# APPENDIX A Chemical methods for predicting the acid mine drainage/acid rock drainage potential of mine wastes in Australia

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## Introduction

Prediction techniques for acid mine drainage/acid rock drainage (AMD/ARD) provide the foundation for developing control and management plans for mine wastes by assisting in the prevention or mitigation of the environmental impact arising from the oxidation of sulphidic mine wastes. The objectives of predictive tests are to (a) determine if a discrete volume of mining waste will generate acid and (b) to predict the drainage quality based on the measured rate of acid formation. Prediction methods can apply to both individual material types or the entire waste dump, although the latter is an extremely complex task.

A complete predictive assessment requires understanding of a number of factors including the nature of the deposit, the mineralogy, the mining and processing operations in addition to local environment and climatic factors. The components affecting the total capacity of a mining waste to generate acid are characterised by the amount of acid generating minerals present (generally sulphides), and the amount of neutralising minerals present. The rate of acid generation is influenced by the type of sulphide mineral, the type of carbonate and other neutralising minerals, the mineral surface area available for reaction, the availability of water and oxygen and the presence of bacteria.

Chemical prediction tests in AMD/ARD fall into two categories, namely static tests and kinetic tests. These have been the subject of a number of comprehensive reviews overseas (BC Task Force 1989, Coastech 1989, USEPA 1994).

### Static tests

A static test determines both the total acid generating and total acid neutralising potential of a sample and is used to predict the potential to produce acid. The standard convention adopted in Australia and the Asia Pacific region is to express the potential for a sample to generate or consume acid in terms of kg $H_2SO_4$ equivalence per tonne of waste. This differs from the convention adopted in the United States and Canada where the potential for a sample to generate or consume acid is in terms of kg $CaCO_3$ equivalence per tonne of waste. The capacity of the sample to generate acidic drainage is calculated as either the difference between, or ratio of, values of acid and neutralisation potentials. Classification schemes are then used to classify the materials as acid generating, non-acid generating or potentially acid generating.

Static tests are conducted quickly and are relatively inexpensive to undertake relative to total mining costs. There are a number of variations of static tests available to predict the acid generation potential of mine wastes as summarised in table A1. Acid-base accounting tests (ABA), modified acid-base accounting tests, BC Research Initial test and the alkaline production test evaluate a maximum potential acidity (MPA) or acid potential (AP), in addition to a neutralisation potential (NP) or acid neutralising capacity (ANC). Variations in the estimation of the acid neutralising capacity via these different methods have resulted in a difference of opinion as to the 'most appropriate' or 'correct' methods, and are often the subject of debate in the AMD/ARD arena (Lapakko 1994, Calow et al 1995).

The hydrogen peroxide test, net acid production test and net acid generation test involve reacting the sample with a strong oxidant, namely hydrogen peroxide, evaluating the net acid production without measuring the acid generation and neutralising potentials separately.

**Table A1** Summary of static testwork in AMD/ARD prediction

| Static test | Method | Reference |
|---|---|---|
| Acid base accounting | The acid potential is based on total S or sulphide S. The neutralisation potential is determined by reacting a finely ground sample with excess HCl as indicated by the Fizz test. The mixture is heated, cooled and titrated to pH 7.0. | Sobek et al 1978 |
| Modified acid base accounting | The acid potential is based on sulphide S. The neutralisation potential is estimated by reacting a finely ground sample with excess HCl as indicated by the Fizz test. The sample is agitated at room temperature for 23 h, followed by titration to pH 8.3. | Coastech 1989 |
| BC Research Initial | The acid potential is based on total S. The neutralisation potential is determined by titration of the finely ground sample as a slurry to pH 3.5 with 1 normal $H_2SO_4$. | Duncan & Bruynesteyn 1979 |
| Alkaline production: sulphur | The neutralisation potential is determined by reacting 20 mL 0.1 molar HCl with 0.4 g solid for 2 h at room temperature followed by titration to pH 4.0. | Caruccio et al 1981 |
| Hydrogen peroxide test | The amount of pyrite in the sample is determined by comparing rates of oxidation with peroxide and comparing temperature profiles against pyrite standards. | Finkelman & Giffin 1986 |
| Modified hydrogen peroxide test | Alkaline components are removed with 6 molar HCl prior to oxidation reaction with hydrogen peroxide. | O'Shay et al 1990 |
| Net acid production | Reaction with hydrogen peroxide followed by titration to pH 7.0. | Coastech 1989 |
| Net acid generation | 250 mL 15% peroxide to 2.5 g sample. React at room temperature for several hours. Titrate to pH 7.0 if final NAG pH is less than 4.0. Temperature profiles may also be measured. | Miller et al 1991 |

### Kinetic tests

Static prediction techniques are useful screening tools for broadly classifying mine wastes. However, they give no information on time-related reaction kinetics nor predict the short and long-term drainage water quality in the field. Such information is obtained by kinetic tests. The tests may be performed in the laboratory and are of a longer duration than static tests and are considerably more expensive to undertake. However, such tests provide information on the rate of sulphide oxidation, rate of acid generation, rate of neutralisation and the nature of pollutants that may be leached out from the materials under certain conditions. Kinetic tests may also be used to test control measures for the wastes (such as layering and blending) and are also used to simulate processes occurring at mining sites.

There are a number of kinetic acid mine drainage prediction techniques that have been utilised over the last two decades. These include humidity cells, humidity columns, the BC Research Confirmation test, batch reactor tests, soxhlet reactor tests, column tests and field tests. Table A2 briefly outlines the nature of these tests. The most commonly used kinetic tests are humidity cells and column tests. Data from both static and kinetic tests used in characterising mine waste samples from various mine sites around the world is currently being collected and collated for an international kinetic database (Ferguson & Morin 1991; Morin 1996).

**Table A2** Summary of kinetic tests in AMD/ARD prediction

| Kinetic test | Method | Reference |
|---|---|---|
| Humidity cells | 200 g of crushed rock (-2 mm particle size) exposed to 3 days dry air, 3 days humidified air and rinsed with 200 mL of distilled water on the seventh day. Leachate analysed for a number of parameters. Test run for 20 or more weeks. | Sobek et al 1978 |
| Humidity columns | 50 to 60 kg of coarse rock material. Water flushing rate equivalent to specific site rainfall. Weekly volume added over 5 days as slow continuous trickle with 50% added on last day. Continuous air flushing through cell. Leachate analysed for a number of parameters. Tests run for minimum of 20 weeks. | Brodie et al 1991 |
| BC Research Confirmation | 5–30 g (-400 mesh particle size) added to bacterially active solution at pH 2.3 to 2.5 and temperature of 35°C. | Duncan & Bruynesteyn 1979 |
| Column tests | Columns containing mine wastes are leached with discrete volumes of water for minimum of 20 weeks. Leachates analysed for a number of parameters.<br>Many variations to basic column leach test include wet/dry cycles, flushing rates, water application rates, recirculation or single pass, innoculation with bacteria, etc. | Bruynesteyn & Hackl 1982;<br>Hood & Oertel 1984;<br>Ferguson & Morin 1991;<br>Miller et al 1995 |
| Batch reactor tests/shake flask tests | 200 g of sample (-200 mesh particle size) is agitated in 500 mL of distilled water as a slurry. | Halbert et al 1983. |
| Soxhlet extraction test | Sample is leached with hot distilled water using soxhlet apparatus for several days to several weeks. The leachates are monitored for a number of parameters. | Sullivan & Sobek 1982 |
| Modified NAG tests | Samples reacted with peroxide. Temperature and pH profiles monitored. | Miller & Jeffrey 1995 |
| Field tests | Test piles constructed on liners using field scale particles. Flow and water quality data collected. | Edgar & Lapakko 1985 |

## Sampling

Sampling is one of the most critical aspects of any prediction program. As the purpose of testing rock material is to allow classification and planning of waste disposal, samples must be selected to characterise both the type and volume of rock materials and also account for the variability of materials that will be exposed during mining. The representativeness of the sample is also a critical part of the assessment program and the number of samples should cover the boundaries of variability within geological units. In addition, the method of sample collection, the length of time of storage and the sample storage environment are important factors for consideration prior to testwork. This subject has been considered in detail in a study undertaken for the Mine Environment Neutral Drainage (MEND) Program in Canada in 1992 (SENES 1992).

The USEPA has also summarised a number of options concerning the number of samples to be collected in a fixed frequency sampling program. The procedural steps recommended in predicting the acid generating potential of mine wastes have been summarised in a recent review as follows (USEPA 1994):

1. Define the geological (or lithological) units that will be encountered during mining. Describe the geology and mineralogy of these units in detail.
2. Develop a sampling plan based on an understanding of geology (eg rock mass, etc). Collect samples to represent a range of compositional variation within a rock unit.
3. Select static or kinetic tests and evaluate potential for acid formation.

4. Evaluate sampling criteria and conduct additional kinetic tests as required.
5. Develop a model as appropriate.
6. Based on findings, classify geological (lithological) units as acid generating, non-acid generating or uncertain.

The responses pertaining to waste characterisation from the OSS/ACMRR questionnaire suggest that the Australian mining industry needs to adopt similar procedural steps to ensure standardisation and uniformity in AMD/ARD prediction.

## Review of chemical prediction methods currently used in Australia

This section reviews both static and kinetic methods and classification schemes generally used in Australia for assessing the AMD/ARD potential of mine wastes. The methods reviewed are specifically acid base accounting (ABA), the net acid generation (NAG) test, the kinetic NAG tests, the geochemical abundance index (GAI) and leach column testwork. Limitations that may be associated with each method are highlighted where appropriate. The criteria for classifying mine wastes as used within the Australian mining industry will also be discussed. On-site water quality monitoring, predictive modelling and field determination of the intrinsic oxidation rate (IOR) will only be briefly described in the present review.

### Acid-base accounting methodology

Acid-base accounting methodology includes measurement of pH and salinity of a paste of the waste material, a measurement of the acid potential (AP) and the acid neutralising capacity (ANC).

#### *pH and salinity of the saturated paste*

The pH measurements of the saturated paste provide an indication of the inherent acidity (or alkalinity) of the material. The pH measurement does not predict the acid-forming potential of the material but reflects the *in-situ* pH of the sample, indicating the immediate reactivity of sulphides and acid neutralising minerals within the sample. The pH of the saturated pastes have generally been determined at sample/water ratios of 1:1, 1:2, 1:2.5 and/or 1:5, the higher dilutions generally used to minimise glass electrode deterioration and to provide supernatant for electrical conductivity measurements. Electrical conductivity (EC) measurements of the saturated paste provide an indication of the salinity of the material. The EC provides an indirect measure of the amount of water soluble salts in the sample. The EC of a 1:5 sample/water extract is generally determined according to an APHA method (Rayment & Higginson 1992).

#### *Acid potential, AP or maximum potential acidity (MPA)*

The acid potential (AP), also termed the maximum potential acidity (MPA), is a function of the total %S in the material and is calculated based on the reaction stoichiometry for pyrite oxidation. This assumes that all sulphur is present as reactive pyrite, and further, that the reaction proceeds to completion. Based on the following stoichiometry for pyrite oxidation,

$$FeS_2 + \tfrac{15}{4}O_2 + \tfrac{7}{2}H_2O \Rightarrow Fe(OH)_3 + 2H_2SO_4,$$

the maximum acidity produced by a sample containing 1% S as pyrite is 30.6 kg $H_2SO_4$/t.

The use of the pyritic sulphur content of a material gives a better estimate of the acid potential, but also increases analytical costs. Often, the sulphidic sulphur content is determined as the difference between the total sulphur content and the sulphate sulphur content, and this is used for the theoretical estimate of the acid potential. However, to accurately estimate the acid potential of the material, it is important to indicate the type of sulphur used in the calculation, and to understand the behaviour of the forms of sulphur in the mine waste.

Methods that assume that sulphur present as sulphate is not acid producing may lead to an underestimate of the acid potential if jarosites and/or other acid producing sulphates are present. In addition, other acid generating sulphides have different stoichiometries from pyrite and need to be accounted for in the theoretical calculation of the acid potential. Nevertheless, there may be non-acid generating sulphates and/or organic sulphur as well as non-acid producing sulphides present. These latter minerals do not contribute to the acid potential but, if present, may cause gross overestimation of the acid potential if the total sulphur content is used for the theoretical estimation of the maximum acid potential.

### *Acid neutralising capacity (ANC)*

Acid formed from pyrite oxidation may react with gangue minerals in the rock and this is quantified in terms of the acid neutralising capacity (ANC). The minerals which contribute most to the overall acid neutralising capacity are usually carbonates such as calcite and dolomite.

The acid neutralising capacity of a waste can be estimated in a number of ways. Generally, it is determined by reacting a sample with a known amount of standardised hydrochloric acid, heating this solution to enhance reaction, and back titrating to determine the amount of acid consumed (Sobek et al 1978). The amount of acid consumed during the test represents the inherent acid neutralising capacity of the sample and is expressed in units of kg $H_2SO_4$ per tonne of material. A number of limitations are associated with this experimental method. Firstly, hydrochloric acid is not the acid generated in the field, and, additionally, the use of strong acid concentrations may dissolve minerals that may not necessarily dissolve under field conditions. Secondly, neutralisation does not take place at, or close to, boiling and the use of boiling acid for those tests may cause overestimation of the ANC by reacting with iron and manganese carbonates.

The modified acid base accounting method replaces the heating process with agitation of the sample with acid for 24 h at room temperature (Coastech 1989). In this case, the ANC may be underestimated as some acid consuming minerals react very slowly in cold hydrochloric acid. Nevertheless, both methods are widely used in the mining industry in Australia due to the low cost of the test and the short time required to complete the test, allowing for analysis of many samples in a short time frame.

Associated with the acid base accounting method is the Fizz test which is a simple test in which the carbonate content of a sample is estimated by observing the intensity of the reaction between a small quantity of the sample and strong hydrochloric acid (Sobek et al 1978). The presence of calcium carbonate is indicated by bubbling or an audible 'fizz'. This fizz is rated on a scale of 0 to 3 from no reaction to a strong reaction and is used to determine the volume and normality of HCl required in ABA testwork. Naturally, there is some degree of subjectivity in determining the fizz rating.

Another method for determining the ANC involves the slow titration of the material with either standardised hydrochloric or sulphuric acid usually to a pH of 3.5. While this titration method may allow for pH values closer to those observed in the field, as opposed to the low pH used in the back titration of the ABA method, there is the possibility of complexation and common ion effects, which may impact on the ANC determination. In addition, some acid consuming minerals react slowly with weak sulphuric acid. The method also requires the use of sophisticated equipment such as automatic titrators, and is time consuming relative to the back titration method, requiring times of at least 24 hours for completion rather than the several hours required for the back titration method. It is not known whether this former method is widely utilised in Australia, but it has been used overseas (Calow et al 1995).

A simple and relatively cheap method of estimating the ANC is based on the total carbon content of the mine waste sample. This method has found usage in some mines in Australia and requires calibration and validation for each specific site. The method would probably not be suitable for coal mines which contain a high abundance of organic carbon.

It is important to ensure a satisfactory determination of the neutralisation potential since its value will impact on the classification of mine wastes as acid generating or non-acid generating. Erroneous classification of an acid generating waste as non-acid generating may result in unanticipated environmental liability.

*Net acid producing potential (NAPP)*

The net acid producing potential (NAPP) is the theoretical balance between the sample's capacity to generate acid (via the oxidation of sulphides) and its capacity to neutralise any acid liberated (ie ANC). The classification of mine wastes as acid generating or non-acid generating is based on NAPP values and will be discussed in detail below.

### The net acid generation (NAG) test

The NAG test provides a measure of the net amount of acid remaining in a sample after all the acid generating and acid neutralising reactions have taken place. In effect, it provides a direct assessment of the potential for a material to produce acid after a period of exposure and weathering. The method uses hydrogen peroxide to oxidise the sulphides contained in the waste. All, or part, of the acid generated by this oxidation is then consumed by the base materials that may be present. A NAG final pH less than 4 would confirm that the material has the potential to generate acid after a period of exposure to oxidising conditions in the field. The net amount of acid remaining after the NAG reaction is determined by titration to pH 7.0. In this case, the NAG is expressed as kg $H_2SO_4$ produced per tonne of material.

The NAG test has been developed as an appropriate field test by Environmental Geochemistry International Pty Ltd (EGI) with funding by members of the Australian Mineral Industries Research Association Pty Ltd (AMIRA) (Miller & Jeffery 1995). AMIRA commissioned EGI to carry out a detailed investigation of the NAG test in 1994 to investigate its potential as a reliable tool for field use within the Australian mining industry. The results of the study generally confirmed the suitability of the NAG test as a reliable tool for predicting the acid generating potential of mine wastes, and for reducing the uncertainties associated with the NAPP prediction procedure from acid-base accounting. However, the study showed that it is important to carry out both NAPP and NAG tests on a sufficiently large number of samples to calibrate the NAG test for routine use at any one particular site. This is particularly important for coal deposits where the organic materials present may preferentially react with the peroxide and for sites where the presence of copper oxide and/or manganese dioxide could catalyse peroxide decomposition.

### The kinetic net acid generation (kinetic NAG) test

Kinetic NAG tests involve the continual monitoring of pH and temperature trends after peroxide addition. These tests may vary widely between material types as a function of the inherent oxidation, acid generation and acid neutralisation characteristics of the material. An objective of the above AMIRA research program was to determine if the kinetics of the NAG test reaction could be related to real-time kinetics of sulphide oxidation and acid generation.

A relationship has been observed between NAG reaction kinetics and the lag period in leach columns before the columns go acid. Work is continuing in this area so that the relationship between the kinetic NAG test, column leach test results and field behaviour is further developed (Miller 1996).

### Criteria for classifying mine wastes

Two criteria commonly used internationally for categorising mine waste samples are the net acid producing potential (NAPP) and the acid potential ratio (APR). The NAPP has the greatest usage in Australia whilst the APR is slowly being adopted by some mines. It is recommended that both criteria are used in conjunction to more accurately classify mine wastes. The NAPP and APR are derived from acid base accounting data.

#### *Net acid producing potential (NAPP)*

The NAPP is calculated from the following equation:

$$\text{NAPP (kg } H_2SO_4\text{/tonne)} = 30.6 \text{ S (\%)} - \text{ANC (kg } H_2SO_4\text{/tonne)}$$

The calculation assumes that all sulphur is present as 'oxidisable' sulphide, and that all ANC is available for reaction with acid generated by sulphide oxidation. Theoretically, a sample with NAPP $> 0$ is classified as potentially acid generating and a sample with NAPP $\leq 0$ is classified as non-acid generating. However, this simple classification does not take into account the capacity, or risk, that a sample may generate acid, nor does it provide any indication of the exposure time necessary before the onset of acid conditions. Nevertheless, for NAPP values greater than 20 kg $H_2SO_4$/tonne and less than –20 kg $H_2SO_4$/tonne, the NAPP classification has general reliability (Hutchison & Ellison 1992). For samples in the range –20 to +20 kg $H_2SO_4$/tonne, there is some degree of uncertainty due to issues such as sulphide reactivity, and the nature and availability of ANC and kinetic processes.

#### *Acid potential ratio*

The acid potential ratio is the ratio of neutralising potential (ANC) to acid potential (AP) of the sample. A sample with ANC/AP less than unity is classified as potentially acid generating whilst a sample with ANC/AP greater than 3 is non-acid generating. A zone of uncertainty remains for values between unity and 3 (Hutchison & Ellison 1992).

#### *The NAG test criteria*

The NAG test was initially introduced as a confirmatory test for classifying mine wastes into the various categories, thereby reducing the uncertainties associated with the NAPP procedure. Where discrepancies are noted between NAPP and NAG tests, further investigations are warranted on the material. Miller (1996) has defined four main categories based principally on the NAPP and static NAG test results for classification of mining wastes. These categories are specifically: acid consuming materials (ACM), non-acid generating (NAF), potentially acid generating-low capacity (PAF-LC) and potentially acid generating-high capacity (PAF-HC). The criteria for these categories are summarised in table A3.

### The geochemical abundance index (GAI)

The geochemical abundance index (GAI) has been used by some sites in Australia to assess the extent of elemental enrichment in mine waste samples. The GAI quantifies an assay result for a particular element in terms of the average crustal abundance for that element (Miller 1995). The index, based on a log 2 scale, is expressed in 7 integer increments (0 to 6). As a general rule, a GAI greater than 3 indicates enrichment to a level that warrants further investigations. Any elevated element level can be compared with published soil/waste criteria

(ANZECC 1992). Values above the published criteria indicate a need to assess the degree of mobility, reactive state and sensitivity to the potential receiving environment.

The overall purpose of the GAI is to identify metals that occur at concentrations which are well above normal background levels. Naturally, in a mineralised deposit, this is likely to be the case and it should be pointed out that the GAI itself does not assess the mobility or reactivity of metals. This can only be determined by further tests such as column leach tests.

**Table A3** Classification of mine wastes according to Miller (Miller 1996)

| Category | Criteria |
|---|---|
| Acid consuming material (ACM) | ANC/MPA > 3; ANC in the order of 50 kg $H_2SO_4$/t and sulphide S content less than 0.5% S. |
| Non-acid generating (NAF) | NAG pH greater than 4; negative NAPP values |
| Potentially acid generating – low capacity (PAF-LC) | NAG pH less than 4; NAG values less than about 5 to 10 kg $H_2SO_4$/t after titration to pH 7; positive NAPP values |
| Potentially acid generating – high capacity (PAF-HC) | NAG pH less than 4; NAG values greater than 10 kg $H_2SO_4$/t after titration to pH 7; positive NAPP values. |

### Leach column testwork

Geochemical kinetic tests, particularly column tests, are used to determine relative rates of acid generation, neutralisation and metal depletion; to compare leaching behaviour of different mine rock classes and types; predict drainage water quality; select or confirm mine rock management and control options; represent site conditions to determine factors controlling AMD; and/or to produce raw data for modelling of environmental impact.

In column testwork, water is added to a sample, the mixture is allowed to incubate for a certain period of time, and samples of leachates are collected and analysed. A number of water application methods are possible including flooding, trickling, continuous application or intermittent application. The leachates are collected periodically and analysed for water quality parameters such as pH; conductivity; acidity or alkalinity; sulphate concentration; calcium and magnesium concentration and dissolved metals. The pH of the collected leachate helps to identify the stage of the acid drainage process. The sulphate production is related to the rate of acid generation and can be used to estimate the intrinsic oxidation rate (IOR) of the material provided sulphate is conserved. The IOR will be discussed in detail below. The calcium and magnesium concentrations can be related to the rate of neutralisation. Additionally, the acidity or alkalinity gives an indication of the extent of acid production or acid neutralisation.

Once the rate of sulphide oxidation is deduced, an estimate can be made of the rate of sulphide depletion and the time to oxidise all the sulphide present in the column, based on the sulphide content of the material. Similarly, an estimate can be made of the rate of depletion of neutralisation potential and the time to consume carbonates present in the waste. These estimates are based on simplistic assumptions that the dominant processes occurring are oxidation by pyrite and neutralisation by calcite.

Column tests can take a long time to provide meaningful results and it is important to ensure they are operated under expected field conditions of wetting and drying. Additionally, the interpretation of test results is site specific and requires careful consideration of climatic factors. There is no standard protocol for column testwork within the Australian mining industry (nor internationally) and only two examples are given below to highlight some of the variations in the methodology.

At the Australian Nuclear Science and Technology Organisation (ANSTO), a typical leaching apparatus comprises a 30 cm diameter PVC column and contains up to 20 kg of mine waste material. The material to be leached is contained in this vessel with no specific compaction technique. Waste rocks are crushed to a nominal size of less than 2 cm, using a rule of thumb that the largest particle in the column should be less than 10% of the column diameter to minimise edge effects, whilst tailings are leached as received. Deionised water is slowly and uniformly dispersed over the entire surface area to ensure complete wetting of the sample. The geometry of the leaching apparatus and the volume of deionised water delivered is selected to closely simulate the average annual rainfall at the mine site as well as to provide sufficient volume of leachate for analysis. The columns are irrigated weekly as a single rainfall event and a heat lamp is situated directly above the column to heat the surface of the columns for eight hours a day, simulating insolation.

The standard column set up used by EGI involves sample sizes of 2.5 kg, crushed to a nominal 4 mm size for waste rock, or used as received for tailings. The sample is placed in the column and initially leached with deionised water at a rate of 400 mL/kg. Leaching with deionised water is carried out at a rate of 100 mL/kg for three weeks and 400 mL/kg for the fourth week. The leachate is collected subsequent to the fourth week's addition and analysed for a number of water quality parameters. The columns are exposed to drying conditions between water additions via the use of heat lamps (Miller & Jeffery 1995).

### On-site water quality monitoring

A number of respondents to the OSS/ACMRR survey indicated that they monitored pH as part of their on-going water quality monitoring. Such measurements provide an indication of the parameters that should be analysed and monitored over time (Miller 1995). Early indicators of sulphide oxidation in mine site drainage are increasing sulphate concentrations, increasing concentrations of major cations and a shift in pH. The chemical composition of AMD/ARD is very much dependent on the mineralogy of the waste material. Metals that should be monitored include Mn, Zn, Cu, Al and Fe. Other metals that should be included depend on their level of enrichment in the sample relative to acceptance criteria for assessing soil toxicity. These elements will be of concern if they are soluble and leach into the environment. Alkalinity is also an important parameter to measure since it will indicate the presence of carbonates.

### Predictive modelling

In a recent Minerals Council of Australia environmental workshop, Woodward-Clyde presented information on preliminary waste block models presently in construction for some recently proposed developed mine sites in Australia (Scott et al 1996). The testwork programs at these sites have been specifically designed to identify the temporal selective handling requirements for AMD prevention during the mining operation. Sampling has involved collection of representative combinations of all waste types identified within the geological database and samples have been subjected to static, kinetic and accelerated predictive tests to build up a database for construction of the preliminary waste block model.

There is also potential for kinetic models to be applied to Australian mine sites to estimate the production of contaminants arising from AMD/ARD. In kinetic modelling, a steady-state geochemical model is constructed to study the water-rock interactions controlling metal release from a waste rock heap. The waste rock heap is treated as a single completely mixed flow-through reactor of unit cross-sectional area and specified height. The geochemical model may include kinetics of sulphide and primary silicate weathering, aqueous speciation equilibrium, formation of secondary mineral phases, and transport. From the joint use of kinetic and geochemical modelling, estimates of the quality of drainage from waste rock piles can be obtained. These tools could be instrumental in providing useful information and predictions that could be adopted in mine planning strategies and rehabilitation measures for waste rock dumps.

ANSTO has used both geochemical and kinetic modelling as a first estimate of the release of hazardous material from two uranium mines in Germany (Brown & Lowson 1997). The potential for release of hazardous materials from these sites was controlled by carbonate and sulphide minerals. The models were based on a steady-state geochemical model developed by Stromberg and Banwart (1994) to study water–rock interactions controlling metal release from waste rock heaps at a copper mine in northern Sweden, and STEADYQL, a mathematical model developed by Furrer et al (1989, 1990) for studying the composition and speciation of soil solutions. For both the copper mine in Sweden and the uranium mines in Germany, field monitoring of drainage water composition has provided a basis for evaluation of model performance.

### The intrinsic oxidation rate (IOR)

The intrinsic oxidation rate (IOR) defines the primary pollutant production rate in a waste rock dump. In column testwork, the IOR can be deduced from the rate of sulphate production as discussed above or directly from the rate of oxygen consumption (Ritchie 1994). In the field, the IOR may be evaluated by analysis of oxygen and temperature profiles, both of which reflect the oxidation rate and gas transport mechanism in the dump. Oxygen and temperature profiles are easily measured with inexpensive instrumentation once an appropriately constructed probe hole has been installed in a waste rock dump. ANSTO has derived simple mathematical models of the IOR to indicate its impact on the time dependence of the overall oxidation in a waste rock dump. Field measurements have been carried out at several mine sites in Australia including Rum Jungle, Norwich Park and Woodlawn (Ritchie 1994) as well as internationally in Sweden, Canada and the United States (Ritchie 1993).

While instrumentation of a waste rock dump can occur at any stage of mine life, implementation at the early stages of mine development is less costly and provides field data at the very early stages of the mine development. As both the parameters of oxygen concentration and temperature are closely related to the pyrite oxidation rate, which is the primary pollutant generation mechanism, they can then be used to provide a direct and rapid indicator of the effectiveness of measures adopted to reduce the oxidation rate in pyritic mine wastes.

## Conclusions and recommendations

This study reports on techniques currently used in Australia for assessing the acid mine drainage potential of sulphidic mine wastes. A number of static methods and kinetic methods for determining the pollutant generating potential of sulphidic mine wastes have been reviewed. Due to the limitations inherent with the static testwork methodology, static methods are only satisfactory for the initial screening of mine waste samples into categories of acid consuming, non-acid generating and potentially acid generating—low capacity or high capacity. Column testwork provides time-series data for the measurement of the acid generating characteristics of the waste material and information on leachate quality under controlled laboratory conditions. Such information is valuable for the identification and evaluation of the geochemical implications of operational placement, long-term storage and management strategies for sulphidic mine wastes.

An assessment of the information received from the OSS/ACMRR survey showed that only 30% of the responding mine sites undertook some form of acid base accounting. Of those, 50% also carried out NAG tests. Less than ten per cent of the responding sites reported having undertaken some form of other test. Most of these sites undertook on-going pH monitoring and/or water quality monitoring or leach column testwork. The latter represents 5% of the responding mine sites. Representative sampling and geological assessment is a critical part of any geochemical assessment program. Of those respondents who specified the number of samples used for ABA tests, almost one-third used less than ten samples for their mine waste characterisation studies. There is no evidence that this number was related to the total amount of waste types generated, but it is unlikely that the number of samples used for the tests were appropriate.

It is apparent from the survey that a protocol is lacking within the Australian mining industry for appropriate sampling of waste samples and the characterisation of mining wastes. It is also evident that existing methodologies for making predictions require identification and validation of the limitations of static and kinetic tests, particularly with respect to site specificity. It is recommended that a protocol is developed such that some standardisation and uniformity is introduced within the Australian mining industry for the characterisation of sulphidic mine wastes. The implementation of predictive models is also encouraged.

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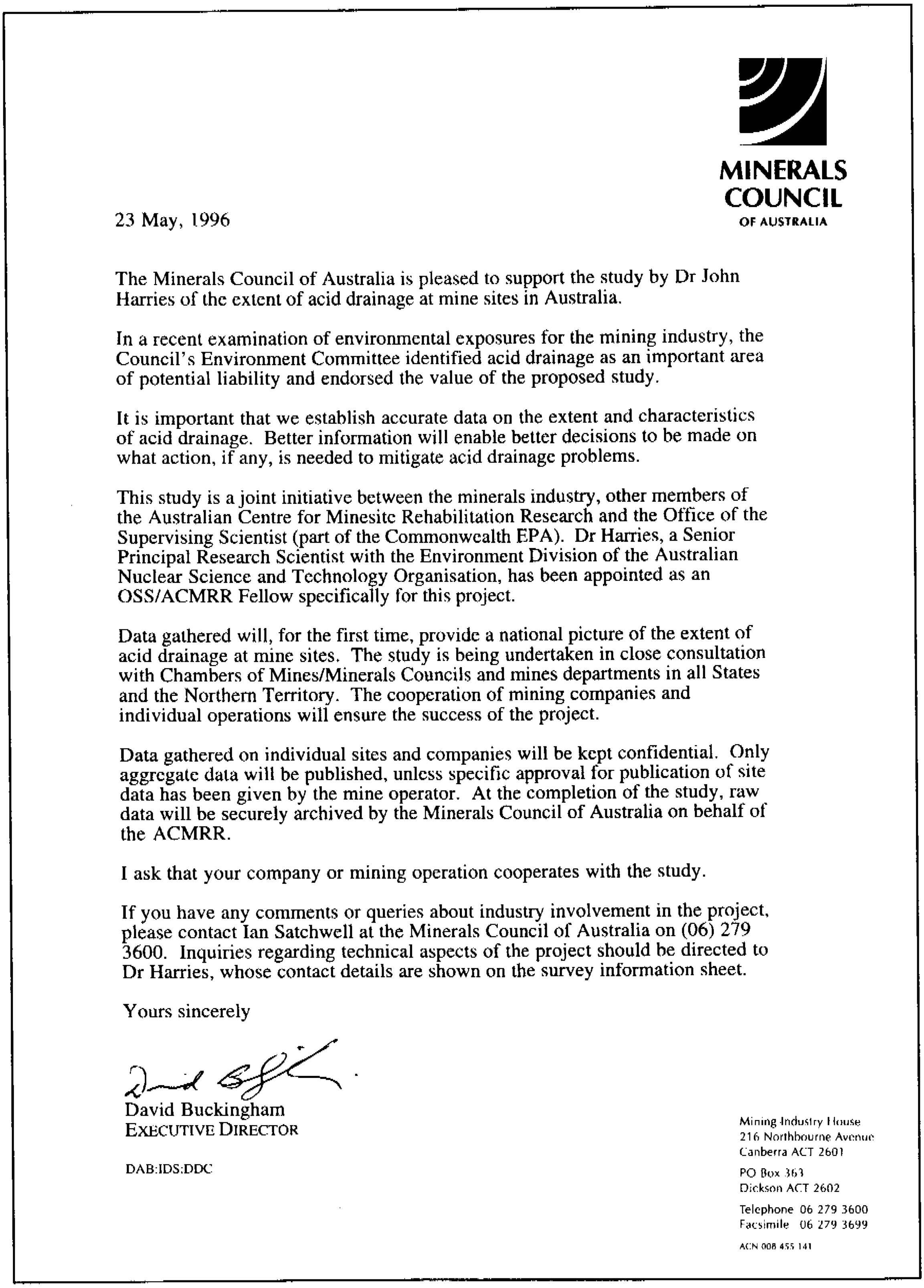
# Appendix B Letter from David Buckingham, Executive Director, Minerals Council of Australia (23 May 1996)



**MINERALS
COUNCIL**
OF AUSTRALIA

23 May, 1996

The Minerals Council of Australia is pleased to support the study by Dr John Harries of the extent of acid drainage at mine sites in Australia.

In a recent examination of environmental exposures for the mining industry, the Council's Environment Committee identified acid drainage as an important area of potential liability and endorsed the value of the proposed study.

It is important that we establish accurate data on the extent and characteristics of acid drainage. Better information will enable better decisions to be made on what action, if any, is needed to mitigate acid drainage problems.

This study is a joint initiative between the minerals industry, other members of the Australian Centre for Minesite Rehabilitation Research and the Office of the Supervising Scientist (part of the Commonwealth EPA). Dr Harries, a Senior Principal Research Scientist with the Environment Division of the Australian Nuclear Science and Technology Organisation, has been appointed as an OSS/ACMRR Fellow specifically for this project.

Data gathered will, for the first time, provide a national picture of the extent of acid drainage at mine sites. The study is being undertaken in close consultation with Chambers of Mines/Minerals Councils and mines departments in all States and the Northern Territory. The cooperation of mining companies and individual operations will ensure the success of the project.

Data gathered on individual sites and companies will be kept confidential. Only aggregate data will be published, unless specific approval for publication of site data has been given by the mine operator. At the completion of the study, raw data will be securely archived by the Minerals Council of Australia on behalf of the ACMRR.

I ask that your company or mining operation cooperates with the study.

If you have any comments or queries about industry involvement in the project, please contact Ian Satchwell at the Minerals Council of Australia on (06) 279 3600. Inquiries regarding technical aspects of the project should be directed to Dr Harries, whose contact details are shown on the survey information sheet.

Yours sincerely

David Buckingham
EXECUTIVE DIRECTOR

DAB:IDS:DDC

Mining Industry House
216 Northbourne Avenue
Canberra ACT 2601

PO Box 363
Dickson ACT 2602

Telephone 06 279 3600
Facsimile 06 279 3699

ACN 008 455 141

## Appendix C People consulted and organisations visited during OSS/ACMRR study

ARCO Coal Australia, Alex Armstrong

Australian Centre for Minesite Rehabilitation, Clive Bell

Australian Geological Survey Organisation, Canberra, Greg Ewers

Australian Mineral Industries Research Association Ltd (AMIRA), Paul Greenhill

BHP (Coal), Peter Roe (Manager Environmental Services)

BHP (Iron Ore), Ron Hillis (Manager Environmental Services)

Boddington Gold Mine, Craig Moreley (Chief Geologist), Megan James

Brukunga, SA, historic mine site

Bureau Mineral Resources, Brian Elliot, re MINLOC and MINRES databases

Burnside Gold Operations (previously Cosmo Howley), Lloyd Beck

Captains Flat, with Philip West, OSS

Central Queensland Mining Rehabilitation Group, Goonyella/Riverside mine, Moranbah, Qld

Chamber of Mines and Energy of Western Australia Inc, Jane Aberdeen

Collinsville Coal Mine, Paul Stathan (Environmental Officer)

Copper Mines of Tasmania at Queenstown, Isobel Stanley and Alan Robertson

Department of Development and Resources (Tas), Tony Christianson, Ralph Botrell, Bill Baker

Department of Environment and Land Management (Tas), John Johnston (Senior Environmental Management Officer)

Department of Mineral Resources NSW, Dennis Paul Frederickson, Chris Wall, Kerry Brooks, Ken Hollands (Manager Environment)

Department of Minerals and Energy (WA) with Bill Biggs, Hugh Jones and Alan Bradley

Department of Mines and Energy (NT), Tony McGill (Director of Mines), David Lawrence and Barry Noller

Department of Mines and Energy (SA)

Department of Mining and Energy (Queensland), John Bywater and Jaixin Zhou

Department of Energy and Mines (Vic), Tony Wissenden,

Department of Land & Water Management (NSW), Graeme Clifton

Environmental Practice Task Force, Minerals Council of Australia

Environmental Workshop, 3rd International and 21st Annual Environmental Workshop, Australian Minerals Council of Australia, Newcastle, October 1996

ERA Environmental Services, Tony Milne

German Creek Coal Mine, John Merritt (Environmental Officer)

Gordonstone Coal Mine, Cathy Brosnan (Environmental Officer)

Hamersley Iron Ore Pty Ltd with Jim Stoddart (Manager Environmental Affairs)

John Anderson, consultant

Kalgoorlie Consolidated Gold Mines (KCGM), Gay Bradley (Senior Rehabilitation Officer), Gary Lye, (Geotechnical Superintendent), Bruce McFadzean, (Open Pit Superintendent)

Kaltails Project (Kalgoorlie Tailings Retreatment Project), Greg Barrett

Kwinana Nickel Refinery, WMC Resources, Les Cousins (Environmental Scientist)

MIM, David Hughes (MIM Manager Environmental Affairs)

Minerals Council of Australia, David Buckingham, Ian Satchwell

Mount Leyshon Gold Mines, Paul Veivers (Environmental Officer)

Mount Tom Price, Hamersley Iron Ore: Ken Ramsey (Environmental Superintendent)

Mt Lyell Rehabilitation Project

North Limited, Peter McNally

Northparkes Mine (NSW), Andrew Reid

NSW Chamber of Mines, Newcastle, John Hannan (Environment Manager)

NT Chamber of Mines, Ms Kezia Purick (Chief Executive Officer)

Office of the Supervising Scientist, Darwin, Peter Waggitt, Peter Bailey

Office of the Supervising Scientist, Canberra, Stewart Needham, Patrick McBride, Philip West

Pajingo Gold Mine (meeting in Charters Towers), Ian Tredinnick (Superintendent Technical Services)

Parks and Wildlife Commission of NT, Rod Applegate,

Peak Hill Mine (NSW), Michael Sutherland

Pine Creek (RGC) Gold Mine, Mike Fawcett, Chris Wilson

Placer Pacific, Sydney, Gavin Murray

Queensland Mining Council, Environment Committee

Ravenswood Gold Mines, Rob Hunt (Environmental Coordinator)

RGC Thalanga Mine, Jim Taylor (Environmental Officer)

RGC Perth, Dennis Brookes

Rum Jungle mine site

Tasmania Acid Drainage Working Group Meeting, Queenstown, Tas

Union Mining, Christine Brown

Union Reefs Mine, Cameron Switzer (Senior Geologist)

Victorian Chamber of Mines, John Reynolds

Western Mining Company (Perth) Michael Anstey (Senior Environmental Advisor—Gold)

Western Mining Company, George White (Group Environmental Advisor)

Woodlawn Mine, Roger Jackman,

2nd National Acid Sulphate Soils Conference, Coffs Harbour

I am very grateful for the wide ranging discussions with the people listed and also the many others I have spoken to by phone and at various meetings.

John Harries

# Appendix D Questionnaire form distributed to mine sites

**CONFIDENTIAL** Minesite ID Number: «MineNo»

## ACMRR/OSS ACID MINE/ROCK DRAINAGE STUDY
### Current Mining Leases

| | | |
|---|---|---|
| 1. | Mine Number | «MineNo» |
| 2. | Mine Name | «Minesite» |
| 3. | Mineral Type | |
| 4. | Contact Person | |
| 5. | Address | |
| 6. | Phone | |
| 7. | Fax | |

The information provided will be used to develop the aggregated data to be used in the ACMRR/OSS study of extent of acid mine drainage and acid rock drainage in the Australian mining industry and the associated liability. Information on these sheets will be treated as confidential.

I would be grateful if you could provide means and ranges and indicate the relative proportions if there is a large range of values. Please use additional sheets if more space is needed or provide copies of printed data or strategies if available.

If you have any queries about the information requested, need any clarification, find the categories do not adequately apply to your operation, please contact John Harries on 02 9717 3896 (work), 02 9520 7562 (home), 02 9717 9260 (fax) or jrh@ansto.gov.au (email).

Please return the completed form to John Harries at ANSTO Environment Division, PMB 1, Menai, NSW 2234 or the fax number above by 25 September 1996.

ACMRR/OSS Acid Mine/Rock Drainage Study

| | | |
|---|---|---|
| 8. | Is **surface water** released from lease treated? | Y/N |
| 9. | Type of water treatment? | |
| 10. | Annual flow ML/y? | |
| 11. | **Ground water:** Premining ground water quality? | Fresh (<1500 mg/L TDS)<br>Brackish (1500-5000 mg/L TDS)<br>Saline (5,000-15,000 mg/L TDS)<br>Very Saline (>15,000 mg/L TDS) |
| 12. | Is ground water quality monitored | |
| 13. | **Opencuts:** | Y/N |
| 14. | Is seepage water pumped? | Y/N |
| 15. | Pumping rate? | |
| 16. | Water quality? | |
| 17. | Any **water filled opencuts/voids?** | Y/N |
| 18. | How much water contained (ML)? | |
| 19. | Water quality? | |
| 20. | **Any underground workings/adits?** Is there seepage water? | |
| 21. | How much? | |
| 22. | Water quality? | |

| | | |
|---|---|---|
| 23. | Have any **acid-base accounting** measurements been carried out? | |
| 24. | If so what sort and how many? | |
| 25. | Any other prediction measurements e.g leach columns? | |
| 26. | **Comments** | e.g.Special site conditions/requirements<br>Proposals to manage AMD/ARD at mine closure<br>Strategic significance of AMD/ARD at this mine |

**CONFIDENTIAL** Minesite ID Number: «MineNo»

Please provide information on mine wastes/residues/stockpiles that contain or might contain potentially acid generating material.

| | | WASTE ROCK/OVERBURDEN/COAL REJECT /CO-DISPOSAL | TAILINGS (Process Residues) | HEAP LEACH RESIDUES | STOCKPILES (low-grade/mineralised) |
|---|---|---|---|---|---|
| 27. | Sections or name of dump/dam | | | | |
| 28. | Weight (Mt) | | | | |
| 29. | Volume ($Mm^3$) | | | | |
| 30. | Area (ha) | | | | |
| 31. | Total Sulfur (%)<br>principal sulfides<br>sulfides %<br>sulfates %<br>organic sulfur % | | | | |
| 32. | Pyrite/pyrrhotite Content (%), what distribution | | | | |
| 33. | Carbonate %<br>what minerals | | | | |
| 34. | Results of Acid/Base accounting measurements on waste (NAPP, NAG, etc) | | | | |
| 35. | Typical pH of seepage from waste | | | | |
| 36. | Long term management strategy | | | | |

## Appendix E List of the mine sites included in the survey

| Minesite | Type |
|---|---|
| Agnew Gold Operations | Au |
| Anglesea Coal Mine | Coal |
| Angus Place Colliery | Coal |
| Appin Colliery | Coal |
| Argyle Diamond Mine | Diamond |
| Aroona & Beltana Mines | Ag/Pb/Zn |
| Avoca Alluvial Gold Project | Au |
| Awaba Colliery | Coal |
| Baalbone Colliery | Coal |
| Bailieston | Au |
| Balcooma Project | Zn/Cu |
| Ballarat East Gold Project | Au |
| Ballarat Gold Project | Au |
| Bamboo Creek Mine | Au |
| Bardoc Davyhurst Joint Venture | Au |
| Bayleys/Lindays Mine | Au |
| Bayswater No 2 Open Cut | Coal |
| Beaconsfield Mine | Au |
| Beenup Mine | Mineral sands |
| Bellevue Gold Project | Au |
| Benambra Mine | Base metal |
| Berrima Colliery | Coal |
| Big Bell Mine | Au |
| Big Rush | Au |
| Biggenden | Magnetite |
| Binduli Gold Mine | Au |
| Blackwater Mine | Coal |
| Blackwood & Duncan Coal Mine | Coal |
| Blair Athol Coal Project | Coal |
| Bloomfield Mine | Coal |
| Blue Bar | Au |
| Blue Mountains Colliery | Coal |
| Blue Spec–Golden Spec Mine | Au |
| Bluebird Gold Mine | Au |
| Boddington Gold Mine | Au |
| Boundary Hill Mine | Coal |
| Bounty Gold Mine | Au |
| Bow River Diamond Mine | Diamond |
| Brimstone Colliery | Coal |
| Brockman No 2 Detrital | Iron Ore |
| Brocks Creek | Au |
| Bronzewing Gold Mine | Au |
| Browns Creek Mine | Au/Cu |
| Brunswick Mine | Au/Sb |
| Bulga Open Cut | Coal |
| Burbanks | Au |
| Burgowan No 12 Underground | Coal |
| Cadjebut & Goongewa Mine | Pb/Zn |
| Callide Mine | Coal |
| Camberwell Coal Mine | Coal |
| Camel Creek–Golden Cup | Au |
| Canyon Colliery | Coal |
| Capel Mine | Mineral sands |
| Century Mine | Zn |
| Chain Valley Colliery | Coal |
| Chalice | Au |
| Channar | Iron ore |
| Charbon Colliery | Coal |
| Chicken Creek Open Cut | Coal |
| Clarence Colliery | Coal |
| Cobar Csa Mine | Cu/Ag/Pb/Zn |
| Collinsville Coal Company | Coal |
| Cook Colliery | Coal |
| Copperhead/Golden Pig Mine | Au |
| Cordeaux Colliery | Coal |
| Cosmo Howley/Burnside Operations | Au |
| Cracow Gold Mine | Au |
| Croydon | Au |
| Crinum Mine | Coal |
| Cumnock No 1 Colliery | Coal |
| Curragh Mine | Coal |
| Darlot Mine | Au |
| Dartbrook | Coal |
| Drayton Coal Mine | Coal |
| Eloise | Cu/Au/Ag |
| Elouera Colliery | Coal |
| Elura Mine | Ag/Pb/Zn |
| Emmaville Tin Mine | Sn |
| Endeavour Colliery | Coal |
| Eneabba Operations | Mineral sands |
| Ensham Mine | Coal |
| Ernest Henry Project | Cu |

| Minesite | Type |
|---|---|
| Ewington 2 | Coal |
| Fimiston Mine/Super Pit | Au |
| Forrestania Nickel | Ni |
| Fortescue | Iron ore |
| Fortnum Gold Mine | Au |
| Fosterville Gold Project | Au |
| Fraser Gold Mine (incl Golden Pig) | Au |
| Gaffney's Creek Goldmine Nl | Au |
| Gecko Copper/Gold Mine | Au/Cu |
| Georgetown Mine | Au |
| German Creek Mine O/Cut | Coal |
| Gidgee Gold Mine | Au |
| Girilambone Copper Mine | Cu |
| Golden Crown | Au |
| Golden Web | Au |
| Goodall | Au |
| Goonyella/Riverside Mine | Coal |
| Gordonstone Coal Mine | Coal |
| Granny Smith | Au |
| Great Australia Copper Mine | Cu |
| Great Greta Colliery | Coal |
| Great Lady Gold Mine | Au |
| Greenbushes Mine | Pegmatite |
| Greenfields Mine | Au |
| Gregory Mine Joint Venture | Coal |
| Gretley Colliery | Coal |
| Gullewa | Au |
| Gunnedah Colliery | Coal |
| Gunpowder Mine | Cu |
| Gympie Mine | Au |
| Harbour Lights Mining Limited | Au |
| Hawks Nest Mine | Mineral sands |
| Hazelwood Mine | Coal |
| Hedges Gold | Au |
| Hellyer Mine | Ag/Pb/Zn |
| Henty Gold Project | Au |
| Hill 50 Gold Mine Nl | Au |
| Hillgrove Gold–Antimony Mine | Au/Sb/As |
| Hilton Mine | Ag/Pb/Zn |
| Holleton | Au |
| Howick Open Cut | Coal |
| Hunter Valley Coal Mines | Coal |

| Minesite | Type |
|---|---|
| Invincible Colliery | Coal |
| Iron Duke | Iron ore |
| Iron Knob | Iron ore |
| Ivanhoe Colliery | Coal |
| Jangardup, Busselton & Waroona | Mineral sands |
| Jeebropilly | Coal |
| Jellinbah Central Mine | Coal |
| Jimblebar Iron Ore | Iron ore |
| Jubilee Gold Mine | Au |
| Jundee Gold Mine | Au |
| Kaltails Project | Au |
| Kambalda Nickel Mine | Ni |
| Kandos No 3 Colliery | Coal |
| Kanowna Belle Mine | Au |
| Kara Mine | Magnetite |
| Kidston Mine | Au |
| Kookynie Project | Au |
| Koolyanobbing Iron Ore Project | Iron Ore |
| Kundana Mine | Au |
| Kurildala | Cu |
| Lady Bountiful Extended Mine | Au |
| Lanfranchi/Schmitz | Ni |
| Laverton Mine | Au |
| Lawlers Gold Mine | Au |
| Leichhardt Creek Tin Mine | Sn |
| Leigh Creek Coalfield | Coal |
| Leinster Nickel Operations | Ni |
| Lemington Mine | Coal |
| Liddell Colliery | Coal |
| Lower Bielsdown Antimony Proj | Sb |
| Loy Yang Mine | Coal |
| Lynas Find | Au |
| M.W. Haenke No. 2 Underground | Coal |
| Maddingley Brown Coal Co | Coal |
| Manumbar | Au |
| Marandoo | Iron ore |
| Mariners Kambalda Nickel | Ni |
| Marvel Loch Mine | Au |
| Marymia | Au |
| McArthur River | Ag/Pb/Zn |
| McKinnons Mine | Au |
| Meandu Mine (Tarong Coal) | Coal |

| Minesite | Type |
|---|---|
| Meekatharra Gold Mine | Au |
| Merrywood | Coal |
| Metropolitan Collieries | Coal |
| Mineral Hill | Au/Cu |
| Moonee | Coal |
| Mount Coolon | Au |
| Mount Gibson | Au |
| Mount Gunson | Cu |
| Mount Hogan | Au/Ag |
| Mount Isa Mine | Pb/Zn/Cu/Ag |
| Mount Rankin Mine | Au |
| Mount Thorley Mine | Coal |
| Moura Mine | Coal |
| Mt Charlotte Mine | Au |
| Mt Keith Nickel Operation | Ni |
| Mt Leyshon Mine | Au |
| Mt Lyell Mine | Cu/Au |
| Mt McClure Gold Mine | Au |
| Mt Monger Gold Operations | Au |
| Mt Monger Joint Venture | Au |
| Mt Morgans Mine | Au |
| Mt Percy Mine | Au |
| Mt Todd Mine | Au |
| Mt Tom Price | Iron Ore |
| Mt Whale Back Mine | Iron Ore |
| Muja Open Cut | Coal |
| Mulline | Au |
| Munmorah Colliery | Coal |
| Muswellbrook No 2 Open Cut | Coal |
| Muswellbrook No 2 Underground | Coal |
| Myuna Colliery | Coal |
| Narngulu Operations | Mineral Sands |
| Narran Vale Mine | Sapphire |
| Nevoria Gold Mine | Au |
| New Celebration Mine | Au |
| New Hope Collieries | Coal |
| Newhill Underground Mine | Coal |
| Newlands Coal Mine | Coal |
| Newstan Colliery | Coal |
| Nifty Mine | Au |
| Nimingarra | Iron Ore |
| Nolans Gold Mine | Au |

| Minesite | Type |
|---|---|
| Norris Mine | Au |
| Norseman Operations | Au |
| North Goonyella Mine | Coal |
| North Stradbroke Island | Mineral sands |
| Northparkes Mines | Au/Cu |
| Norwich Park Mine | Coal |
| Oakdale Colliery | Coal |
| Oaky Creek Mine | Coal |
| Olympic Dam Operations | Cu/U/Au/Ag |
| Ora Banda | Au |
| Orebody 18 | Iron ore |
| Orient Well | Au |
| Orlando Project | Au |
| Osborne Mines | Au/Cu |
| Paddington Mine | Au |
| Pajingo Gold Mine | Au |
| Palm Springs | Au |
| Pan West Tantalum | Tantalum |
| Pannawonica–Deepdale | Iron ore |
| Paraburdoo Mine | Iron ore |
| Parkes Gold Project/Calerie | Au |
| Pasminco Mining – Broken Hill | Ag/Pb/Zn |
| Peak Downs Mine | Coal |
| Peak Hill (NSW) | Au |
| Peak Hill (WA) | Au |
| Pine Creek | Au/Ag |
| Plutonic Gold Mine (Inc Freshwater) | Au |
| Poseidon South | Au |
| Potosi Mine | Ag/Pb/Zn |
| Preston Extended Mine | Coal |
| Quamby Gold Mine | Au |
| Ranger Mine | U |
| Ravensworth/Narama Mine | Coal |
| Red Dome Gold Mine | Au/Cu/Ag |
| Red, White And Blue | Au |
| Redbank Mine | Cu |
| Reddestone Creek No. 1 & 2 | Sapphire |
| Reedy Gold Mine | Au |
| Renison Tin Mine | Sn |
| Rishton | Au |
| Riverina | Au |
| Rixs Creek Mine | Coal |

| **Minesite** | **Type** |
|---|---|
| Rosebery Mine | Pb/Zn/Cu/Au/Ag |
| Rustlers Roost Gold Mine | Au |
| Sandstone (Elmina) | Au |
| Sandstone Mine | Au |
| Saraji Mine | Coal |
| Savage River Mines | Iron ore |
| Scuddles Zinc Mine | Zn |
| Selwyn Gold Mine | Au/Cu |
| Shamrock Mine | Au |
| Sons Of Gwalia Mine | Au |
| South Blackwater Coal Mine | Coal |
| South Bulga Colliery | Coal |
| South Bulli Colliery | Coal |
| South Walker Creek | Coal |
| Springvale Colliery | Coal |
| St Arnaud | Au |
| St Ives Gold Mines | Au |
| Stawell Gold Mine | Au |
| Stratford Coal Mine | Coal |
| Strathdarr Mine | Sapphire |
| Tahmoor Colliery | Coal |
| Tallawang Magnetite Mine | Magnetite |
| Tanami (Central Desert J.V.) | Au |
| Tarmoola Mine | Au |
| Telfer Gold Mine | Au |
| Temora Mine | Au |
| Teralba Colliery | Coal |
| Thalanga Mine | Base metal |
| The Granites Gold Mine | Au |
| The Peak Mine | Base metal |
| Thiel Well Gold Operation | Au |
| Three Mile Hill Project | Au |
| Tick Hill | Au |
| Tiwest Joint Venture | Mineral sands |
| Tomago Mine | Mineral sands |
| Tower Colliery | Coal |
| Tuckabianna Gold Mine | Au |
| Two Boys Gold Mine | Au |
| Ulan Coal Mine | Coal |
| Union Reefs Gold Mine | Au |
| United Collieries Pty Ltd | Coal |
| Vickery Mine | Coal |

| **Minesite** | **Type** |
|---|---|
| Viney Creek | Mineral sands |
| Wallarah Colliery | Coal |
| Wambo Colliery | Coal |
| Wannaway | Ni |
| Warkworth Mine | Coal |
| Wattle Glen Open Cut | Coal |
| Wattle Gully Gold Mine | Au |
| West Cliff Colliery | Coal |
| West Wallsend Colliery | Coal |
| Western Collieries Ltd | Coal |
| Westside Mine | Coal |
| White Devil Mine | Au |
| Whiteheads Project | Au |
| Wilkie Creek Coal Project | Coal |
| Wiluna Gold | Au |
| Windarra Nickel Project | Ni |
| Windimurra Vanadium Mine | Vanadium |
| Woodcutters Mine | Base metal |
| Woodlawn Mine | Pb/Cu/Zn |
| Wyee Colliery | Coal |
| Yallourn Mine (SECV) | Coal |
| Yandan Gold Mine | Au |
| Yarrabee Mine | Coal |
| Yarrie Mine | Iron ore |
| Yilgarn Star Project | Au |
| Yoganup North/Yoganup Extended | Mineral sands |
| Youanmi Gold Mine | Au |