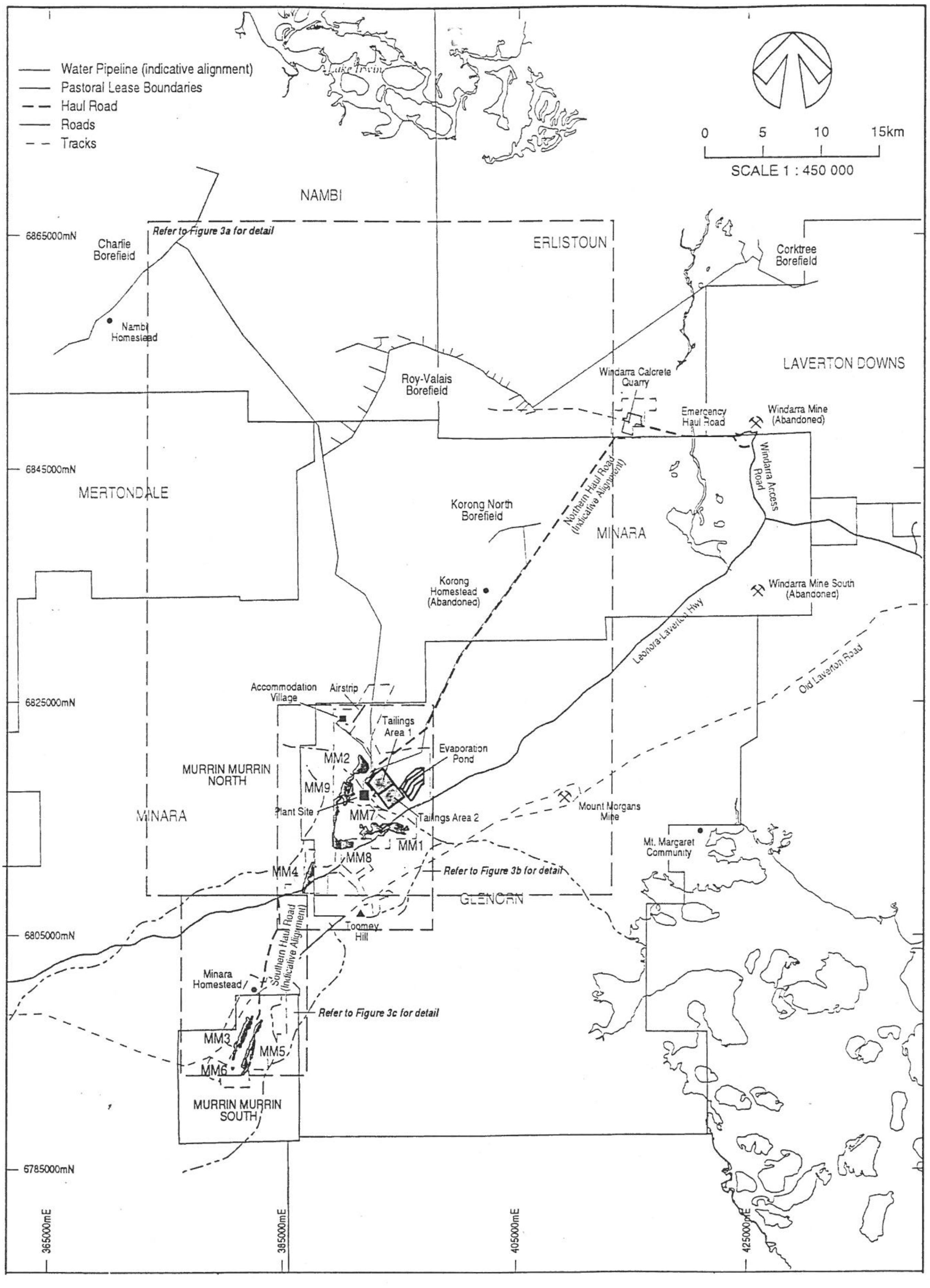

Water Pipeline (indicative alignment)
Pastoral Lease Boundaries
Haul Road
Roads
Tracks
0 5 10 15km
SCALE 1 : 450 000
Lake Irwin
NAMBI
ERLISTOUN
Refer to Figure 3a for detail
6865000mN
Charlie Borefield
Nambi Homestead
Corktree Borefield
LAVERTON DOWNS
Roy-Valais Borefield
Windarra Calcrete Quarry
Emergency Haul Road
Windarra Mine (Abandoned)
Windarra Access Road
6845000mN
MERTONDALE
Northern Haul Road (Indicative Alignment)
Korong North Borefield
MINARA
Korong Homestead (Abandoned)
Windarra Mine South (Abandoned)
Leonora-Laverton Hwy
Old Laverton Road
6825000mN
Accommodation Village
Airstrip
Tailings Area 1
Evaporation Pond
MURRIN MURRIN NORTH
MM2
MM9
Plant Site
MM7
Tailings Area 2
MM1
MM8
MM4
MINARA
Mount Morgans Mine
Mt. Margaret Community
Refer to Figure 3b for detail
GLENORN
Toomey Hill
6805000mN
Southern Haul Road (Indicative Alignment)
Minara Homestead
Refer to Figure 3c for detail
MM3
MM5
MM6
MURRIN MURRIN SOUTH
6785000mN
365000mE
385000mE
405000mE
425000mE

Figure 2

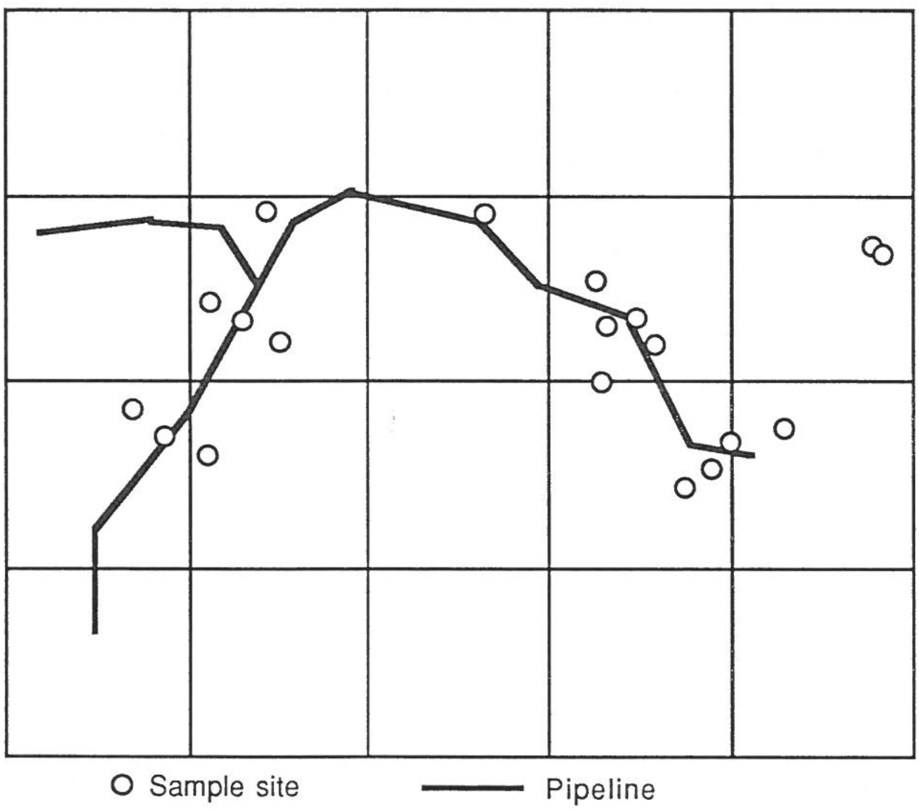
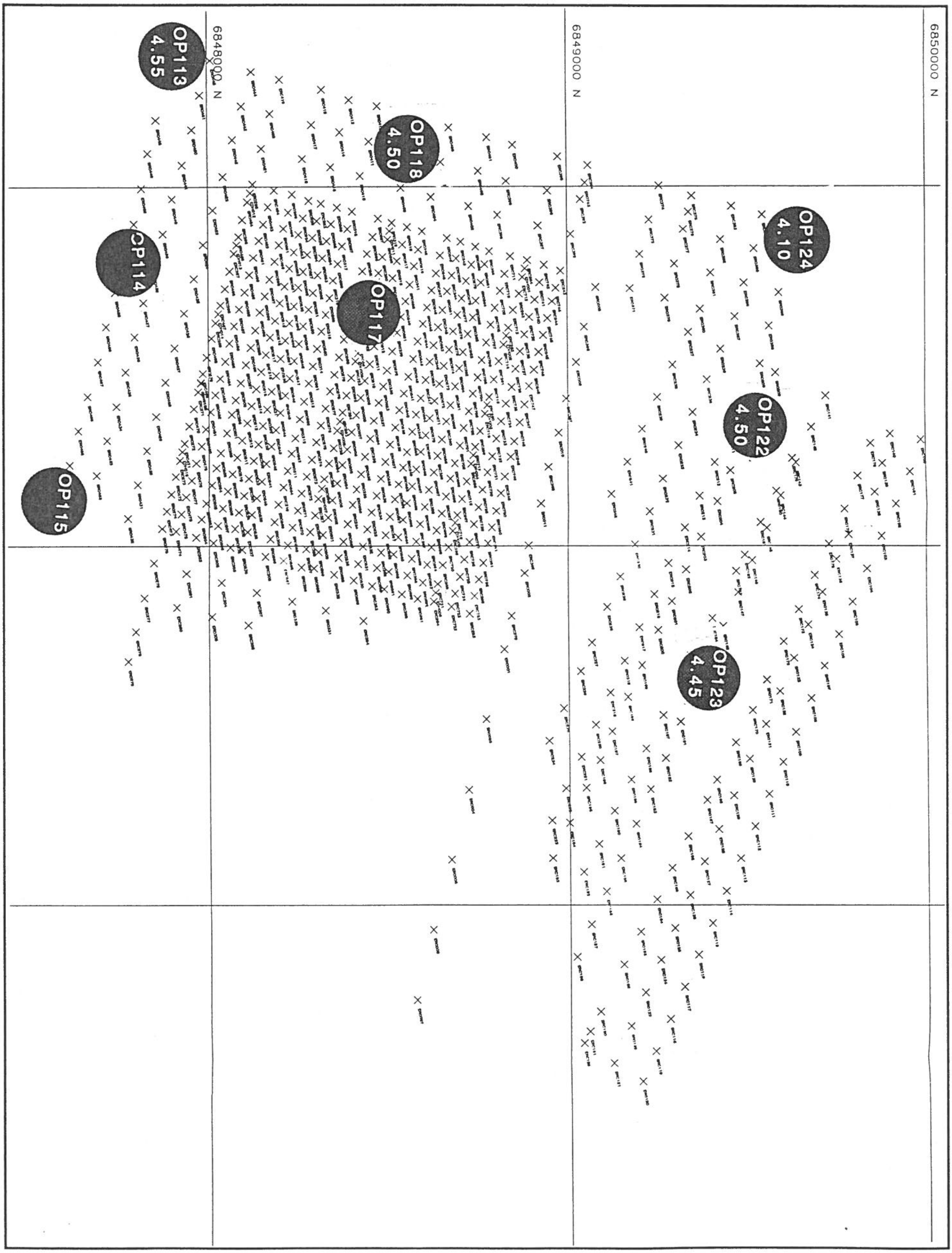


Figure 3

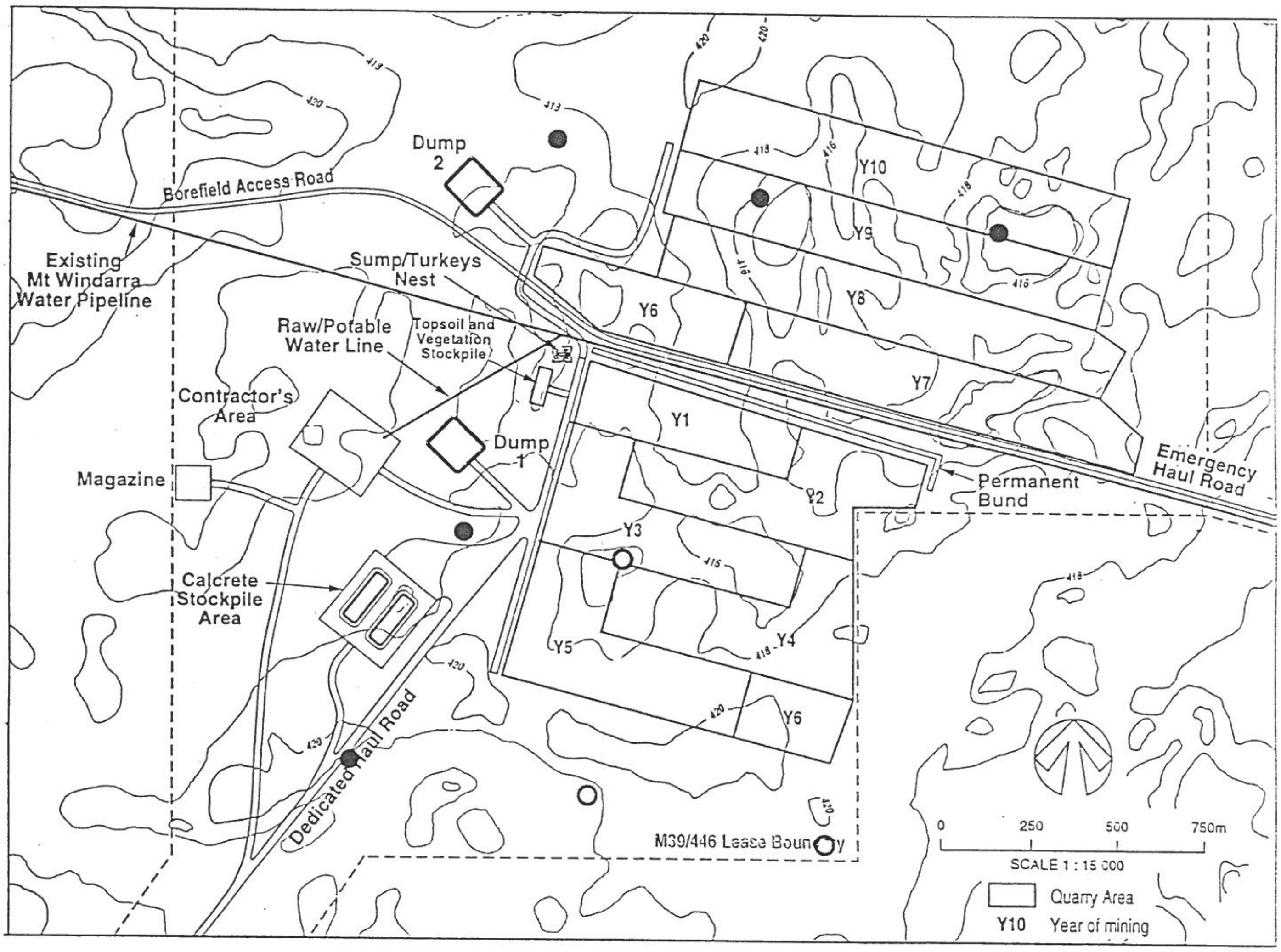
To be provided when source map is available.

Figure 4



6848000 N
6849000 N
6850000 N
OP113 4.55
OP118 4.50
OP114
OP117
OP115
OP124 4.10
OP122 4.50
OP123 4.45

Figure 5



Dump 2
Borefield Access Road
Existing Mt Windarra Water Pipeline
Sump/Turkeys Nest
Raw/Potable Water Line
Topsoil and Vegetation Stockpile
Contractor's Area
Magazine
Dump 1
Calcrete Stockpile Area
Dedicated Haul Road
Emergency Haul Road
Permanent Bund
Y1
Y2
Y3
Y4
Y5
Y6
Y6
Y7
Y8
Y9
Y10
M39/446 Lease Boundary
0
250
500
750m
SCALE 1 : 15 000
Quarry Area
Y10 Year of mining

Figure 6

Figure 6: Variation from the mean level of the water in each monitored bore in the Windarra Calcrete Quarry over a period of 20 months to 28 August 1998.