ENVIRONMENTAL MANAGEMENT CONSIDERATIONS AND REHABILITATION AT A SALINE MINESITE IN ARID WESTERN AUSTRALIA[1]

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Abstract: Sunrise Dam Gold Mine, operated by Acacia Resources Limited, is located 700 km northeast of Perth, Western Australia in the arid rangelands (ranchlands). Gold ore is mined from an open pit and treated in a Carbon-in-Leach plant at a rate of 1.2 million tonnes per annum. Rainfall is less than 250 mm per year and there is a great diversity of temperatures diurnally and monthly. The minesite is located on the edge of Lake Carey a large salt lake. Groundwater extracted from the open pit operations has TDS levels in excess of 150,000 ppm. Lower levels of the regolith below 2 m have soil salinities up to 80,000 ppm TDS. The fresh rock below 100m depth contains low levels of pyrites and other sulphide bearing minerals. Research work is being undertaken to obtain data on leaching of soil salts, suitable vegetative or other effective erosion control methods, water control, and the extent of capillary rise of salts in the waste rock dumps. Vegetative rehabilitation is further complicated by the role of gypsum used as a topsoil cover and its effect on total salinity and sodium absorption ratio. The paper will present an overview of the site operations, the environmental management procedures including waste recycling, rehabilitation research, options and techniques for both waste dumps and tailings storage facilities. Government regulations and standards, visual amenity and social implications will be described.

Additional Key Words: dewatering, hydrocarbons, compliance, salinity

Introduction

The Sunrise Dam Gold Mine (SDGM) is owned and operated by Acacia Resources Limited and mines the Cleo gold deposit as an open pit mining operation.

Location

The mining project is located in the Mt Margaret Mineral field of the Mt Morgan Mineral District, 25 km south of the Granny Smith Gold Mine and 55 km south of the Town of Laverton in the Northeastern Goldfields and some 700 km (440 miles) northeast from Perth (Figure 1). Most aspects of the mining operation are very similar to other gold mines in the region.

The Cleo deposit lies on the eastern shore of a large salina, Lake Carey. The Cleo deposit is on the eastern shore and is contiguous with Placer-Granny Smith (PGS) Limited's Sunrise deposit.

Mining Operations

The Cleo deposit has a resource of 21.7 million tonnes at an average grade of 4.11 grams per tonne (g/t) containing 2.9 million ounces of gold (as at March, 1998). Extensive exploration has increased the resource significantly since the commencement of operations. Pre-development mining commenced in July 1996 and the first gold ingot was poured in March 1997. The project currently is mining lake sediments, palaeochannels and saprolitic material to produce gold bearing ore and processing the ore at a rate of 1.2 million tonnes per annum through a gravity/Carbon-in-Leach (CIL) gold treatment plant to produce gold bullion. The milling circuit currently is being up-graded with the installation of an additional ball mill to increase the throughput to 2 M tonnes per annum.

Mine overburden (waste) is being placed on a single waste dump currently holding 27 (March 1999) million bank cubic metres (bcm) of saline lacustrine and saprolitic material (clay). The waste dump is located to the west and northwest of Cleo deposit.

The CIL tailings are placed in a 50 ha tailings storage facility (TSF) located some 2.5 km east of the pit and 1.5 km north of the CIL plant.

It is anticipated that further modifications will occur, such as an extension of the mining operation at the open pit, potential development of underground (decline access) mining, major changes to the

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processing circuit and haul road or pipeline amendments. A new tailings disposal system (central thickened discharge) is being developed at the present time.

To date a total area of 433 ha has been disturbed during construction and operation of the mine. With the current knowledge of the orebody, and the current development plans, it is anticipated that for the known life of the mine (12 years) that a further 400 ha may be disturbed.

The mine and milling operations are operated 24 hours a day with two 12 hour shifts. Staff and contractors work a fly-in, fly out roster to Perth and are accommodated on site.

General Environment

The mine is located in an unpopulated, remote region. Laverton, the nearest town, has a population of less than 1000 people. The only large town in the region is Kalgoorlie, which is over 400 km from the minesite via gazetted roads. The region is predominantly vegetated by Mulga Shrubland, characterised by low hardy *Acacia* trees (Mulga) with an understorey of chenopod species and/ or native grasses. There are many large inland salt lakes in the region. The most common animals in the region are kangaroos and emus.

The main activity in the region, apart from mining, is the running of very large sheep stations of marginal grazing capacity. The mine is located on Mt Weld Station which is approximately 400,000 hectares (~1 million acres) in size. The estimated carrying capacity of the station is 22,500 sheep over summer, following a 'fair' winter season (Pringle, 1994).

The Laverton area is semi-arid and has an average annual rainfall of approximately 224 mm, with three-quarters of this rainfall occurring in the late summer to mid-winter period. On average, rain falls on 41 days each year. However, inter-year variation can be extreme, with large rainfall events associated with rain-bearing depressions (remnants of tropical cyclones forming off the north-west coast) causing flood events in late summer to early autumn. The winter rain is of frontal origin, as low pressure systems cross the State and cold fronts penetrate inland. Prolonged drought, extending over several years, is also common.

Evaporation is estimated, by interpolation from Bureau of Meteorology maps of pan evaporation isopleths and records for Kalgoorlie and Yamarna (130 km NNE of Laverton), to be 3,450 mm per year.

Temperatures range from maxima of 45°C and more in the summer to minima as low as 1°C in the winter.

Prevailing winds are generally light and variable, but high wind speeds may be experienced during storm events associated with tropical cyclones. The prevailing wind is generally easterly, varying between north-east to south-east year round; in the period May to October a north-westerly component becomes significant.

The project area generally is flat with undulating sandy aeolian dunes within one to two kilometres of the Lake edge, gypsiferous dunes bordering Lake Carey, and islands composed of gypsiferous materials within the Lake. The alkaline and saline soils of the salt flats are associated with the elongated salt lake system.

The geomorphology of the western half of the project site is described as being level to very gently inclined plains with saline alluvium, sandy banks and low sand dunes above surrounding saline plains, undulating kopi dunes, or gently undulating plains with calcrete rubble. Claypans, drainage foci, areas of sand sheet and alluvial plains subject to sheet flow occur on the boundary of the system (Pringle *et al* 1994).

The geomorphology of the eastern section of the project has alluvial plains subject to sheet flow, frequently with fine ironstone gravel mantles, and sparse, generally narrow and unincised concentrated drainage tracts.

The SDGM tenements are located in the southern portion of the Archaean- aged Laverton Tectonic Zone within the Yilgarn Block of WA. The geology of the region is poorly exposed, deeply weathered, and extensively covered by surficial sediments and deep soils. The region consists of a north-trending greenstone package bounded by undifferentiated granitoids to the east and west. The central portion of the greenstone package, in which the SDGM tenements are located, consists of acid to intermediate volcanics and sedimentary rocks, sandwiched between two corridors of predominantly mafic and ultramafic extrusive and intrusive rocks. Late stage intrusives of loosely granitoid composition occur throughout the area.

Gold mineralisation in the region is typically structurally controlled and hosted by a wide range of rock types.

The geology of the tenement area, based on aeromagnetic interpretation, is dominated by a northerly plunging antiform. The Cleo prospect is located on the western limb of this fold structure.

Groundwater

Hypersaline groundwater (250,000 - 280,000 mg/L TDS) occurs within a few metres of the ground surface in the pit area. At Cleo pit, the water table was within 5 metres of the surface and has been lowered as a result of continuous dewatering activities around and within the Cleo pit and the adjacent Placer/Granny Smith Ltd's Sunrise pit.

The aquifers form a series of layers:

- Superficial formations of ferruginous and grey waxy lacustrine clays and thin fluvial pisolitic gravel and coarse sand beds, extending to depths in excess of 40 m BGL; and
- Fractures and/or contact zones within the weathered and fresh Archean bedrock.

The aquifers are complex, irregular and of unknown lateral extent.

Pit Dewatering

Dewatering of the pit, at a rate of 2,000 – 4,000 m^3/day, has been undertaken for the life of the mining operation. A maximum of ten bores have operated at any one time. Abstracted water used in the gold treatment process averages around 750 m^3 per day, and an estimated 500 m^3 is used for dust suppression of mine roads. The remaining mine dewater is pumped to Lake Carey, where it is discharged at a point in the lake approximately 20 m from the eastern shoreline. The discharge point is the same as that currently used for discharge of mine water from Placer/Granny Smith's adjacent Sunrise pit.

Pit dewatering has lowered the water table in the immediate vicinity of the pit, but has not affected ecosystems in that area. The cone of depression is locally confined to the immediate area surrounding the pits. The salinity levels in the groundwater would suggest that the vegetation in the area would not be dependent on this groundwater.

Pit Dewatering Pipeline

Given the high salinity levels and the estimated size of the local groundwater resource, the abstraction of groundwater for pit dewatering and as make-up process water does not present an environmental sensitivity, while the water remains within the pipeline system. If the hypersaline water is released to the environment there is the possibility of localised adverse impact on soils and vegetation. Dewater pipelines are placed in bunded trenches and are flow monitored and inspected daily, with water quality checked by regular sampling and analysis. All spills and minor leaks are reported internally by the environmental incident reporting system.

Saline Discharge

Lake Carey is a very large inland saline playa lake. The lake covers approximately 1000 sq km, but includes many small aeolian-formed gypsiferous islands within the lake. The lake is generally not covered by surface water, except following rainfall events sufficient to create overland flow. A thin salt crust forms over much of the lake surface during summer when evaporation rates are very high. Groundwater salinities of the lake are in the range of 250,000 – 280,000 mg/L.

Based on the large size of Lake Carey itself and the fact that mine water has been discharged approximately 20 m from the eastern shoreline of the lake, no adverse environmental impacts have been visually identified at this stage. There was a build up of surface salt on the lake bed when the discharge water had evaporated. However, this salt was dissolved and dispersed with the first inflow of natural runoff water onto the lake surface. Ongoing observation will determine whether the salt crust will return after the lake dries out. Brine shrimp and water birds were observed very close to the discharge in lower salinity lake water, following high rainfall in 1998, suggesting that only the immediate discharge zone is of a high salinity.

An independent study was recently carried out on the discharge to attempt to understand the potential impact of the discharge on the lake. Although there is an area of elevated salinity levels, it was concluded that over the long term the impact was expected to be minimal. Collaborative research with other companies is planned to increase the knowledge of salt lake ecology.

Monitoring of the discharge includes:

- Sampling of the discharge water quarterly
- A programme of subsurface groundwater and surface water sampling on a quarterly basis i.e. subsurface groundwater samples are taken from near the outlet position, and locations North and South of the discharge point (away from area of disturbance). Surface water samples are taken from

the same locations however this is subject to seasonality.

- A photo monitoring point has been established and photos taken at quarterly intervals to visually record the extent of 'ponding'.
- The boundaries of the discharge "plume" are mapped to monitor any area changes over time.

Tailings Disposal

Tailings from the processing plant is pumped to a paddock style Tailings Storage Facility (TSF) located to the north of the plant. The TSF covers a total surface area of 50 hectares with the embankment walls at a current height of approx 5 metres. The surface area selected was based on limiting the rate of rise of tailings in the TSF to 1.5 m/year, to optimise consolidation of tailings by evaporative drying. Outside batter slopes of 2:1, inside slopes of 2:1 and a crest width of 8 m were constructed. Material suitable for embankment construction was used from the Cleo pit.

Peripheral discharge of tailings is undertaken using multiple discharge spigots, to allow beach formation (for solar drying) and capture of decant via a tower located in the middle of the TSF. Beach angles of about 1% occur for saprolite material, and may increase to 2% when fresh rock is being processed.

A new TSF is required to accommodate the increased tailings production following a significant resource increase since the commencement of the mine. It is proposed to build a central thickened discharge (CTD) disposal system at a new location. The new CTD TSF will eventually cover an area of approximately 300 ha.

Tailings Behaviour

The hypersaline pit dewatering water is used in the processing circuit. Consequently the discharged tailings is also saline. A pond area of less than 5 hectares was predicted under average climatic conditions and it was hoped that it could have been kept to the practicable minimum to maximise water re-use efficiency and consolidation of tailings by solar drying. Decant is returned to process via pumping using a submersible pump in the decant tower. The hypersaline water used in the process has resulted in some difficulties being evident for return of the decant water to the process circuit. Additional pipeline capacity was required to be installed to increase the rate of return water to reduce the significant ponding of water on the surface of the TSF.

Recent research conducted as part of a MERIWA (Minerals and Energy Research Institute of Western Australia) project has indicated that even moderate levels of salinity of the tailings water causes a severe reduction in the surface evaporation rate. The research carried out has shown that evaporation can have a very significant effect on the consolidation behavior of mine tailings. Potential evaporation rates in the region are greater than 3m/yr, however, for saline tailings the actual rate, even from saturated tailings could be anywhere between about 40% and 5% of this rate (Newson and Fahey, 1998).

Seepage

To control seepage of tailings water through to the groundwater, a clay blanket has been installed over the base of the TSF, 0.5 m-thick (two 0.25 m lifts) over the 5-hectare decant pond area and 0.25 m-thick over the remainder of the TSF floor. The material identified as suitable for clay blanket construction was extracted from the Cleo pit.

Additionally, a seepage underdrainage system was installed under the decant pond area with 80 mm-diameter slotted pipes at 10-metre centres. Pipes were covered with graded filter sand to minimise risks of blinding by fines. Seepage drains to a small membrane-lined decant pond were located outside the middle of the south wall of the TSF. Drainage water is pumped over the wall (returned) to the TSF decant pond. A sophisticated system of level sensors and alarms has been installed to ensure that inflow to the underdrainage decant pond does not overtop the pond wall. The automatic control valves can be manually over-ridden if visual inspection indicates a fault is present.

Ten monitoring bores have been located around the TSF. The bores are monitored monthly and samples analysed as required by the Department of Environmental Protection (DEP) licence. The results are submitted to the DEP.

Stability analyses by Williams & Associates (1995), covering both static and earthquake-loaded scenarios, show that adequate factors of safety have been provided by the design and materials utilised in the TSF.

Waste Dump

The waste dump is currently designed to have a 250 hectare footprint and will be 30 metres high. There is a backward sloping berm at every 10 metres vertical height and the slopes are battered down to 15° slopes. Waste rock drains to control erosion are installed at intervals along the waste dump and are designed to manage a 100 year, 72 hour rainfall event. Typically the dump is topsoiled with 20-30 cm of gypsiferous topsoil material, contour ripped and seeded with predominantly *Atriplex* (saltbush) and *Maireana* (bluebush) (*Chenopodiaceae*) species. Other local species are also included in the mix. No trees are seeded due to the high salinity of the waste material.

Management of Potential ARD Materials

Campbell & Associates (1995, 1998) have carried out geochemical characterisation of mine waste. Twenty-one samples obtained from drill cores were taken from the lake-sediment, saprolite, transition and fresh-rock zones and were tested in 1995 for pH and electrical conductivity, total sulphur and sulphate-sulphur, acid-neutralisation capacity (ANC), net acid-producing potential (NAPP) and net acid-generation (NAG). The methods used in this work were those that are now standard practice in the industry. In particular, the NAG test is a direct measure of the potential to produce acid via sulphide oxidation, as it measures the reactivity of the sulphides present and the availability of the ANC. Further testwork is being carried out on material from the Cleo SW deposit.

In terms of potential for acid production on exposure to oxygen, all lake sediment and saprolite samples were shown to be barren – i.e., with negligible capacity to either produce or consume acid.

Most of the transition and fresh-rock samples were non-acid forming, reflecting low-to-moderate sulphur contents and abundant carbonates. Less than 10% of the total waste volume – some sulphur-rich transition and fresh-rock zone material – was shown to be potentially acid-forming, reflecting comparatively high sulphur contents and relatively low carbonate levels.

In late 1999 or early 2000, when the first fresh rock/sulphidic transition zone wastes become available, it is proposed to encapsulate these potentially acid-forming materials into the body of the waste stockpile, to further minimise the small risk of acid-generation from the oxidation of sulphides. The material will be covered with lake sediment/saprolitic waste shown in the test-work to have no potential to produce acid on exposure to oxygen and have the additional benefit of being a material with high clay percentages.

Salinity

Recognising the importance of soil salinity to rehabilitation planning, a survey of salinity was conducted in samples from 10 drill-holes selected to represent the range of lithologies encountered across the Cleo deposit (John Consulting Services 1995). Samples were taken over five-metre intervals and pH and conductivity determined on a 1:5 water extract. The results of this study identified salinity as a significant constraint to plant growth. pH in excess of 8 is common (and as high as 9), and salinity, which shows no consistent pattern with depth, averages 34,000 mg/kg TDS (3.4% by weight). This study did not record salinity as electrical conductivity (EC) and it is thus difficult to know how accurate are the results of the analyses.

To obtain more meaningful indications of the effect of salinity on revegetation, a soil chemistry specialist was contracted to commence more detailed studies on salinity and the effect that gypsum applications may have on the soil parameters and thus revegetation (Soil Management Consultants 1998).

Samples were taken from a topsoil stockpile and from the reconstructed soil profiles of four rehabilitation trial sites. The rehabilitation trial sites had either gypsum dunal material or red loam (desert) soil respread as "growth medium" (or topsoil). All samples were analysed for pH and $EC_{1:5}$. Selected samples were examined in more detail to determine the EC and ion composition of both 1:5 soil:water extracts and saturation extracts.

Most of the samples contained gypsum, varying between 1% in red loam topsoil stockpiles to 76% for gypsum dunal material. It was found that the $EC_{1:5}$ was greater than 220 mS/m for most samples as this is the EC of saturated gypsum. Values of $EC_{1:5}$ above this level are due almost solely to an increase in the concentration of sodium chloride. The clay subsoil (the overburden material) was found to have EC_{se} ranging from 6400 mS/m to 13000 mS/m.

Samples from the topsoil stockpile had variable levels of gypsum and this was reflected in the EC1:5 values which ranged from 7 to 452 mS/m. The concentration of sodium chloride is generally low (0.02-0.64%) compared with the overburden material. It was recognised that gypsum applications to the red loam topsoil would be useful to maintain a beneficial supply of soluble calcium, which is useful to lower Exchangeable Sodium Percentage (ESP) and to maintain the maximum possible permeability.

It appears that leaching of salts from the topsoil and gypsiferous materials has occurred and has resulted in a soil horizon suitable for vegetation establishment, with little associated leaching of salts from the overburden material. In addition, the capillary rise of salts from the overburden during periods of dry weather may adversely affect the red loam topsoil and gypsum dunal materials. This could adversely affect long term vegetation establishment and growth / cover on the overburden dumps.

Revegetation

The policy of the WA Department of Minerals & Energy (DME) is for mining operators to revegetate disturbed areas at their mining operations. Since 1997, SDGM has been undertaking rehabilitation trials to identify those species with the potential to revegetate the saline overburden dumps. The trials are ongoing and have included work by a PhD student.

Seeds of locally available species have been collected and seeds of native species from the region known to successfully revegetate saline areas have been sown on the dumps each year from 1997 to 1999. Successful establishment of *Atriplex* (saltbush) and *Maireana* (bluebush) species has occurred along with other local species including *Frankenia* and *Halosarcia*. Most of the saltbush and bluebush species are palatable to the sheep and native animals that will graze on the rehabilitated land.

As new local species that have the potential to assist the establishment and longevity of vegetation on the dumps are identified, they will be trialed on the dumps.

Research

SDGM currently is undertaking research projects in conjunction with academic institutions investigating the potential for revegetation of the overburden dumps by species of the genus *Halosarcia*. This genus is common around the edges of salinas and on salt affected ground where waterlogging does not occur regularly.

Research projects have been initiated with an adjacent minesite to examine the fauna of the salt lake and the potential effects of discharge of mine groundwater on the lake.

Ongoing research projects include the rehabilitation trials for the overburden dumps, factors affecting completion criteria, and the soil factors affecting vegetation establishment.

Options For Rehabilitation

As stated above, the statutory authorities require rehabilitation of minesites by revegetation of disturbed areas. It is possible that a sustainable vegetative cover is not possible on the hyper-saline overburden dumps, even with a substantial cover of gypsiferous dunal material or red loam topsoil.

An option is to cover the outer batters (slopes) of the waste rock (overburden) dumps with competent waste rock. SDGM has a plentiful supply of competent non-acid generating rock that would form a stable, safe and non-erosive cover over the saline overburden. However, the site must "prove" that a sustainable vegetative cover is not possible before the DME would concur with the use of "rock armouring" of the dump surface. Rehabilitation during 1998 with the assistance of very good winter rainfall has been very successful, therefore it may not be necessary to pursue any alternatives.

Environmental Management

Environmental Management Systems and Procedures

Acacia Resources operates under an Environmental Policy, and a corporate Environmental Management System. The company is a signatory to the Australian Minerals Industry Code for Environmental Management. The minesite is developing a site-based Environmental Management System and has documented Environmental Procedures. An Environmental Management Committee meets bi-monthly to discuss environmental management issues.

Waste Minimisation

Waste minimisation and recycling of waste products has been identified as a management requirement at WA minesites. At the present time, the majority of minesites recycle waste hydrocarbons, 200 L drums and cyanide boxes.

An initiative by an industry employee has resulted in separation and recycling of materials with the proceeds of the sales going to a State operated Children's Hospital. Waste materials such as iron, steel and other metals, aluminium, glass, and lead/acid batteries are collected free of charge by a registered recycler and the recycler's costs are deducted from the income from the material's sale. The proceeds are forwarded to the Children's Hospital.

Many minesites have purchased a commercial high temperature fan-forced burner called an "Enviroburner". The electric fan on a cover fits snugly over a 200 L (44 Imp gal) drum. Waste mill grease, oily rags, mobile and stationary vehicle oil filters, domestic kitchen waste and office wastes can be incinerated in this high temperature incinerator with no particulates (smoke) being generated. The downside is plastic materials that may generate toxic fumes cannot be burnt in the incinerator.

Monitoring

Monitoring at the site includes:

- Monitoring of the saline pit dewater discharge point into Lake Carey
- Monitoring of the observation bores around the pit to determine the height of the water table and therefore the rate of drawdown.
- Monitoring of the TSF groundwater monitoring bores is conducted monthly. The static groundwater levels are recorded and samples collected for chemical analysis.
- Monitoring of the groundwater drawdown levels at the potable and process water borefields is undertaken three times per week. Water quality samples are collected and analysed each quarter. A triennial, and comprehensive, hydrogeological report is required to be submitted to the Water & Rivers Commission, with the first report due in April 2000. Yearly progress reports are submitted.
- Climatic data are collected at the administration office by an automatic recording station and downloaded onto the Acacia network.
- A register of fauna deaths is kept. Road kills are the most common cause of fauna death.

Conclusion

Mining of the gold resource in this harsh saline and arid environment poses many challenges that may take a number of years to identify suitable long term and sustainable solutions.

Acacia Resources, through the EMS has identified the risks to protection of the environment and appropriate research and trials have been commenced as well as management procedures developed.

Local and regional co-operation within and between the mining community and statutory authorities ensures that technology is exchanged for the long term future of mining in the region.

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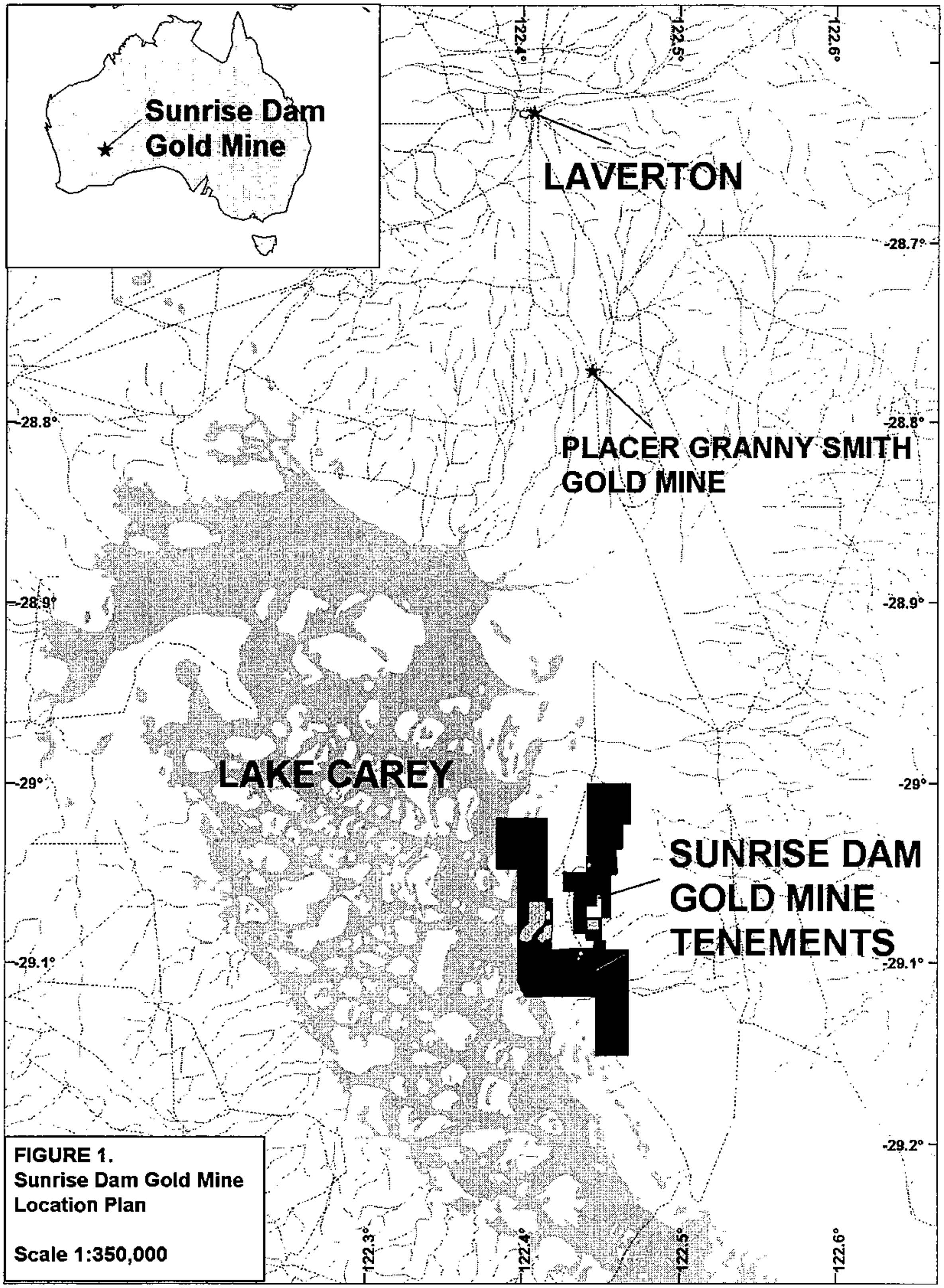

FIGURE 1.
Sunrise Dam Gold Mine
Location Plan

Scale 1:350,000