AN OVERVIEW OF ACID ROCK DRAINAGE POTENTIAL
IN
ARID AND SEMI-ARID REGIONS
OF
WESTERN AUSTRALIA

BY

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Cover Photograph: Western Mining Corporation , Mount Keith Nickel Mine

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Executive Summary

The Department of Minerals and Energy (DME) through an exchange program with the United States Department of the Interior, Bureau of Land Management (US BLM) has developed a series of recommendations for consideration by the Department to help identify and classify those mine sites with high potential for the development of environmental problems related to acid rock drainage (ARD).

Acid rock drainage has historically been the most significant environmental problem associated with the mining of ores that contain sulphide minerals. ARD is caused by the oxidation of sulphide minerals, producing acid and heat. The low pH effluent associated with this reaction can act to liberate metals with a variety of associated environmental problems.

David Williams, a geologist with the US BLM was detailed to work with DME during a four month period from October 17, 1994, through February 13, 1995, on acid rock drainage potential in Western Australia (WA). Mr. Williams visited numerous sites throughout WA to observe site conditions and collect samples which were analysed for ARD potential.

Most of the greenstone hosted gold mines in Western Australia have limited potential for the development of acid rock drainage. This is due to the extensive carbonate alteration often associated with gold mineralisation in the Archaean greenstone belts. The carbonates present in the deposits often have the capacity to neutralise any acid produced by the weathering of sulphides contained in the ore bodies. While this may limit the potential for classic low pH acid rock drainage, the potential for the release of other metals and contaminants will vary depending on the specific geochemistry and environmental conditions of each deposit.

Polymetallic massive sulphide deposits may have high potential for the development of acid rock drainage and should be carefully scrutinised.

All mineral deposits should be carefully evaluated to assure the potential for acid rock drainage is identified in all waste units to be handled, even where the metals or materials being recovered are not specifically associated with sulphide mineralisation.

The arid to semi-arid climate and the topography of WA combine to make it unlikely the types of widespread problems related to acid rock drainage that accompanied mineral development in the Western United States, areas in Canada, Europe and Scandinavia, and more temperate or tropical portions of Australia will develop. Problems in WA are likely to be areally restricted to lands adjacent to the site of disturbance. The lack of water to serve as a contaminant transport mechanism means that impacts are likely to be restricted to local adverse impacts to reclamation success, offsite impacts to native vegetation and groundwater supplies (where groundwater is suitable for beneficial use). These impacts can be locally severe and persistent. The limited annual precipitation, extensive periods of drought coupled with rare major precipitation events will likely mean any potential problems will take a correspondingly longer time to develop than is true in a more temperate environment. Consequently, problem sites may not be recognised for many tens of years or more. This emphasises the need for appropriate waste characterisation work prior to the initiation of mining activity.

The following measures are recommended in order to limit adverse environmental impacts related to acid rock drainage:

1) All NOIs that involve above ground disposal of waste material should include preliminary waste characterisation work as part of the NOI submitted to the Government.

2) Additional waste characterisation will be necessary when the preliminary characterisation work has identified a potential ARD problem. The additional waste characterisation work may include a continuing comprehensive program of static testing.

3) Sites where characterisation work identifies a potential for ARD must be closely evaluated for long term engineering stability and water management of all sulphidic material. Rehabilitation emphasis must focus on the durability of the proposed cover system used to isolate sulphidic materials.

4) Operator monitoring plans should be developed for sites where static or kinetic testing has identified a problematic unit. These plans should focus on the measures to prevent adverse impacts that might result from ARD throughout the project life.

5) Action is urgently needed at abandoned minesites where ARD is being generated to identify solutions and rehabilitate the sites to prevent further adverse environmental impacts.

Several suggestions for industry practice and further research are discussed in Chapter IV. These principally focus on gathering more information on both the testing of materials for ARD and the actual performance of sites in the field.

CHAPTER I INTRODUCTION

History and Regulatory Framework Compared to the Western United States, Australia has a relatively recent history of exploration and development. Many of the early mining centres of the Western US were in the prime of their development years when Coolgardie and Kalgoorlie were discovered in 1892 and 1893 respectively. These and other discoveries effectively quadrupled the population of Western Australia in the 10 years from 1890 to 1900. Gold production peaked shortly after the turn of the century, falling to very low levels during the depression years of the 1930s. The only other mineral production during much of this time was from the coal mines of the Collie area, where mining started in the late 1890s. In the mid 1960s the major iron deposits of the Pilbara and the nickel deposits at Kambalda began production. This heralded the modern era of prospecting and development that continues today. Discoveries have included mineral sands, bauxite, diamonds as well as additional iron ore, gold and other metalliferous deposits (WA DME, 1993).

Currently the mineral industry in Western Australia is of crucial importance to the Western Australian economy. Approximately 1 job in 6 in Western Australia is related to mineral production. Western Australia contributes 44% of Australia's mineral production, substantially aiding the Australian balance of payments through the export of refined and raw mineral products (WA DME, 1993). Mineral production is the primary source of export income for WA.

The management of mineral exploration and development in Western Australia is primarily the responsibility of the Department of Minerals and Energy (DME). The Department was formed as the Department of Mines in 1894 following closely the important discoveries at Coolgardie and Kalgoorlie. The name of the Department was changed to the Department of Minerals and Energy in 1992 reflecting changes in responsibilities in the nearly 100 years since its founding. While the Department administers 17 separate acts of Parliament, the important ones for the purpose of this report are the Mines Regulation Act 1946 and the Mining Act 1978. Ownership of most minerals in Western Australia is vested in the Crown and they are administered by the Department on behalf of the entire community. Mining titles are administered by the Department in such a manner as to provide for access to minerals with security of tenure for the mineral developers. It is important to note that ultimate mineral title or reward in Western Australia remains vested in the Crown and is available only through leases administered by the Department. There is no provision whereby lands are patented and become private land as provided for by the General Mining Law of 1872 in the US.

It is in the area of mine development, environmental review and mine permitting that the Western Australian system differs the most with the system in the US. Perhaps because of the different relative "age" of the industry and the different levels of historical environmental impacts, the mining industry in the US has to operate in what is largely an adversarial role with the respective State and Federal permitting agencies. The industry and the Department in Western Australia have evolved what is essentially a co-operative or self regulatory system. The DME has few regulations relating to environmental management of mining operations. The main instrument for control of operations is through conditions placed on the mineral titles that grant company's development access. The breach of these conditions potentially threatens access to minerals since the Department, through the Minister for Mines, can forfeit the title.

The mining leases granted by the Department include a provision requiring operators to submit a written proposal to the State Mining Engineer prior to any actual mining. These proposals can vary widely depending on the scope of the proposed activities. For larger proposals, and for those in environmentally sensitive areas, the Environmental Protection Authority can require a formal "Environmental Review and Management Program" under the Environmental Protection Act of 1986. This is essentially the equivalent to an "Environmental Impact Statement" in the US system of project review and approval. The EPA is an "independent adviser" to the Western Australian Government responsible for assuring environmental protection. Mining proposals are coordinated through an existing Memorandum of Understanding between the EPA and DME. The DME is responsible for the assessment of mining proposals, but individual projects may require the Department to coordinate with several other agencies. Those projects with the potential for significant environmental impacts are automatically referred to the Environmental Protection Authority for assessment.

The Department has a staff of 10 environmental officers located in Perth, Kalgoorlie, and Karratha to monitor activities and ensure exploration and mining operations are conducted in an environmentally sound manner. The Department has published a series of Guidelines that detail sound practises for exploration, development and mining in Western Australia. Many of the larger mining companies also have developed their own environmental guidelines, which are often based at least in part on the Department's guidelines(Lindbeck, 1993).

Unlike the US, the Australian Federal Government has only a limited role in the mine permitting process in Australia.

The limited number of inspectors relative to the level of activity in Western Australia means that to a large extent the Department must rely on operators to conduct their operations in compliance with the existing guidelines. Larger mining companies generally have an environmental staff with the specific responsibility for environmental protection. For smaller operations compliance can depend on the staff at the actual minesites. The officer responsible for environmental compliance may have several other responsibilities in addition to their environmental responsibilities. Some of these responsibilities can compromise the role of environmental protection.

Geology A detailed discussion of the geology of Western Australia is outside the scope of this project, however, some general information on the geology will help to gain an understanding of Acid Rock Drainage issues in Western Australia. Two separate cratonic units, the Pilbara and the Yilgarn, encompass much of the Western portion of the State (Figure 1). These cratons have been geologically stable for approximately 2.5 to 3.0 billion years. The geology of these cratons has been divided into several different provinces and terranes. These divisions have been based on structural complexity and lithology. In the Pilbara Craton these differences are comparatively obvious, while in the Yilgarn Craton, the differences are considerably more subtle(GS WA,1993). The dominant lithology of both cratons is granite-greenstone terrane characteristic of older Precambrian shield or cratonic areas. Many of the ore deposits in this terrane are associated with greenstone belts. The lithology in the greenstone belts commonly includes a variety of volcanic and volcaniclastic rocks. These can include tholeeitic basalts, komatiites, ultramafic units, basalts, andesites, and sedimentary rocks including shales, cherts and banded iron formations. These greenstone belts are virtually always structurally complex. The mineralogy of ore deposits within the greenstone belts can vary widely, but virtually all deposits include either pyrite (FeS_2), or pyrrhotite ($Fe_{(1-x)}S$), in the primary mineral assemblage. In the greenstone belts it is not uncommon for the alteration associated with ore emplacement to be carbonate rich. This carbonate enrichment can include the minerals; ankerite ($Ca(Mg/Fe/Mn)(CO_3)_2$), siderite ($FeCO_3$), dolomite ($Ca/Mg(CO_3)_2$) and calcite ($CaCO_3$). This mineral assemblage can have important ramifications for the development of "acid rock drainage"

Climate and Topography, and Vegetation Much of inland Western Australia is characterised by highly variable precipitation which may average as little as 200 mm (8") per year. Precipitation patterns can vary widely depending on seasonal rainfall, infrequent cyclonic depressions, and summer thunderstorm rainfall. South of the Tropic of Capricorn (23° 20′ Latitude) summer daily high temperatures vary from warm (30°C-40°C) to unpleasantly hot (43°C-50°C) with correspondingly high evaporative rates. Winter temperatures are mild with daytime high temperatures ranging up to 25°C and infrequent freezing during nights. Most rainfall may occur during the winter season of April through October.

North of the Tropic of Capricorn the weather pattern changes to a monsoonal pattern. Annual precipitation can vary from as little as 200 mm (8") per year up to 1.5 metres per year (58"). Seasonal rainfall patterns are reversed from the more southerly portions of the state with most precipitation falling during the months between November and March. Falls can be heavy as showers associated with tropical depressions move inland. Temperatures range from warm daytime highs during the winter months to unpleasantly hot during the summer. Humidity is very high during the monsoonal season.

The topography of much of inland Western Australia is characterised by limited relief. In some areas relief may be as little as 25 metres over several thousand hectares. Often what relief there is, is confined to "breakaway" topography where more resistant lateritic horizons have been largely eroded away. This can leave small scale plateau features which may rise up to 20 metres above the general terrain. Water flow patterns in this land of low relief are expressed mainly through sheet flow features, particularly during higher intensity precipitation events. Watercourses may actually contain surface flows only a few days a year. An extensive series of inland "lakes" throughout Western Australia is likely to contain water only during years of above average seasonal rains, or following passage of a tropical depression system. The lack of surface water flow in watercourses only serves to highlight their importance as subsurface water flow corridors. This is often evidenced by extensive development of eucalypts along the drainageways.

Vegetation throughout much inland Western Australia is low shrubs consisting of mulga, acacia, hakeas, with areas of eucalypts along stream courses and areas with more soil moisture available. Undergrowth consists of spinifex, saltbush, and other drought tolerant species. In much of the area the vegetation has been severely impacted by grazing by domestic and feral species.

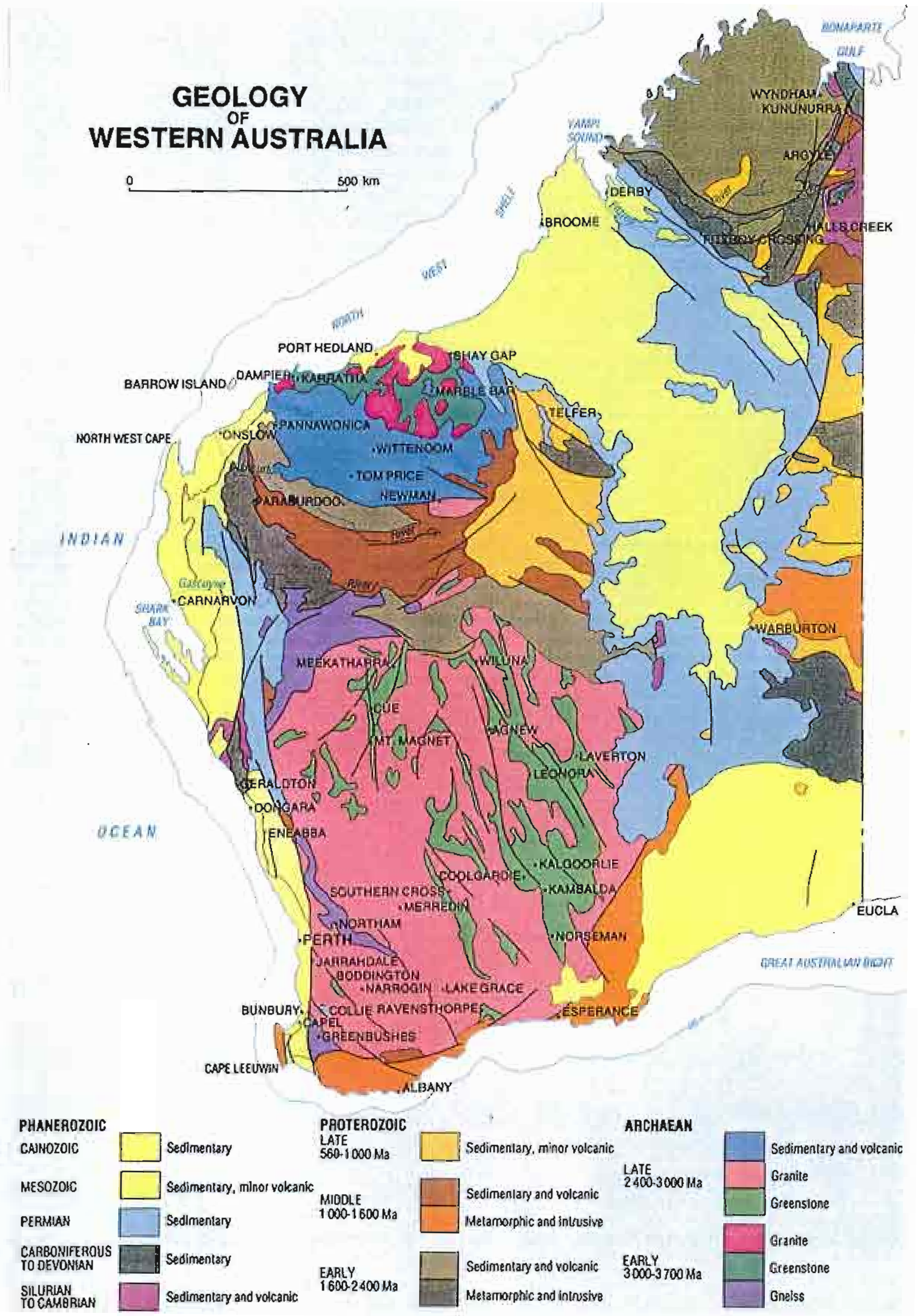
Recent Developments Within the last ten to fifteen years gold mining in Western Australia has undergone something of a renaissance similar in many respects to the growth of the gold mining industry in the Western US. This renaissance is due largely to new technologies that enable the recovery of gold from increasingly low grade deposits. These technologies have included the now common cyanide heap leaching process, and more recent technologies that enable more companies to increase treatment of refractory ore. Bioxidation is one of these newer technologies that continue to allow companies to mine low grade sulphidic deposits even as the mineralogy changes. Other changes include more efficient mining equipment, and computer programs that maximise efficiencies of data representation and equipment usage. Much of the recent mining has been confined to the oxidised upper portions of orebodies where the ore is relatively easier to both mine and mill. Ore deposits in WA have highly variable depths of oxidation, generally from 40 to 80 metres in depth. However, in any particular deposit, the depth of oxidation can vary up to nearly 100 metres depending on the site specific geology and structure. Regional groundwater in WA can also vary dramatically both in quality and depth. Salinity can vary from less than 1,000 ppm Salinity to over 300,000 ppm Salinity. Over much of the Goldfields area groundwaters fall into the hypersaline category. To some extent the flat topography of WA limits the depth of economic open cut mining. Increasingly open cut mines are likely to be of sufficient depth that large volumes of primary or sulphidic ore will be exposed through the mining process. Because these ores and associated wastes will represent the last material removed from the open cut, early consideration of appropriate waste handling requirements is important so as to avoid placing the most reactive materials in the outer portions of waste rock dumps.

It is important to note that Western Australia does not have an extensive history of production of ores from primary or sulphidic mineralisation. Much of the ore recovery to date in Western Australia has come from the more shallow and oxidised portions of deposits. Only within the past ten years has the mining of primary ores with their associated waste dumps and tailings facilities become more common. There is no legacy of environmental problems from past metal mining of sulphidic ores as exists in the Western US.

Current Project Acid rock drainage (ARD) has historically been the most significant environmental problem associated with the mining of ores that contain sulphide minerals. ARD is caused by the oxidation of sulphide minerals, producing acid and heat. The low pH effluent associated with this reaction can act to liberate metals with a variety of associated environmental problems (Refer to Appendix F for a brief summary of the chemistry of ARD).

The Department has recognised that ARD is not necessarily restricted to areas with more tropical or temperate climates. The Department has an ongoing staff exchange program with the US Department of Interior, Bureau of Land Management. The Department decided to continue the exchange program by inviting a technical specialist from the Bureau to Western Australia to review the potential for ARD in arid and semi-arid regions of Western Australia and develop recommendations for the Department on any changes that may help the Department identify and limit impacts, if any, due to ARD. David Williams, the District Geologist in the Butte, Montana BLM Office has been seconded to the Department during the period October 1994 through February 1995 to complete this work.

Figure 1
Generalised Geologic Map of Western Australia



CHAPTER II WORK PERFORMED

A project of this scope requires several different approaches in order to adequately address the potential issues and develop technically sound recommendations. Given the relatively short duration of the review it was necessary to break the work into the segments discussed below:

A. Acid Rock Drainage Survey

On October 7, 1994, Keith Lindbeck, Manager, Environment and Rehabilitation Section, Mining Operations Division, DME sent out to all Registered Mine Managers on record an Acid Rock Drainage Survey Questionnaire for WA Minesites. A copy of the survey is attached as Appendix A. Of the approximately 120 copies of the survey distributed, 60 were returned and evaluated. The purpose of the survey was to get a general idea of the level of consideration previously devoted to ARD potential at various mines, identify sites mining sulphidic waste and also to determine which sites might be suitable for site visits. Some of the information from the survey is represented in the Table 1 below. This Table also reflects sites visited that had not responded to the survey. Of the 70 sites either responding to the survey or visited, 63 (90%) mine "fresh rock". Virtually all those mines operating in fresh rock involve sulphidic ore, waste or both.

The comment's section in the table reflects either notes from the respondents or the author's own thoughts on ARD potential prior to visiting the site,(H-high, M-medium, L-low potential for ARD, and Characterisation Work) Several respondents noted the arid conditions in Western Australia made any ARD problems unlikely.

Table 1

Eastern Goldfields Province

DEPOSIT	ARD RESPONSE	FRESH ROCK	SULPHIDES	COMMENT
Paddington *	# 15	Yes	Py,Aspy,Pyrr, Cpy	MH
Cork Tree Well	# 36	Yes	Py	
Grants Patch	# 24	No		M
Jubilee/New Celebration *	# 51	Yes	Py,Pyrr,Cpy	L
Kalgoorlie *		Yes	Py,Tl	ML
Gidgi Roaster		Yes	" "	Roaster
Wiluna *	#53	Yes	Py,	ML
Teutonic Bore*	Abandoned	Yes	Py, Cpy, etc	Past Problems
Granny Smith		Yes		ML
Windarra *		Yes	Ptl,Pyrr,Py	Char. Work
Leinster *		Yes	"	Char. Work
Mt. Keith *	#48	Yes	"	Char. Work
Kambalda		Yes	"	Char. Work
Nepean *		Yes	Ptl,Pyrr,Py	
Norseman	# 42	Yes	Py,Pyrr	MH
Mt Pleasant	# 9	Yes	Aspy,Py	
3 Mile Hill *	# 39	Yes	Py,Sph,Gln,Mr	ML
Harbour Lights *	#38	Yes	Py,	
Tarmoola *	#12	Yes	Py,	

Mt. Morgan	# 47	Yes	Py,Pyrr	Char. Work
Zuelica	# 30	No		
Mt. McClure	# 18	Yes	Py,Pyrr	
Binduli	# 6	No		
Kanowna Belle *		Yes	Py,Aspy	Roaster
Coolgardie Gold *	#7	Yes	Py, Aspy,	
Bellevue	#17	Yes	Pyrr,Cpy,Aspy	
Duketon	#37	No		
Lynas Find	#34	Yes	Py	
Zelica	#30	No		
Lawlers	#20	Yes	Gln,Py,Aspy,Cpy	
Ora Banda	#41	Yes	Py,Pyrr	
Mt. Monger	#55	Yes	Py,Pyrr, Aspy	
Laverton	#57	No		
Darlot	#60	Yes	Py,Cpy	
Thiel well	#58	Yes	Py,Cpy	

Murchison Province

DEPOSIT	ARD RESPONSE	FRESH ROCK	SULPHIDES	COMMENT
Hill 50 *	# 45	Yes	Py,Pyrr	M
Paddys Flat	# 44	Yes	Py,Aspy	Char. Work
Scuddles *	#40	Yes	Py,Sph,Gln,Cpy	Past Problems
Bluebird *		Yes	Py,	
Haveluck *		Yes		
Hill 60 *		Yes		M
Big Bell *	# 31	Yes	Py,Pyrr	Char. Work
Plutonic	# 29	Yes	Pyrr,Py,Aspy	
Fortnum	# 28	No		
Golden Crown*	# 16	Yes	Py,Pyrr,Aspy,Gln	UG
Reedy	# 43	Yes	Py,Pyrr	
Mt. Gibson *	# 3	Yes	Py,	
Mt Morgan	#47	Yes	Py,Pyrr	
Sandstone	#35	No		

Southern Cross Province

DEPOSIT	ARD RESPONSE	FRESH ROCK	SULPHIDES	COMMENT
Copperhead *	# 26	Yes	Py,Pyrr,Mr,Cpy	ML/M
Nevoria *	# 27	Yes	Pyrr,Py	M
Mt. Hope *	# 8	Yes	Pyrr,Py,Mr	UG
Gidgee *	# 3	Limited	Py,Aspy	L
Youanmi *	# 33	Limited	Py,Aspy	L
Yilgarn Star *		Yes	Pyrr,Py	
Cosmic Boy *	#52	Yes	Pyrr, Pent,Py...	
Diggers Rock *	#52	Yes	Pyrr, Pent, Py..	
Mt. Dimer *		Limited	Py,Sph,Gln,Cpy	
Fraser	#25	Yes	Pyrr,Py,Cpy,Gln	

Mines in the Pilbara, Kimberly and Proterozoic Rocks

DEPOSIT	ARD RESPONSE	FRESH ROCK	SULPHIDES	COMMENT
Bamboo Creek	#11	Yes	Py,Aspy,Mr	M

Telfer	#56	Yes	Py,Cpy,Brn,Chc	
Cadjebut	# 32	Yes	Mr,Sph,Gln	L
Argyle *	# 50	Yes	Py	Char. Work
Marymia	# 49	Yes	Py,Pyrr	
Comet	# 46	Yes	Aspy	
Nifty *		Yes		
Mt. Whaleback*	#21	Yes	Py	Past Problems Char. Work
Yarrie *		Yes	No	
Tom Price	#42a	Yes	Py	
Channar	#14	Yes	No	
Paraburdoo	#13	Yes	No	

Sites in the Deposit column visited are marked with *.

B. Literature Review

Literature reviewed falls into two categories: a) general acid rock drainage literature reviewed and, b) articles on the geology, and mineral deposits of Western Australia.
A wide variety of ARD literature has been routinely used as reference material during the course of this project and can be found in the reference section. The specific requirements of this project are such that most general ARD literature is helpful only for resolving particular questions that came up during the course of the research. What would be most useful to DME and the mineral industry in WA is a rational way of approaching the risk of any potential ARD. One alternative to approach this problem is to rely on geologic models of ore deposits. Work by Geoff Plumlee and others of the US Geological Survey in the references below focuses on the likely impacts to the environment of different ore deposit models listed in Table 2.

Plumlee, G.S., Smith, K.S., Ficklin, W.H., Briggs, P.H., and McHugh, J.B., 1993, Empirical studies of diverse mine drainages in Colorado: implications for the prediction of mine-drainage chemistry: Proceedings, 1993 Mined Land Reclamation Symposium, Billings MT.

Plumlee, G.S.,Smith, K.S., Ficklin,W.H., 1994, Geoenvironmental Models of Mineral Deposits, and Geology-Based Mineral-Environmental Assessments of Public Lands, Unpublished talk presented at the April,1994 Mine Closure Conference in Whitefish MT

This work can form the basis for an analysis of the risk related to the development of mineral deposits in a wide variety of physical settings because the specific mineralogy and geochemistry of the ore deposit will control both the likelihood and the potential severity of acid rock drainage. This approach will give qualitative ideas on the likely impacts to the receiving environment. The same sorts of environmental signatures that have resulted from the natural weathering process (acid rock drainage), and have been used by geologists and prospectors to initially identify ore deposits (eg. gossans, "iron caps", etc.) can also be used to make predictions on the impacts to the environment of the accelerated weathering of sulphidic waste material associated with mining activity.

Table 2 reflects an <u>initial</u> attempt to categorise mineral deposits based on limited information available from literature on each of the deposits. Literature on mineral deposits is often incomplete in regard to even a preliminary attempt at waste characterisation. What may be important from the authors' viewpoint with respect to the ore deposit, may be of limited usefulness in any waste characterisation scheme.

Table 2 Geoenvironmental Characteristics of Sulphide Deposits

Deposit Characteristics	Environmental Signature	Deposits
Pyrite rich massive sulphides	Very low pH, high metals	Fe Ore deposits, Scuddles
Sulphide rich ores incl: py,eng, brn,etc. Wallrock altered to Si, alunite, kaolinite	low pH, high metals	Big Bell, Mulline, Bamboo Ck.
Pyrite and base metal rich polymetallic veins and disseminations in wallrock with low acid buffering ability	Moderate-low pH, moderate to moderately high metals	Telfer , Paddy's Flat (?) Mt. Clement, Sandstone, Golden Crown, Fraser (?), Horseshoe,
Pyrite rich, base metal poor veins and disseminations in wallrock with low acid buffering ability	Low pH, relatively low metals	Golden Pole, Watertank Hill, Hill 60, Bounty Reedy, Copperhead S, Nevoria, Bellevue, Grants Patch (As!)
Pyrite and base metal rich polymetallic veins that are carbonate rich or occur in wallrock altered to contain carbonate	Near neutral pH, moderate metals	Teutonic Bore (?), Kalgoorlie, Copperhead N Granny Smith, Paddy's Flat (?), Three Mile Hill (?)
Pyrite and base metal rich polymetallic replacements and veins in carbonate rich sediments	Near to above neutral pH, moderate metals	Cadjebut (?)
Polymetallic veins with moderate to low pyrite and base metal content that are carbonate rich or occur in carbonate rich wall rock	Near to above neutral pH, low metals	Gidgee, Nevoria, New Celebration (?), Harbour Lights, Paddington, Norseman, Wiluna, Windarra, Leinster (?), Mt. Keith, Bluebird
Pyrite poor polymetallic replacements in carbonate rich sediments	Above neutral pH, very low metals	Cadjebut (?)
Pyrite poor Au-Te veins and breccias with carbonate gangue	Above neutral pH, very low metals	Kalgoorlie

After Plumlee et al, 1993, 1994

Two deposit models developed by Plumlee et al, are not represented in Western Australia. As noted in the table below these models include hot spring ores in acid altered wallrock and "porphyry Moly" deposits in igneous wallrock. It is possible because of the age, typically 2.4-2.7 BY, and extensive alteration of deposits in Western Australia, "hot spring deposits" would not be identifiable as such. "Porphyry Moly" deposits are characteristic of Cretaceous-Tertiary age granitic intrusives in the Intermountain Western United States.

Their absence in Western Australia is probably indicative of fundamental changes in ore deposit formation between the Archaean and the late Mesozoic.

Deposit models deleted from the chart because of their absence in Western Australian mineral deposits.

Deposit Characteristics	Environmental Signature	Deposits
High sulphide, low base metal hot spring ores in acid altered-wallrock	Low pH, moderate metals	
High sulphide, low base metal porphyry Mo ores in igneous wallrock	Low pH, moderate metals	

C. Site Visits

An important aspect of this project was the series of site visits conducted to examine the mineralogy, geochemistry and other important characteristics of actual deposits in the field.

The following sites and the dates visited are listed below and displayed on Figure 2:
A more detailed series of notes from the field visits is attached as Appendix B

October 20, 1994 BHP/Mt Whaleback, Jimblebar
October 21, 1994 Mike Manganese, Portman Mining/Woodie Woodie,
WMC/Nifty Copper
October 22, 1994 BHP/Yarrie, Shay Gap
October 23, 1994 CRA/Ellendale diamond prospect, Phillips Range diamond prospect
October 27, 1994 CRA Argyle diamond mine
October 28, 1994 CRA Argyle diamond mine
November 3, 1994 GMA/Youanmi
November 4, 1994 Arimco/Gidgee
November 14, 1994 Normandy Poseidon/Scuddles
November 28, 1994 PanCon/Paddington, WMC Windarra
November 29, 1994 Ashton/Harbor Lights, Mt Edon/Tarmoola,
Abandoned(Black Swan)/Teutonic Bore, WMC/Leinster,Mt Keith
November 30, 1994 Wiluna Gold/Wiluna
December 1, 1994 Dominion/Haveluck, St. Barbara/South Junction, Bluebird
December 2, 1994 Normandy Poseidon/Big Bell, Golden Crown, WMC/Mt Magnet
December 3, 1994 Reynolds Australia/Mt Gibson
December 28, 1994 Abandoned(Glengold Holdings)/Kundip
January 4, 1995 Forestania/Cosmic Boy, Diggers Rock,
Abandoned(Nova Resources)/Hatters Hill
January 5, 1995 Normandy Poseidon/Bounty, Orion Resources/Yilgarn Star,
Jingellic Minerals/Nevoria
January 6, 1995 Burmine/Copperhead, National Mine Management/Mt Dimer
January 8, 1995 Abandoned (Black Swan)/Teutonic Bore
January 9, 1995 GMK/Jubilee, Newcrest/New Celebration

January 10, 1995 Herald Resources/Three Mile Hill, Tindals, KCGM Superpit
Aberfoyle Resources/Bardoc
January 11, 1995 WMC/Kambalda, Delta Gold/Kanowna Belle January 12, 1995 Beckmont Holdings/Nepean, KCGM Gidgi Roaster
January 13, 1995 Coolgardie Gold/Bayleys, Lindsays, Broken Hill Metals/Hopes Hill

The purpose of the initial field trip was primarily to become familiar with the geology and mineral resources of Western Australia. Following the initial field trip and literature review in Perth, the nature of the site visits changed to focus more specifically on ARD issues. The purpose of the minesite visits was to become generally familiar with the geology at the mine site, usually visiting with the mine geologist. On the basis of the discussion with the mine geologist, samples were collected from representative rock types at the minesite. This information could then be used to refine observations and hypotheses on ARD for any upcoming site visits

Other typical observations at minesites included depth and quality of groundwaters in the area, depth and extent of oxidation, ore deposit and host rock mineralogy and structure and any waste rock special handling or characterisation work. Where applicable, mine waters were sampled for pH with a field pH meter. Thirty-five mm slides were taken of most of the sites visited.

D. Sampling Program

Samples were collected as noted above at most of the minesites visited. Generally the samples were collected to be representative of the major rock types at the minesite. Samples were frequently collected from ore or low grade material to represent what essentially would be a worst case scenario for ARD. It was often noted during field visits that waste rock described as lacking sulphides, contained abundant sulphides visible in hand specimen. While the extensive sampling of waste and other material from throughout the region of site visits can help provide some general guidance on the potential for ARD in Western Australia, the data available for any one minesite does not represent a statistically significant number of samples. Conclusions based on the sample data on a minesite by minesite basis should be made with caution.

The detailed sampling instructions provided to laboratories for bid solicitation are attached as Appendix C and are based on accepted waste characterisation procedures. The Net Acid Generation test is one of the most recent additions to waste characterisation work. While not universally accepted, there is an increasing amount of data that supports its use.

A detailed list of the samples is attached as Appendix D.

Samples were analysed locally by the Chemistry Centre and Analabs for the following parameters, which represent a fairly typical suite of "static" waste characterisation tests:
120 samples were analysed, with the results of 13 samples being received too late for inclusion in the report.

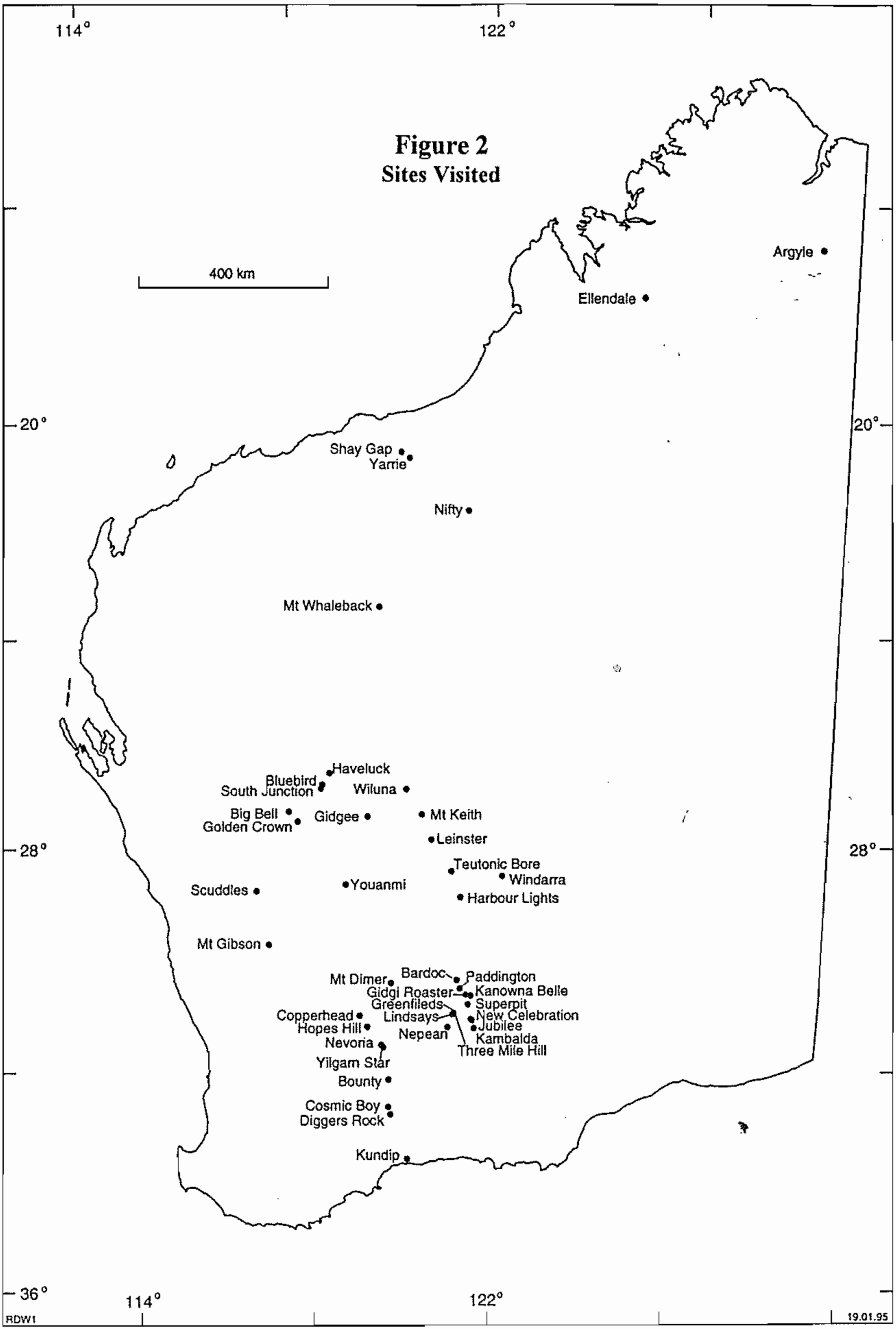


Figure 2
Sites Visited

pH: Measured on slurry using samples of crushed rock or as received tailing material. This is a measure of the "inherent" acidity or alkalinity of the sample.

EC (Electrical Conductivity): Measured on a slurry using crushed rock or tailings as noted above. This is a measure of the "inherent" salinity of the sample. In waste materials, high EC values often represent an accumulation of weathering products in the sample.

Total Sulphur (S), Measured as a percentage. Total sulphur, in conjunction with sulphate sulphur below, is used to calculate the APP or Acid Production Potential. The APP is measured in kg H_2SO_4/tonne or tons $CaCO_3$/ 1000 tons (North America).

Sulphate Sulphur (SO_4) Measured as a percentage. Sulphate sulphur is important because it will generally not contribute to the oxidation of sulphide minerals. If the total sulphur value is used without accounting for sulphate sulphur, it is possible to over estimate the APP of samples.

ANC (Acid Neutralising Capacity). This calculation is based on the presence or absence of materials in the sample capable of neutralising produced acids and is reported in kg H_2SO_4/tonne. Typically these are the various carbonate minerals. The actual ability of the carbonate minerals to neutralise produced acid in a field or waste dump setting may not be the same as calculated in the lab for a variety of reasons.

The APP and the ANC together constitute the "Acid Base Account" or ABA and are reported in this report as Net Acid Production Potential (NAPP). If the sample has a higher APP value than the ANC value, the sample is theoretically capable of producing acid. Conversely, if the ANC value is higher, the sample is theoretically capable of neutralising any produced acid. In practice there is an extensive zone of uncertainty in the -20 to +20 kg H_2SO_4/tonne range of values. Some recommendations suggest that if the ANC value is at least 3 times the APP value the sample will not generate acid (BC AMD Task Force, 1990). More recently British Columbia has changed the ANC to APP ratio to 4 : 1 (Price, 1994).

NAG (Net Acid Generation) This test is a more recent addition to the suite of waste characterisation tests. The test involves the addition of H_2O_2 as an oxidant to the sample which provides some indication of the sample's ability to oxidise and the ability of any contained minerals to neutralise produced acid. Results can be reported either as final pH or as kg H_2SO_4/tonne as is done in this report. The advantage of the NAG test is the relative simplicity and speed with which it can be carried out. The NAG test does not always correlate well with existing more widely accepted tests.

Three samples were collected and subjected to a standard series of soils analyses.

One water sample was collected and analysed for contained metals.

CHAPTER III FINDINGS

A. Observations based on Site Visits

Several representative minesites and the results of any sampling will be discussed briefly on a site by site basis.

BHP/Mt Whaleback

The Mount Whaleback deposit occurs in a banded iron formation (BIF) complex of approximately 2.5 BY age. Associated waste units include: various different shale units, a dolerite lithology and lower grade BIF units. Waste rock volumes total approximately 300m tonnes. The shale units include the McRae Shale and the Sylvia Formation. The McRae Shale includes 3 sub-types: a black shale that includes abundant diagenetic (?) pyrite, a "brown-red" variety, and a "weathered" variety. The black shale member is a black pyritic shale unit with coarse blebs of pyrite up to 5 cm in size. The distinction between the latter types is not clear from the characterisation work performed (Campbell, 1993), nor was it obvious in our field visit to the site.

These same characteristics make the ultimate disposal of the black shale unit of critical importance in assuring successful reclamation and limiting the potential for acid leachate from the waste complex.

Initial characterisation work determined the Net-Acid Producing Potential (NAPP) to be 270 kg H_2SO_4/tonne. The corresponding values for the BIF, weathered and brown McRae Shales were all equal at 0.61 kg H_2SO_4/tonne. The McCrae Shale had no capacity to neutralise produced acid (Campbell,1993).

BHP has recognised the potential for ARD associated with the McCrae Shale in the Mt Whaleback pit The black shale unit is obviously a highly reactive waste unit, requiring careful handling in the operational stage due to spontaneous pyrite oxidation and subsequent generation of SO_2 (Plate 1a) The potential was recognised through operational measures necessitated by SO_2 gas generated by oxidising pyrite. Oxidising pyrite has impacted work practises in the pit, (Plate 1a) workers being required to wear breathing or face protection depending on levels of SO_2 present at the actual worksite. The McCrae Shale can pose serious rehabilitation problems, as it is capable of impacting cover material, further complicating rehabilitation (Plate 1b). The high NAPP and corresponding low ANC values at Mt Whaleback probably represent a worst case lithology for waste handling in Western Australia.

CRA/Argyle Diamonds

The Argyle Diamond deposit occurs in a lamproite pipe in middle Proterozoic quartzite deposits. These sedimentary deposits consist of the Revolver Creek Formation, Hensman Sandstone, and the Lisadell Formation. Associated waste units include: various quartzite units, 3 separate shale bands up to 30 metres in thickness within the quartzite, and sub economic portions of the lamproite.

Plate 1a Mt Whaleback Precipitation of Sulphur from venting SO_2 gas at a recently completed blast drillhole in the reactive McRae Shale unit.

Plate 1b Mt Whaleback "Burn through" of cover material placed over reactive McRae Shale unit materials.

Concern for ARD associated with the shale units lead CRA to undertake initial characterisation work in late 1991. The questionable unit is believed by Argyle to be one of the shale units in the Revolver Creek Formation. Two sets of samples were evaluated, 5 in November 1991, and 11 in January 1992. The initial set of samples averaged 0.49% Sulphur and had comparable ABA/NAG values suggesting some potential for acid generation, while the later samples contained much less Sulphur, the highest value being 0.17% Sulphur (Riley,1994). Thus the two groups of samples were at odds with each other, there being no other information presented on which to base a conclusion concerning the geochemistry of the waste unit.

The Argyle operation commenced operations in the 1985 and the reclamation plan at the time was to leave the waste dumps as end dumped facilities without reducing the slope of the material or attempting to revegetate the slopes. The dumps will, however, require some measure of stability which ensures long term resistance to erosion. In the field the dumps display a wide variety of stability and erosive characteristics, ranging from highly erosive material that has either undergone minor mass failure, or displays extensive evidence of erosion, to coarse durable quartzite showing little to no evidence of instability or erosion as dumped. Many of the most erosive sites are clearly dominated by the Revolver Creek shale units. Thus, the Revolver Creek Shale units are potentially a problem both from the standpoint of questionable geochemistry and poor stability and erosion resistance characteristics. It appears that Argyle had given little consideration to the ultimate configuration, and construction requirements of the waste dump complex. Waste material has historically been placed wherever it was most expedient at the time it was mined. If in fact the Revolver Creek Shales are the questionable units, then the inconsistent results should be clarified, either by performing additional work, or clarifying work done in the past. Additional work is likely to show the unit has limited potential to produce acid. From the standpoint of dump construction there are other reasons to selectively handle this material: it is simply not suitable for use on the external faces of the dumps.

Argyle needs to review their methods of dump construction in order to assure adequate volumes of coarse durable rock are available in the right locations and at the right times during the remaining mine life. A conceptual plan should be developed which displays the approximate ultimate waste dump configuration including water management. This plan should identify what portions of the dump complex will be revegetated, what portions will be "armoured", and where the relevant coversoil and coarse durable rock will be either stockpiled or direct handled.

Normandy Poseidon Scuddles/Golden Grove

Bob Dye , Environmental Officer, Perth Inspectorate, and I, with staff from the mine visited the tailing impoundment, stopping at what is essentially a sump for what little remediation and interception work has been done to intercept and dispose of leakage through the west side of the tailing embankment. The tailing embankment is constructed of gray-green waste rock, with an upper lift of buff coloured material from the decline for the Gossan Hill development. There were no visible sulphides in the waste rock used to construct the tailing embankment. There is a steady, but slow, flow into the "sump" area where a small pump is pumping the leachate to a small lined "decant" pond.

Plate 2a Scuddles Environmental Officer, Bob Dye, Perth Inspectorate measuring TDS values in leachate collection trench below tailing impoundment.

Plate 2b Big Bell Photo of leakage from the tailing facility taken from the crest of the embankment.

On the basis of our field measurements, the leachate has a pH of 3.7-3.8 and a TDS of 5200(Plate 2a). Below the road there is considerable vegetation damage and salt accumulation both at the surface and in shallow backhoe trenches which expose the leachate. There is evidence of plant stress or salt accumulation from 50-100 metres below the embankment. The tailing is obviously a sulphide rich product with sulphides (pyrite and chalcopyrite) readily visible in hand specimen. There appear to be other areas around the embankment leaking nearly as extensively as the first site visited. The mine geologist described the deposit as a classic polymetallic massive sulphide deposit. The hanging wall contact was described as a knife edge contact, with little contamination crossing the contact, while the footwall contact was described as a little more "fuzzy", but still quite sharp. The bulk of the waste rock currently produced remains underground as backfill. The mine is currently experiencing a shortage of backfill underground. The existing wasterock stockpile at the surface results from the original decline, which was constructed in the volcaniclastic rocks of the footwall. Upon examination of the waste rock, it was found to be predominantly a greenstone unit similar to the waste rock used to construct the tailing embankment, however it did contain abundant pyrite, including some fairly substantial chunks of massive sulphides (up to 30-40 cm on a side). Much of the greenstone present in the waste rock dump probably averages 3-5% pyrite/chalcopyrite. In spite of the obvious abundance of sulphides, there was little evidence of active oxidation taking place; no venting at the dump margins or leachate below the dump, no extensive zones of salt deposition, and no obvious oxidised zones. As noted in Table 3, the NAG and the NAPP both reflect an ability to generate acid that make it important this unit be returned underground. If this material were to be disposed of at surface it would not be suitable for exterior portions of dumps.

Normandy Poseidon/Big Bell

There are currently problems with tailings management at Big Bell, and also problems with historic tailings that include high sulphide material and Mercury (Hg). Currently there is no open cut mining at Big Bell, all mining being underground. All waste rocks in surface dumps are oxidised (?), with all sulphide bearing waste being returned either underground or into the disused pit. Groundwater at the mine has salinity of 10-15,000 TDS, and a pH of 4.2 -6.0. Heavy metals in groundwater are consistently below detection limits. Depth to groundwater is approximately 25 metres. Within the ore zone sulphides are predominantly pyrite/pyrrhotite, while outside the ore zone the percentage of the two minerals is reversed. There is also some marcasite present. The primary alteration in the deposit is a potassic enrichment evidenced by biotite and K-feldspar alteration. Generally there is very little quartz or carbonate, with what little carbonate there is being minor fracture or joint filling.

There are numerous seeps below the north and east walls of the embankment. The tailing material is deposited on an unprepared surface of weathered granitic rock, with the decant basically at the high point in the impoundment. This has caused the operational problems at the site evidenced by the extensive seeps below the embankment (Plate 2b). The measured pH of one of the numerous seeps below the embankment was 7.8, which most likely reflects the limited retention time in the impoundment. The historic tailing material Posgold inherited when they acquired the property could be seen to have oxidised (Plate 3a). Separate samples of both oxidised and unoxidised material were taken. The corresponding NAPP and NAG values are discussed in the Sample results section below. The fresh rock is an amphibolite which is altering to a biotite schist with minor sulphides (<3%), associated with minor quartz veining sub-parallel to schistosity.

Plate 3a Big Bell Historic tailing material at Big Bell, currently being reprocessed. Note apparent oxidation limits.

Plate 3b Western Mining Corporation Hill 50 Photo of current operations showing some of the historic operations.

Western Mining Corporation/Mt Magnet/Hill 50

The Mt Magnet/Hill 50 Deposit has been selected primarily because it represents one of the best examples of waste material with extensive neutralisation capacity. WMC inherited a considerable amount of disturbance when they acquired various pieces of the property (Plate 3b). They have been slowly whittling away at these older disturbances. Where possible, sulphide wastes have been encapsulated in oxide waste. Smaller pits are generally all in oxidised material. Groundwater in the area can be anywhere from 5-25 metres, though in the area of operations it is depressed by extensive dewatering. TDS is generally in the range of 10,000. Samples were taken from a dump crest, a low grade stockpile as well as the bottom of the Boomer pit and the Hill 50 decline. The pH of a sump pond at the bottom of the Boomer pit was 7.9. Rock was a light green to dark green altered basalt which had a fairly strong dilute HCl fizz. Additional discussions of the sample results from Hill 50 are discussed below in the sample results section.

St Barbara Mines/South Junction and Bluebird Pits

St Barbara Mines recovers ore from two pits in a greenstone hosted deposit. Oxidation is variable but generally quite deep (75-90 metres). The bottom of the South Junction pit west of the Great Northern Highway includes the usual greenstone type assemblages, and a quartz albite porphyry. Ore is hosted in quartz carbonate veining, ± fuchsite. At the upper levels of the pit the porphyry is entirely altered to clays and iron oxides. Water, which is of good quality, is a problem operationally and all dewatering reports to the mill as process water. The pH of water ponded at the bottom of the pit was 7.8. The greenstone unit at the bottom of the pit consisted of chlorite-albite with some talc. Sulphides were estimated at 2-4%. The quartz-albite porphyry unit includes < 1% pyrite, and this may be associated with alteration/weathering as fresher hand specimens of the porphyry seemed to have fewer sulphides. The Bluebird pit to the East of the highway was more extensively oxidised, probably because it hasn't reached the same depth as the South Junction Pit. The Bluebird pit includes a dolerite dike that has accessory sulphides, but it was not sampled due to blasting. It does not constitute a significant percentage of waste.

Black Swan Resources/Teutonic Bore

Teutonic Bore was a polymetallic sulphide deposit mined to recover copper and zinc in the late 1970s until approximately 1985 (Plate 4a, b). There is very little specific information available on file concerning the deposit. The lithology is a fairly typical looking greenstone assemblage with very limited quartz siderite veining. Mineralisation includes chalcopyrite, pyrite, galena, and sphalerite. There are abundant massive sulphides all along the haul road in the waste rock bund. During the period the mine operated there was no statutory requirement to perform reclamation at the site. Following the completion of operations the site was abandoned without any reclamation work having been performed (Plates 5-7).

This site may well represent a worst case scenario for ARD in Western Australia. The extensive dump complex is characterised by essentially random dumping of sulphidic waste along the top and exterior margins of the dump. Extensive areas at the site are covered with a variety of different sulphidic materials in the form of intermediate processing sites, coarse ore stockpiles, waste rock dumps, tailing material and routine spillage. As such, the site essentially constitutes an uncontrolled field scale test. Evidence of impacts from ARD at the

Plate 4a Teutonic Bore View of the adit at the bottom of the pit. The lake water pH is near neutral (6.7-7.1).

Plate 4b Teutonic Bore Photo looking to Southeast across lower tailing impoundment

Plate 5a Teutonic Bore Sulphidic material on the exterior face of the waste rock dump complex.

Plate 5b Teutonic Bore Impacts to vegetation from runoff below tailing impoundment.

Plate 6a Puddle on coarse ore stockpile with pH measured at 3.2.

Plate 6b Puddle adjacent to abandoned office and shop buildings. pH measured at 3.0

Plate 7
Panorama Looking West from Teutonic Bore Ore Stockpile

site includes offsite impacts to vegetation below tailing impoundments and possibly waste dumps (Plates 5a &b), low pH waters at the site (Plates 6a & b), and the general absence of vegetation throughout the site. The striking blue lake in the pit is actually close to neutral pH (6.7-7.1). Metals and other contaminants in the pit water are not strongly anomalous with the possible exception of SO_4.

Western Mining Corporation/Nickel Deposits

Several WMC nickel deposits are grouped together because of generally similar geology and the existing waste characterisation work WMC has performed. Common lithologies in the nickel deposits include ultramafics, komatiites, peridotite rich basalts and often minor interbedded sedimentary units. The interbedded sedimentary units are often pyritic, but generally make up only a limited percentage of the overall waste stream. Common sulphides associated with nickel mineralisation include: pentlandite (Fe,Ni)S, violarite (Ni_2FeS_4), pyrrhotite ($Fe_{1-x}S$) and pyrite (FeS_2). Carbonate alteration is a frequent component of the nickel mineralisation, but it is not present at all mine sites. The absence of carbonates has a significant effect on the acid producing potential. NAPP values for nickel deposits can range from 190 kg H_2SO_4/tonne to strongly negative values reflecting high ANC values. For nickel deposits it is quite likely the different stoichiometry of the sulphide mineralisation (pentlandite, violarite and pyrrhotite) means that the calculated NAPP overstates the samples ability to generate acid (Campbell 1995). The variation in characterisation work done in the past for nickel deposits only serves to highlight the importance of the site specific geochemistry of the deposits.

Nepean

Nepean is an underground nickel mine that operated in the 1970s. The complex includes a camp site, a shaft and hoist/shop area complex, miscellaneous settling ponds, a waste dump approximately two hectares in size, and an intermediate processing site below the waste dump. It is located at the very western edge of one of the greenstone belts as evidenced by extensive clean granite and pegmatite in the dump complex. Mineralisation is probably typical pyrrhotite/pentlandite ± violarite nickel mineralisation hosted in dolerite in the greenstone complex. Some minor calcite veining is present in the various greenstone complex rocks in the waste dump. Recent rains left several areas with standing water. Two small ponds in the processing site measured pHs of 5.4 and 4.3 (Plate 8a). The pH of a small seep from the dump complex measured 6.5 (Plate 8b). The three ore bins at the shaft still contained ore and were all dripping leachate from incident precipitation. It was not possible to collect a sample of the leachate to measure pH.

Nepean and Teutonic Bore are particularly important sites. Nepean indicates that given the proper physical characteristics, waste dumps in much of Western Australia may be capable of collecting and storing water that falls as incident precipitation, and discharging leachate. This accentuates the crucial importance of limiting water infiltration on waste dumps through revegetation and effective surface water control.

Teutonic Bore is important because it represents an uncontrolled field scale test of a site's ability to generate low quality waters and offsite impacts. Teutonic Bore indicates that given the proper geochemical characteristics, sites in Western Australia are capable of producing low pH waters and associated offsite impacts.

Plate 8a Nepean Intermediate processing facilities below waste rock dump. pH of standing water is 4.3.

Plate 8b Nepean Site of small seep below waste rock dump. Site is visible only as the darker area in this photo. The pH of the seep was 6.5.

The work conducted during this project would naturally lead to some refinement of Table 2 based on Plumlee's work shown in Chapter II. While this form of analysis is useful in establishing a general framework for environmental risks associated with differing deposit models, it may be best suited to geologic provinces with a wider variety of differing ore deposit models than are present in Western Australia. The Geoenvironmental Modelling was used as a screening methodology and was useful in that respect. After a review of many deposits in Western Australia, many of the greenstone hosted gold deposits will fall into the limited portion of the chart featuring carbonate alteration with moderate to low pyrite and base metals content. The chart and the resultant field visits highlight the difficulty of attempting to characterise deposits based solely on a literature review. The limited literature on a deposit may suggest the presence of carbonates, but usually provides insufficient information on which to base even a guess on waste characteristics. Conversely, the absence of mention of carbonates in the literature does not exclude its presence in the field.

B. Sample Results

The testwork results on the EC, pH, acid base accounting, and net acid generation are represented in Table 1 below. The full testwork laboratory reports are attached as Appendix E.

1. Inherent Acidity/Alkalinity and Salinity

Most of the samples showed high pH values ranging from a high value of 9.7 for a sample from Mt Gibson and 9.6 for two separate samples at Wiluna to a low value of 3.0 for tailing material at Teutonic Bore. The next lowest value was 5.3 for tailing material at Scuddles. Most values were between 8 and 9. EC values range from 28,000 uS/cm for the tailing material from Teutonic Bore to a low of 200 for a BIF from Tarmoola and talc schist at St Barbara. There may be a weak correlation between the EC values and SO_4,, which would be expected.

2. Acid Base Accounting

In general the most conspicuous feature of the results is the rather substantial ANC values for many of the samples. Acid Neutralisation Capacity (ANC) values range from a low of 2 kg H_2SO_4/tonne shared by a BIF at Tarmoola and a quartz vein with pyrite at Mt Gibson to a high of 540 kg H_2SO_4/tonne from a greenstone with associated talc and pyrite from St Barbara Mines South Junction pit. Only Kundip, Teutonic Bore, Mt Gibson and the quartz albite unit at St Barbara South Junction pit consistently show low ANC values. Values at Mt Gibson range from 2 to 7 kg H_2SO_4/tonne, while values at Kundip range from 4 to 10 kg H_2SO_4/tonne and the quartz albite porphyry at the South Junction pit has values of 3 and 4 kg H_2SO_4/tonne.

The Acid Producing Potential (APP) values are based on the total S % subtracting the SO_4 -S % to arrive at a number for "sulphide sulphur" which is then used to calculate the APP. This number is based on the assumption that all sulphide sulphur is present as pyrite (FeS_2). For many of the deposits sampled this assumption is not valid, since arsenopyrite and pyrrhotite are present in many of the deposits as noted in Table 1. Dissolution kinetics and stoichiometry for pyrrhotite and arsenopyrite are different from those for pyrite and this difference may be reflected in the Net Acid Generation test results discussed below.

Acid Producing Potential values vary widely as might be expected over such a varied lithologic and areally extensive sample population. Many of the samples with the highest APP values were specifically selected to represent a worst case sample for any given deposit. With the exception of Mt Gibson, virtually all gold deposits and the associated sulphide mineralisation have relatively low APP values coupled with relatively high ANC values. Sample values range from 0 at several sites to 744 kg H_2SO_4/tonne for tailing material at Scuddles. The average APP value is 44 kg H_2SO_4/tonne for all the samples. The ANC values for the same group of samples averages 101 kg H_2SO_4/tonne. The Mt Gibson samples average 76 kg H_2SO_4/tonne APP and only 5 kg H_2SO_4/tonne ANC. These samples can be considered to represent worst case numbers, being samples of material that would normally be handled as ore. They are an indicator that careful selection of material to be processed would be considerably more important at Mt Gibson than at many of the other minesites visited because of the limited neutralising capacity of rocks at Mt Gibson.

The only deposits sampled representative of polymetallic massive sulphides include Scuddles/Golden Grove, Teutonic Bore, and tailings at Kundip (Ravensthorpe). While this is a comparatively limited sample population, the values for APP and ANC suggest these deposits merit close scrutiny.

3. Net Acid Generation

The Net Acid Generation results are presented in Table 1 above and also in Table 2 below where they are compared directly with the NAPP results. Sample values are plotted only for those samples with NAPP values higher than -20 kg H_2SO_4/tonne or where there were anomalous results.

Net Acid Generation results reflect positive values (acid generation) for only 34 of the 107 samples. Eight of the these results were anomalous, since the samples had either 0.03 % S or less. These samples may reflect H_2O_2 attack of ferro-magnesian silicates (Campbell,1995).

There is some agreement between the NAG test and NAPP values for samples with Sulphide S values less than 1.5% and NAPP values less than 25 kg H_2SO_4/tonne. Higher values for either Sulphide S or NAPP result in the NAG test being considerably lower than the NAPP. Thus the NAG test would suggest less ability to generate acid than the NAPP. Several of these samples include sulphide minerals other than pyrite, so this variation from the NAPP results may be a reflection of the different dissolution kinetics and stoichiometry of the other sulphide minerals present in the samples. For these samples the results nonetheless suggest a strong ability to produce acid. The NAG test results are based used in conjunction with other tests, information from the other tests being useful in assisting interpretation of the NAG test.

4. Discussion

Most of the samples analysed are unlikely to produce acid and would be classified as "Non Acid Forming" based on both the NAPP and the NAG values. This is primarily a reflection of the extensive carbonate alteration associated with ore emplacement in many of the ore bodies sampled. Within the deposits sampled there are some notable exceptions that would result in either all or portions of some deposits being classified as either "Acid Forming" or "Potentially Acid Forming". Either of these classifications could require special consideration in either waste handling or waste dump construction and monitoring.

The data collected does not permit any classification of mineral deposits and mineralogy that excludes deposits from review on a case by case basis. Each deposit must be analysed to assure ARD is properly considered.

The best testing procedures for each deposit must be based on an understanding of the geology and geochemistry of each deposit. It is likely a range of tests will prove most useful. The ABA testing is always a good place to start and can provide backup checks on other more easily run tests, like Leco Sulphur analysis or NAG testing.

Samples are unlikely to generate acid when the NAPP value is below -20 kg H_2SO_4/tonne, or the ANC value is at least 3 times the NAPP value . Ideally these should be backed up by NAG testing substantiating the ability of a sample to neutralise produced acid.

Table 3 Sample Results

Client ID	pH	EC	Sulphide Minerals	Lithologic Description	Total S	SO4	APP	ANC	NAG
		uS/cm			%	%	KgH2SO4/Tonne		
Bb1a	8.1	328	Py,Pyrr	Big Bell UG Waste,Amphibolite	0.15	0.03	5	20	N/A
Bb1b	8.0	3100		Same	0.05	0.01	2	19	N/A
Bb1T	7.2	7300		Big Bell Tails	0.98	0.32	28	11	17
Bb2t	7.7	3220		Big Bell Historic Tails (Unox ?)	1.98	0.3	58	24	N/A
Bb3t	6.8	3030		Same (Oxidised?)	2.22	0.84	59	13	55
Bb10	4.4	3.84		Amphibolite schist slightly ox.	3.98	1.05	111	4	17
Bb11	7.4	979		Same, less oxidised	0.5	0.06	15	137	N/A
Gg1	8.2	644	Py	Golden Crown UG Ore	0.73	0.03	23	289	N/A
Gg2	8.7	3700		Same, waste	0.27	0.01	8	71	N/A
H501	8.4	583	Pyrr,Py	Hill 50/Boomer pit Gs w/QV, Py	1.91	<0.01	60	207	N/A
H502	8.7	3200		Same	0.07	0.01	2	244	N/A
H502a	8.8	424		Same	0.16	<0.01	5	292	N/A
H503	8.5	753		Same	1.13	<0.01	35	96	N/A
H504	8.3	3600		Same	0.46	0.01	14	350	N/A
H51	8.2	520		Hill 50/decline GS w/Qtz vn,sulph	1.87	0.02	58	108	N/A
H52	7.6	480		Same	0.76	0.09	23	228	N/A
H53	7.7	549		Same	6.34	0.09	193	354	N/A
H54	8.7	230		Same	0.17	<0.01	5	135	N/A
H56	8.4	700		Hill 50 Greenstone from Dump	0.11	<0.01	3	381	N/A
H57	8.5	491		Same	0.1	0.03	3	402	N/A
HL12	8.6	520	Aspy,Py	Harb.Lts. GS w/Fuch,minor sulph,carb	0.11	<0.01	3	326	N/A
HL21a	8.8	549		Same, south end	0.4	<0.01	13	373	N/A
HL21b	8.6	550		Same, GS w/Qtz ,Carb vn,minor sulph	0.23	0.01	7	270	N/A
HL2a	8.6	649		Same south end Greenstone	0.24	<0.01	8	340	N/A
HL2b	8.5	560		Same	0.3	0.01	9	205	N/A
HL3a	8.7	912		Same, north end Ox. GS	0.03	<0.01	0	19	N/A
HL3b	9.0	~400		Same	0.02	0.02	0	13	5
HL41	8.0	4130		Tailing Material	0.33	0.33	7	18	N/A
Mg11	9.7	325	Py	Mt Gibson Orion Pit adj to shear	0.39	0.03	12	41	2
Mg12	8.0	654		W/QV and Pyrite	11.1	<0.01	347	26	133
Mg13	7.8	3800		Same	7.52	0.03	235	7	79
Mg13-2	7.4	~1000		Same	<0.01	0.03	0	2	2

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Client ID	pH	EC	Sulphide	Lithologic Description	Total S	SO4	APP	ANC	NAG
		uS/cm	Minerals		%	%	KgH2SO4/Tonne		
Mg21	7.8	1078	Py	Donkey Pit Biotite Schist	5.03	0.06	157	29	109
Mg22	8.5	678		Same	1.66	0.03	52	85	28
Mg23b	8.2	670		Same, Biot. Sch. w/Qtz vn,w/Py	4.47	0.04	140	6	64
Mg31a	8.1	1961		Qtz AB Porphyry(?)	0.03	0.03	1	6	1
Mg32a	8.1	2170		Greenstone	0.13	0.03	4	10	N/A
Mg32b	8.4	N/A		Same	0.06	0.02	2	9	N/A
Mg33a	7.4	2050		Same, Sl. more oxidised	0.02	0.03	0	7	5
Mg33b	7.0	700		Same	0.01	0.02	0	3	4
Pa1a	7.8	4000	Py,Aspy	**Paddington Shale w/Py**	0.46	0.03	14	7	8
Pa1b	8.0	6300	&Pyrr	Same	0.45	0.03	14	19	0.4
Pa2a	8.0	7580		More oxidised shale	0.19	0.27	3	403	N/A
Pa2b	8.2	2000		Same	0.06	0.18	2	366	N/A
Pa3t	7.9	44000		Tailing Material	0.48	0.54	9	96	N/A
Ra1a	78.0	3810	Py,Cpy	**Kundip (Ravensthorpe)Unweathered tails**	0.13	0.51	0	37	N/A
Ra1b	7.5	3800		Same	0.1	0.21	0	6	0.4
Ra2a	7.1	7180		Same, Sl more oxidised tails	0.22	ND	7	29	N/A
Ra2b	5.5	19000		Same	0.27	0.81	0	4	0.6
Ra3a	7.2	2600		Unoxidised tails	4.2	0.72	121	41	73
Ra3b	7.5	2900		Same	4.44	1.02	126	10	33
Ra4a	7.6	15370		Same directly above 3b oxidised	0.31	ND	10	20	N/A
Ra4b	7.8	9000		Same	0.13	0.47	0	10	N/A
Sb1	9.0	199	Py	**St Barbara Talc Schist**	0.02	<0.01	0	27	3
Sb2a	8.1	785		Same Qtz Ab Porphyry	0.02	0.27	0	5	N/A
Sb2b	8.8	1200		Same	<0.01	0.01	0	4	18
Sb3a	8.1	1237		Same	0.02	0.03	0	7	7
Sb3b	8.1	1500		Same	<0.01	0.01	0	3	13
Sb4	9.0	520		Same, Qtz vn w/Carb,Fuch	<0.01	<0.01	0	28	N/A
Sb5	9.0	264		Same	0.02	<0.01	0	89	N/A
Sb6	8.6	N/A		Same, GS w/Talc,Py	0.3	<0.01	9	137	N/A
Sb7	8.9	460		Same as above	0.11	<0.01	6	540	N/A
Sc1a	8.6	367	Py,Cpy,	**Scuddles, GS w/Py**	1.08	<0.01	34	64	19
Sc1b	9.2	270	Sph,Gln	Same	1.09	0.01	34	12	23

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Client ID	pH	EC	Sulphide	Lithologic Description	Total S	SO4	APP	ANC	NAG
		uS/cm	Minerals		%	%	KgH2SO4/Tonne		
Sc2	5.3	27700		Tailing	24.6	2.49	728	ND	480
Tb1	8.4	440	Py,Cpy...	Teutonic Bore GS in Waste Bund	3.9	0.03	122	15	37
Tr5a	8.6	431	Py	Tarmoola Granite	0.38	<0.01	12	92	N/A
Tr5b	9.1	450		Same	0.18	<0.01	6	21	N/A
Tr6a	8.9	341		Same, breccia	0.07	0.03	0	81	N/A
Tr6b	9.1	410		Same	0.1	<0.01	3	40	N/A
Tr7a	8.4	420		Greenstone w/Sulph.	1.12	<0.01	35	46	N/A
Tr7b	8.8	360		Same	1.66	0.01	52	259	N/A
Tr8a	8.1	313		BIF	0.05	0.03	0	3	4
Tr8b	8.0	200		Same	0.02	0.03	0	2	4
Wlh10a	8.7	814	Py, Aspy	Wiluna,Happy Jack,S ore zone	0.3	0.03	9	306	N/A
Wlh10b	8.6	678		Same,	0.19	0.03	6	281	N/A
Wlh11a	8.5	1882		Same, Oxidised material	0.14	<0.01	4	17	N/A
Wlh11b	8.7	560		Same	0.01	0.04	0	11	N/A
Wlh121	8.4	643		Same, Low Mg Basalt	0.12	ND	4	261	N/A
Wlh122	9.6	690		Same	0.03	0.01	0	116	N/A
Wn1a	9.4	799		Same, North Pit ore zone	0.08	<0.01	0	191	N/A
Wn1b	9.2	3400		Same	0.09	0.01	3	147	N/A
Wn2a	9.7	586		Same. FW Greenstone	0.04	ND	0	145	N/A
Wn2b	9.6	550		Same, Footwall GS	0.01	0.01	0	15	N/A
Wn3b	8.5	3700		Same, Interbedded Metaseds	0.09	0.07	3	19	N/A
Wn5a	7.7	4500		Same, shear w/Py Blebs	7.14	0.03	129	56	155
Wn5b	7.4	5700		Same	10	0.53	301	10	29
Wn6	9.3	540		Same as above	2.02	0.01	63	145	N/A
Wn7	8.6	784		Same, Sedimentary Unit	2.73	<0.01	85	105	51
Wn8a	9.0	659		Same, small intrusive(Qtz Porph?)	0.23	0.03	7	227	N/A
Wn8b	9.3	410		Same	0.15	0.01	5	92	N/A
Wn9a	8.6	975		Same, HW ore zone	2.42	0.03	76	235	N/A
Wn9b	8.8	1000		Same	1.8	0.02	56	211	N/A
Yo1a	8.6	635			4.13	0.54	121	57	83
Yo1b	8.9	480	Py,Aspy	Youanmi "Granite" from pit Backfill	3.36	0.02	105	21	13
Frs1t			Ptl,Pyrr	Forrestania Tailing Material					

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Client ID	pH	EC uS/cm	Sulphide Minerals	Lithologic Description	Total S %	SO4 %	APP	ANC	NAG
							KgH2SO4/Tonne		
Frs2				Same,BIF from Waste Rock Dump					
Frs3				Same, Metasedimentary unit					
Dr1			Ptl,Pyrr	**Digger's Rock BIF Oxidised**					
Dr2				Same, Ultramafic No Visible Sulphide					
Bo1			Pyrr,Py	**Bounty, Basalt, No visible Sulphide**					
Bo2				Same, FW pod material					
Bo3				Same, BIF					
Ys1			Pyrr,Py	**Yilgarn Star, Schist,minor Py**					
Ys2				Same, metabasalt, Qtz,cal vn					
Nv1			Pyrr,Py	**Nevoria, Amphibolite, minor QV**					
Nv2				Same, w/minor Py					
Ch1			Gln,Pyrr	**Copperhead, BIF w/Pyrr**					
Ch2			&Cpy,Py	Same, talc chlorite schist					
Ch3				Same, Ultramafics at "saddle"					
Ch4				Same, CH north dolomite "lode"					
Md1			Py,Sph,	**Mt Dimer, Granite from Waste**					
Md2			Gln,CPY	Same, Shear in granite					
Md3			& Brn	Same tailing material					
Tb2	7.8	370	Py,Cpy,&	**Teutonic Bore, Waste from pit**	0.62	0.07	18	8	13
Tb3	6.2	10000	Gln,Sph	Same, process material near ore stkpl	7.21	2.9	191	8	18
Tb4	3.0	28000		Same, solidified tailing material	18.1	17	381	-88	105
Jb1	9.0	120		**Jubilee, Talc chl schist w/carb**	<0.01	<0.01	0	23	N/A
Ti1	7.7	1100	Py,Aspy,	**3 Mile Hill Tindal QtzBiot Porph**	2.16	0.16	65	10	43
Ti2	8.1	Gelled	Pyrr,CPy	Same, Ultramafic	0.4	0.11	11	9	4
Kc1	8.3	1400	Tl,Py	**KCGM Superpit subgrade w/carb**	1.08	0.04	33	58	N/A
Kc2	8.4	8200		Same, "marginal "	0.39	0.02	12	164	N/A
Kb1	8.8	580	Py,Aspy	**Kanowna Belle "Grit" w/carb**	<0.01	<0.01	0	49	N/A
Kb2	7.5	3500		Same, lowgrade from oxidised in pit	0.1	0.04	3	2	2
Ne1	8.9	200	Pyrr,Ptl?	**Nepean, GS/UM adj to shaft**	0.01	0.01	0	8	N/A
CG1	8.4	350	Aspy,Py	**Coolgardie Gold low grade,Aspy**	0.55	0.03	17	137	N/A
					1.662376	0.425128	44.50467	101.5	

Table 4 Comparison of NAPP and NAG Values

Lithologic Description	NAPP	NAG
Big Bell UG Waste,Amphibolite Schist	-17	N/A
Same	-15	N/A
Big Bell Tails	16	17
Big Bell Historic Tails (Unox?)	34	N/A
Same, (Ox?)	46	55
Amphibolite schist sl. Ox	107	17
Harb.Lts. Oxidised GS unit	-13	5.4
Same	-13	5*
Tailing	-11	N/A
Mt Gibson Orion pit adj to shear	-29	2
Same w/ Qtz vn, Py	321	133
Same w/ Qtz vn, Py	228	79
Same as above	-2	2*
Donkey pit, Biotite schist	128	109
Same	-33	28
Same, Biot. Sch. w/Qtz vn,w/Py	134	64
Same, Quartz Albite porph.	-5	1
Same, GS	-7	N/A
Same	-6	N/A
Same, sl. more oxidised	-7	N/A
Same	-7	5*
Same, sl. more oxidised	-3	4
Paddington Shale w/Py	7	8
Same	-5	0.4
Same, oxidised shale unit	-364	N/A
Ravensthorpe, (Kundip) unweath tails (?)	-6	0.4
Same, Sl. oxidised tails	-4	0.6
Same unoxidised tails	80	73
Same. unoxidised tails	116	33.3
Same, oxidised, directly above 3b	-6	N/A
Same	-10	N/A
St Barbara, Talc schist	-27	3
Same, Quartz Albite Porph.	-5	N/A
Same, Quartz Albite Porph	-4	17.6
Same	-7	7*
St Barb. Qtz Ab Porph	-3	13*
Same, Qtz vn w/Carb,Fuch	-28	N/A
Scuddles GS w/Py	-30	19
Same	22	23
Same, Tailing	728	480
Teutonic Bore GS in Waste Bund	107	36.9
Same from pit bottom	10	13
Same, Process Material	183	18
Same, Tailings	381	105
Tarmoola Granite	-15	N/A
Tarmoola GS w/Sulph	-11	N/A
Same, BIF	-2	4
Wiluna oxidised material	-11	N/A
Same	-13	N/A
Same, Footwall GS	-15	N/A
Same, Interbedded Metaseds	-16	N/A

Table 4 Comparison of NAPP and NAG Values (Continued)

Same, shear zone w/ Py blebs	73	155
Same	291	29
Same, sedimentary unit	-20	51
Youanmi "Granite" from pit Backfill	84	13
Same	64	83
Three Mile Hill,Tindal, Qtz/bio/porph	55	43
Same, ultramafics	2	4
Kanowna Belle, lowgrade ox from pit	1	2
(* Indicates less than 0.03 % Sulphur)		

4. Sample Results Discussion of Specific Deposits

The results from several deposits merit some additional discussion.

Normandy Poseidon Golden Grove/Scuddles

Sample results from the waste rock suggest it would be rated as "Potentially Acid Forming", based on a conflicting NAPP values of -30 and 22 kg H_2SO_4/tonne and NAG values in agreement at 19 and 23 kg H_2SO_4/tonne. There is little confusion on the tailing material based both on the NAPP value of 728 kg H_2SO_4/tonne and a NAG value of 480 kg H_2SO_4/tonne and also on the acid waters that currently leak from the impoundment. The Scuddles tailings are clearly "Acid Forming" and will require careful consideration during the development of a rehabilitation program.

Normandy Poseidon Big Bell

Sample results from Big Bell are somewhat contradictory in regard to waste rock units. Samples of amphibolite returned NAPP/NAG values of -122 kg H_2SO_4/tonne, N/A and 109 and 17 kg H_2SO_4/tonne respectively leaving considerable room for confusion. There can be little confusion on the tailing material all of which rates either as "Potentially Acid Forming" (current tailing material) or "Acid Forming" (historic tailing material) based on values of 35 and 48 kg H_2SO_4/tonne for the historic tails and 17 kg H_2SO_4/tonne for the current tailing material. Interestingly there was little difference in the results of the two different coloured samples from the historic tailing material shown in plate 3a. The NAPP values were 35 and 48, which corresponded with NAG values of N/A and 55. The reason for the N/A NAG value is not known. The only other difference between the two samples was the higher percentage of sulphate in the weathered tailings, 0.84% versus 0.3%, which would be expected in a more weathered sample.

Western Mining Corporation Hill 50/Mt Magnet

All samples at Hill 50 reflect the abundant carbonate present throughout the deposits. APP values range from 2 to 197 kg H_2SO_4/tonne, while ANC values range from 96 to 402 kg H_2SO_4/ton. The NAG values also reflect the samples' ability to neutralise any produced acid.

Teutonic Bore

All samples at Teutonic Bore would be classified either as "Potentially Acid Forming" (only one sample), or "Acid Forming" (three samples) based on both NAPP and NAG results. The three samples are all strong acid producers as is discussed in the field results section.

Kundip (Ravensthorpe)

All the unoxidised tailings at Kundip would be characterised as "Acid Forming" based on both the NAPP and the NAG test results.

CHAPTER IV RECOMMENDATIONS

A. Recommendations for DME

The existing legislative and regulatory framework is sufficiently flexible that no major legislative or regulatory changes are necessary at this time to protect surface resources. A minor change in Section 84 of the Mining Act of 1978 to include a reference to groundwater could help insure Western Australia's important groundwater resources are adequately protected.

On the basis of the sampling and site visits conducted during the course of the project, the following items are recommended for consideration by the Department:

1) All NOIs that involve above ground disposal of waste material should include preliminary waste characterisation work as part of the NOI submittal.

Preliminary waste characterisation work should focus on a geologic evaluation of waste rock units at the site (eg. surface exposures, drill hole data, etc.). The general geologic relationships, waste rock lithology, mineralogy and alteration, and baseline hydrology are examples of information that is valuable in preliminary waste characterisation. Potential ARD problems, typically sulphide minerals in a waste rock unit, can be quickly highlighted during a preliminary waste characterisation program.

2) Additional waste characterisation will be necessary when the preliminary waste characterisation work has identified a potential ARD problem. The additional waste characterisation work may include an ongoing comprehensive program of static testing:

At this stage, waste characterisation work should focus on a detailed geologic evaluation of waste rock units at the site (eg. surface exposures, drill hole data, etc.). The general geologic relationships, waste rock lithology, mineralogy and alteration, sulphide morphology and distribution, distribution of rock units with the potential to neutralise acid production (eg. carbonates), baseline hydrology, and physical waste rock and process material properties are all examples of information that is valuable at this stage for predicting the potential development of ARD.

Static tests are a fairly quick and inexpensive preliminary determination of the risk of acid production. Typically samples can be run in two to three weeks with costs from $30 to $170 per sample. Static tests attempt to predict acid producing potential based on the acid generating and acid neutralising minerals present in the sample and are discussed in the work performed chapter. In the event there are uncertainties following static tests, it may be appropriate for further evaluation by kinetic testing. The actual tests that will best characterise a particular deposit will likely include a mix of Acid Base Accounting, Sulphur determination and Net Acid Generation.

Kinetic tests are used as an attempt to duplicate in the laboratory how the waste will behave in the weathering environment. They are considerably more time consuming and expensive than static tests. Time to complete a test can range from several days to several months. Costs range from $3,000 to $5,000 per sample.

3) Sites where characterisation work identifies a potential for ARD must be closely evaluated for long term engineering stability and water management of all sulphidic material including: tailing facilities, waste rock dumps, haul roads, plant facilities, and any other portions of the site where sulphidic waste is potentially exposed at the surface. Rehabilitation emphasis must focus on the durability of the proposed cover system used to isolate sulphidic materials.

4) Operator monitoring plans should be developed for sites where static or kinetic testing has identified a problematic unit. These plans should focus on the measures to prevent adverse impacts that might result from ARD throughout the project life. This could include a comprehensive monitoring program utilising lysimeters, neutron probes, thermistors etc. as has been done at other waste dump monitoring programs.

5) Action is urgently needed at abandoned minesites where ARD is being generated to identify solutions and rehabilitate the sites to prevent further adverse environmental impacts.

Table 5 is a representation of a systematic approach throughout a project life of a characterisation and monitoring program.

B. Recommendations for Industry Practice

1) The industry should begin the process of environmental and waste management evaluation at an early stage during exploration programs. There is a considerable amount of environmental, geological and geotechnical information which can be routinely collected during exploration at little additional cost. This information can be invaluable in assuring both a complete NOI submittal to the Department, and adequate consideration by the company of the likely economic impacts of environmental protection.

2) The industry should coordinate with the Department to refine what levels of static and kinetic testing are appropriate for different types of deposits throughout the varied physiographic regions of Western Australia.

3) The industry, through the Chamber of Mines and Energy, should seek to highlight successful examples of waste characterisation and handling throughout mine life, from initial exploration through final rehabilitation.

4) For sites where ARD has been identified as a concern, the industry should develop internal monitoring programs, highlighted through the Annual Reports to the Department, that focus on prevention of ARD.

5) The industry, through the Chamber of Mines and Energy, should evaluate the performance of existing waste rock dump rehabilitation. Waste rock dump construction at many sites may not represent landforms with long term stability.

C. Recommendations for Further Research

The industry and the Department may wish to consider the following suggestions for future research:

1) Kinetic testing of several representative ore/waste suites to compare with the database developing on static tests throughout WA. Do the static tests accurately reflect actual environmental conditions?

Specific questions should include: a) What allowance should be made in static testing for mineral deposits with extensive carbonate alteration consisting mostly of siderite or ferroan dolomite and ankerite? These minerals may not be effective at neutralising produced acid, thus producing ANC numbers which may overstate the ability to neutralise acid and thus not reflect actual conditions. b) What allowance should be made for sulphide minerals, usually arsenopyrite and pyrrhotite which have different stoichiometry for acid formation than pyrite? The calculated APP numbers for samples with arsenopyrite and pyrrhotite may not accurately reflect the sample's ability to produce acid. c) What is the fate of arsenic or any other environmentally significant elements released during the oxidation of sulphides?

2) Detailed hydrogeologic and geochemical evaluation of rehabilitated and unrehabilitated sulphidic waste dumps to determine if actual rehabilitation measures in place are effective at limiting the environmental impacts of oxidation of contained sulphidic material. Additional information can be obtained on the likely quantity and quality of any potential leachate.

3) Detailed evaluation of the hydrology of an unrehabilitated waste rock dump that details the water balance for the dump.

Table 5 Sample Waste Characterisation Program

Project Stage	Waste Characterisation	Site Characterisation
Initial Exploration	General geologic evaluation	General site environmental conditions
Advanced Exploration	Detailed geologic evaluation Determination of representative samples of waste and ore lithologies If sulphides are present, initial characterisation work	Assemble base line information available from drilling program, depth to groundwater, water quality,
Project Development	Detailed waste characterisation work "Static" testing could include: ABA, NAG Sulphur analysis Are units ARD generators? Are "kinetic" tests required? If no ARD generating units present continue normal planning process If ARD units present Develop detailed control strategy	Detailed Base Line Monitoring Geotechnical evaluations Detailed site design planning Are proposed waste sites suitable?
Operations	Continue testing program to assure control strategy Waste handling program follows control strategy developed above	Monitor waste facilities
Closure	Complete rehabilitation as developed through control strategy	Monitor rehabilitation work

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Appendix A

Acid Rock Drainage Survey Form

(827/94)

ACID ROCK DRAINAGE (ARD) SURVEY
WA MINESITES

1. SITE DETAILS:

   (a) Project Name: ______________________

   (b) Project Operator: ______________________

   (c) Project Mailing Address: ______________________

   ____

   (d) Telephone: ______________ Fax: ______________

   (e) What are your project products? (Gold, Silver, Nickel, Iron Ore, etc)

   ____

2. DO YOU MINE FRESH ROCK? YES/NO

   (If you answer "NO" to Question 2 - no further responses required)

3. DOES THE FRESH ROCK CONTAIN SULPHIDES? YES/NO

   ____

4. IN WHAT FORM ARE THE SULPHIDES (e.g. pyrite, pyrrhotite, marcasite, chalcopyrite, arsenopyrite)?

   ____

5. ARE YOUR SULPHIDES CONTAINED IN YOUR WASTE ROCK? YES/NO

6. ARE YOUR SULPHIDES CONTAINED IN YOUR ORE? YES/NO

   ____

7. HAVE YOU UNDERTAKEN ANY CHARACTERIZATION TESTING ON YOUR SULPHIDES? YES/NO. IF "YES" WHAT CHARACTERIZATION TESTS HAVE BEEN CARRIED OUT? (Please give examples)

   ____

   ____

8. HAVE YOU UNDERTAKEN ACID BASE ACCOUNTING OF YOUR SULPHIDES? YES/NO

   ____

9. HAVE YOU UNDERTAKEN CALCULATIONS FOR "NET NEUTRALISING POTENTIAL" OR "NET ACID PRODUCTION POTENTIAL"? YES/NO

   ____

10. HAVE YOU UNDERTAKEN ANY KINETIC TESTS TO SIMULATE ARD PRODUCTION? YES/NO

    IF YES, DID THE TESTS INDICATE A POTENTIAL PROBLEM? YES/NO

    ____

11. HAVE YOU SEEN ANY EVIDENCE THAT ARD MAY OCCUR AT ANY OF YOUR SITES? YES/NO IF YES, PLEASE IDENTIFY THE SITES.

    ____

12. ANY OTHER COMMENTS YOU MAY WISH TO MAKE? (ATTACH)

______________________ Signed

______________________ Date

7 October 1994
BMV445FI

Appendix B

Field Notes From Site Visits

FIELD NOTES
OCTOBER 19 - 28, 1994

October 19, 1994 0600 - 1900 En route from Perth to Newman

October 20, 1994 @ Newman/Mt Whaleback Weather Hot (38-40) and sunny
Keith and I met with Mike Anstey, Sr. Environmental Officer, BHP Iron Ore. We also met with David Todd, Mgr, Occupational Health and Safety Department.

Following introductions and general discussions we adjourned to the main conference room where Mike gave us a summary overview of BHP Iron Operations in general. BHP produces a variety of ores from Mt. Whaleback and numerous satellite ore deposits. Generally ores from the satellite deposits are blended with higher quality ore from Newman to produce the desired quality ore. Cumulative tonnage from all deposits is 49 mm tonnes per year (TPY) Yandi produces 11.5 mm TPY, Yarrie, 10-15 mm TPY. Major market is Japan (33%), with lesser amounts going to other Asian markets and some going to the limited Australian market as well.

Following the general overview we gathered our field gear and left for a site visit of the Mt. Whaleback deposit. The problematic unit here with respect to ARD potential is the McRae shale, a dense, black, pyritic shale unit which occurs in the upper portions of the "Centre Pit". We first visited the waste dump complex where the McRae shale is being dumped. The dumping technique at this point is fairly standard end dump construction. The proposal for reclamation of the dump at this point is to come over the top of the shale portion of the dump with 1-2 lifts of oxidised rock and perform some lysimeter work to assure the placement of the upper lifts restricts water movement into the shale portion of the dump. Mike will be working with John Bennett on the lysimeter work. We looked at an upper dump where the McRae shale had been covered with an oxidised rock, (oxidised McRae shale..??) to an indeterminate depth. This was ineffective at reducing the oxidation of the underlying shale unit as evidenced by active venting throughout the dump complex. This was indicated both by "burn through" in the cover rock, active venting and strong SO2 odour throughout the area. Several photos were taken, but my camera did not completely rewind the film, I may have to get copies from Keith...

Following the visit to the dump, we visited the McRae shale in the pit. The McRae shale is <u>actively</u> venting in the pit which poses serious operational problems! Drilled blast holes must be sleeved and blasted immediately after loading, as heat from the vigorous oxidation reaction will detonate the holes if not blasted immediately after loading. The SO2 levels are closely monitored in the McRae shale area, and in portions of the pit below the McRae shale. The levels can require either workers wear either 1/2 or full face mask protection from the generated fumes.

We also looked at scalloping (moonscaping) in portions of the waste dump facing toward the Mine Industrial Complex . Success here is rather mediocre, due probably to poor quality cover soil. BHP is investigating using materials from OB 29 and fines at Jimblebar as cover soil substitute. Mike gave me a copy of the Waste Rock Geochem sampling document.

After lunch, we met with Mark Endersby, Environmental Officer and looked at OB 29 and then drove down to Jimblebar to review operations there and also look for pebble mound mouse sites.
We found several sites, both occupied and unoccupied.

After returning to Mt. Whaleback, we left the site at approximately 1700.

October 21, 1994 Weather hot (38 - 40) and sunny

We departed Newman at approximately 0700 for Mike Manganese and Woodie Woodie, arriving at Mike Manganese at approximately 1200. At Mike we met Dean O'Keefe, the geologist on site. Mike is a MnO2 replacement of chert in Proterozoic metasediments. Permian tillite caps the deposit. Woodie Woodie is a similar type of deposit with several different pits. Some reclamation has recently been performed. In general Woodie Woodie is quite a mess!, with considerable surface disturbance unreclaimed and an enormous quantity of general debris remaining.

Following our brief visit to W-W, where we saw only the caretaker, we continued on to Nifty copper. At Nifty we met John Drummond, who is manager of safety/environment. Nifty is a fly in - fly out camp. Mine employees work 2 weeks on/weeks off, technical staff is 9 days on/5 days off. Most staff live either in Port Hedland or Perth. Nifty started operations in October 1992 and they have reached 75% of their target production. Currently they are mining only oxide ore. They estimate 10 years reserves on hand and their are several favourable exploration targets close by. Mining is done by contract to Leighton Contractors. The mine manager, who is also the environmental officer was out. Robin DeVries, a geologist escorted us on the mine site. Ore in the Nifty deposit at this level is malachite, azurite, native copper, and cuprite. Below the oxide zone the deposit includes chalcocite and chalcopyrite. Robin said they are running at 50% capacity due to surfectants and organics in the plant. Water quality of "Lake Nifty " , which results from the dewatering of the main pit ,is good. Strip ratio is currently 6:1. Nifty does have diagenetic pyrite in an identified shale unit, but they have done no testing of the material at this time. I discussed ARD testing with Robin. The host rock is a completely silicified carbonate unit, which at first glance in hand specimen looks to be an unaltered carbonate. We also looked at portions of one of the waste rock dumps which had been sequentially reclaimed to a "pseudo-dune" with salvaged sand. The reclamation was quite good, even considering the relatively short time since salvaged sand was placed.

October 22, 1994 Weather hot and sunny

We departed Nifty at approximately 0700 for Yarrie, driving through a brush fire en route! We toured Yarrie with John Cetafonti. Yarrie mines approximately mm TPY, with a 7 year mine life, of which 6 years are left. The ore is a high grade hematitic ore with very few impurities. There is some limited shale associated with the deposit at a depth of 70-80 metres. There is some pyrite associated with the shales and John and I discussed doing some tests on the shale unit. The reclamation plan at Yarrie will basically be to fill in some of the valleys with the waste rock creating essentially artificial bluffs, replicating the existing topography. These waste dumps will generally shield the mine site from visibility. Following the visit to Yarrie we went and looked at the reclamation at Shay Gap. Shay Gap has been essentially totally removed and is being rehabilitated. Following this site visit we drove on to Broome.

October 23, 1994 Weather hot (40+) and humid

En route to the Phillips Range project up the Gibb river road, we stopped and looked at Ellendale diamonds site rehab work, again driving through an active range fire. Much of the country along the Gibb River Road had been burned on one side or the other of the road.

At Phillips Range we met Greg Brennan and looked at several sites west of camp where bulk samples had been taken. Total material sampled was 150,000 tonnes at an expenditure to date of $20mm. The estimated size of the deposit is approximately 22 hectares. The top 150 metres of the kimberlite pipe is approximately 70% waste consisting of country rock (quartzite) which collapsed back into the pipe after emplacement. We looked at the tailing impoundment and plant, Greg showing us the XRF separator. We also looked at samples of diamonds. They estimate 70% are gem quality. Evening entertainment at the barbie was provided by "Old Number 1", the fruit eating steer!

October 24, 1994 Weather hot (40+) and humid

We departed Nifty at 0600 en route to what turned out to be Fitzroy Crossing. en route we stopped at Wadjina, Tunnel Creek and Geike Gorge National Parks.

October 25, 1994 Weather hot (40+) and humid

We departed Fitzroy Crossing at 0800 en route to Bungle Bungle National Park. 11 km up the road to the park, the extreme washboard surfaces broke a wire to the fuel pump and we rolled to a stop. After a brief exam we figured out what the problem was, repaired it and retreated to the main highway. We continued on to Kununarra arriving at 1700.

October 26, 1994 Weather hot and humid

Due to the cancellation by Bow River, this was an extra day. We drove out to the Argyle dam in the morning. After lunch in Kununarra I drove off to Wyndham, getting only 40 km before the car self destructed, requiring a tow back into Kununarra. This required a major overhaul of our plans.

October 27, 1994 Weather hot and humid

We met Jim ? EPA, Steve Brice, DOME, Rich Harris and Jim Kendal of DRD, and John Phillips of GHD at the airport prior to catching the 10:30 twin otter flight to Argyle. At Argyle we met Dave Fletcher, Perdy ? and Jamie ? and toured the alluvial sites after lunch. We looked at several large sample plots starting to the north of the airport which had been rehabbed, and gradually worked our way back to the south to Gap dam. Along the way we looked at several different generations of reclamation work, which has improved in recent years as Argyle has learned what works. At the area with reclaimed stream work ongoing, Jamie estimated rehab costs to be approximately $5,000 per hectare, excluding stream restoration work. We stayed at Argyle that nite.

October 28, 1994 Weather hot and humid

We got underway at 0700 being joined by Bill Hammond (Argyle), John Phillips and Barry McMahon. We looked at the AK 1 tailing impoundment, where there was an extensive general discussion of changes to the original proposal. Following this we looked at tailings sites for the alluvial plant, and the LIA area. Afterwards we adjourned to the conference room for a general discussion of EQ risk (Barry) and permit process discussions.

Field Notes
November 3-4, 1994

Bob Dye and I left for Youanmi Gold/Gidgee Gold/Sandstone at approximately 0830 Thursday November 3, 1994. We arrived at Youanmi at approximately 1530 and met with Peter Secker, the mine manager. Youanmi is mining at the rate of 140 TPD, they hope to be at 300 TPD by February, and 600 TPD by next November. They have achieved 86% recovery with the bacterial process, and they expect recovery may go as high as 91%. All waste from the process is delivered to the tailing site. Their current underground reserves are estimated to be 1.4 mm tonnes, with an additional .7 mm tonnes likely . We toured the site looking at the tailing storage areas and driving down to the open cut. At the open cut, waste material from the underground workings are being backfilled into the pit. The open cut has storage available for approximately 18 months worth of mining. Following that, they will need to construct surface dumps. The waste material being dumped into the pit was identified as a granite from the footwall. They are dewatering the pit at the rate of 12 litres/second. The dewater pond is highly saline, 60-70k TDS. We did not go down and actually look at the rock in the pit, which was a dark gray/green rock when viewed from the pit road. It was described as containing extremely small quantities of pyrite. On the way back up the road, we stopped and looked at some rock Peter identified as the "granite waste rock". From the vehicle it was clear this unit obviously contained abundant pyrite. This unit was either misidentified or there was some confusion at the site as in hand specimen it was neither a granite, nor mostly barren of pyrite. The rock is a fine grained gray/green slightly schistose rock containing 3-5% pyrite. It is most likely one of the greenstone units. Pyrite was visible in virtually all the material at this spot. Arsenopyrite as well as pyrite is also a common constituent of the sulphides in the ore. Following this tour, we returned to the office where we discussed the geology with the mine geologist (Michael...). He described the waste rock as "just a plain old biotite granite, with maybe 1 speck of pyrite/hectare". There is some sericitic alteration adjacent to the shear zone. We left the site still slightly confused about the actual nature of the mysterious "granite". At any rate, the material we examined by the side of the haul road certainly appeared to be identical to the material being placed at the bottom of the pit.

On November 4, 1994 we left Sandstone at 0745 for Gidgee Gold, stopping at Montague, a reclaimed site, en route. At Gidgee we met with Peter Steckis, the mine manager and Paul King, who has numerous responsibilities, among them being reclamation and the tailing dams. We visited the tailing dam structure, looked at some direct seeding on the top of the old tails and discussed the long term stability of the external embankments. I visited with Steve ...., the mine geologist on the geology of the site. Most of the rock units at this site are metavolcanics associated with greenstone belt rocks. There is some pyrite and arsenopyrite associated with the waste rock. All of the limited quantity of fresh waste rock is returned to the Kingfisher pit (approximately 5,000 TPM). We looked at several of Gidgee's pits and some ongoing direct haul soil/reveg work as well as some older reclamation in various stages of completion/success. In looking at the various pits/haul roads/developments it was clear Gidgee has not considered the overall impacts of some aspects of their activities. There is often substantially more surface disturbance than required.

Field Notes
November 14-15, 1994

Bob Dye and I left for Scuddles/Golden Grove (Murchison Joint Venture) at approximately 0800 on Monday, November 14, 1994. We arrived at Scuddles at approximately 1415 on a warm and windy day. We met with Bruce Anderson, Rob Will and Kewan Bond at the main mine office and following introductions and some routine odds and ends we went to look at the tailing impoundment. We stopped at what is essentially a sump for what little remediation/interception work has been done. The tailing impoundment is constructed of gray-green waste rock, with an upper lift of buff coloured material which I believe came from the decline for the Gossan Hill work (?). I did not see any sulphides in the impoundment waste rock, which is a typical Australian "greenstone", a gray green fine grained rock with slight schistosity but no relict sedimentary (or volcanic) features. It probably consists primarily of chlorite and albite (?). There is a steady, but slow, flow into the "sump" area where a small Honda pump is pumping the leachate to a small lined "decant" pond. Based on our field measurements, the leachate has a pH of 3.7-3.8 and a TDS of 5200. Below the road there is considerable vegetation damage and salt accumulation both at the surface and in shallow backhoe trenches which expose the "groundwater". There is evidence of plant stress or salt accumulation from 50-100m below the embankment. Several photos detail this site, where samples 94-11-2(S), 94-11-3(S) were taken. Sample 94-11-4(T) was taken just above this site from the tailing material. The tailing is obviously a sulfide rich product with sulphides/pyrite readily visible in hand specimen. Based on Kewan's info there is no contamination below the "cap rock" that the tailing embankment was supposed to be keyed into. This is based on the monitoring bores located 100m to the west of the embankment that monitor water quality below the cap rock. These bores are 30-40m in depth. As we drove around the tailings embankment it looked like the embankment is leaking as extensively in other areas as at the first site visited. Following this we returned to the office where I visited with Terry Burns, the mine geologist until Thursday when he departs to become chief mine geologist at Nifty Copper. Terry described the deposit as a classic massive sulfide deposit. The hanging wall contact was described as a knife edge contact, with little contamination crossing the contact, while the hanging wall contact was a little more "fuzzy", but still quite sharp. The bulk of the waste rock produced now remains underground as backfill. They are experiencing a shortage of backfill underground right now. The existing wasterock stockpile at the surface results from the original decline, which was constructed in the volcaniclastic rocks of the footwall. Terry doubted there would be much sulfide in the surface waste rock pile. Upon examination of the waste rock, it was found to be predominantly a greenstone unit similar to the tailing embankment described above, however it did contain abundant pyrite, including some fairly substantial chunks of massive sulphides (up to 30-40 cm on a side). Much of the greenstone present probably averages 3-5% pyrite/chalcopyrite. Terry admitted to being surprised at the amount of sulphides present in the waste pile. This pile is quite likely to be returned underground as backfill because of the current backfill shortage. This would be good. In spite of the obvious abundance of sulphides, there was little evidence of active oxidation taking place; no venting or leachate, no extensive zones of salt deposition, no obvious oxidised zones.

Following this I rejoined Bob, Rob Will, Kewan Bond and Stephen xxxxx, the exploration geologist for a look at Scuddle's exploration and a project to the south of Scuddles (Minjar Well). This project was a bit of a mess (Bob says "disaster") with considerable semi-broken material scattered throughout the project area. Scuddles exploration also needs considerable additional work as most of the drill holes remain to be plugged and cleaned up.

Field Notes
November 28,1994

Following the trip to Kalgoorlie on Sunday, I met Mark Cannon and some of the other staff at Kalgoorlie on Monday morning, November 28. Weather sunny and warm. Mark and I departed for Paddington, arriving there at approximately 9:30. At the site we met with Alan Sylvester, Ian Robertson and Steve Charley Paddington throughput is currently at 1.4 mm TPA, soon to go to 3.0-3.5 in the near future. Pan Con has done some characterization work, which they should be sending to me in Perth. I think the work was done by Graeme Campbell when he was still with ACG/Woodward Clyde. This work had identified a pyritic black shale (Black Flag beds) in the mafic and ultramafic greenstone horizons as a potential problem. The ore zone and related mineralisation are associated with extensive carbonate alteration. The characteristics of the carbonate alteration vary slightly depending on the assemblage, but most commonly it is described as a ferroan dolomite. The pyritic shale unit constitutes less than 5% of the waste and is either handled separately and isolated or is preferentially blended with carbonate rich waste. Paddington II pit is currently 160 m in depth, going to 270 m with stage III. Pits are dewatered, no info on specific volumes. Groundwater quality is poor, 75-100,000 TDS values. This water is usable in the mill, with high Lime and cyanide consumption. Groundwater values are high in Ca, Mg. In Paddington I pit the shale unit can include pyrite, minor chalcopyrite, and native silver. In hand specimen the unit is a dark gray fine grained shale unit. Pyrite is less than 5% of the sample, occurring along bedding planes within the shale. Sample 94-11-28-1. The total thickness of the more pyritic shale unit is 5-10 M thick. Inspection of the ore zone shows a light gray-green unit with ferroan-dolomite alteration which includes pyrite, arsenopyrite, and pyrrhotite. Sulphides consist of less than 5% of the ore. Sample 94-11-28-1 is from the bottom of the pit, 94-11-28-2 is from the oxidised portion of the shale unit in the upper pit. 94-11-28-3(t) is from tailing at the NE corner of the impoundment.

Following the site visit at Paddington Mark returned to Kalgoorlie, and I headed north to Windarra. We departed the site at approximately 11:00 AM. I arrived at Windarra at approximately 2:15 in the PM. Mining is essentially complete at Windarra, and within the next year it is likely the entire plant will be salvaged and removed and the majority of the site rehabilitated. The deposits at Windarra were hosted in ultramafic rocks within the Laverton Greenstone Belt. The related lithologies in the deposit include other ultramafic units, 2 horizons of banded iron formation and a granite as the footwall unit. Windarra also processed ore from Beasley Creek and Lancefield. The Lancefield ore is associated with some sulphides, mainly pyrite. The Lancefield ore was roasted at the Windarra plantsite. Reclamation at Windarra South and Beasley Creek has been completed. Some of the lithologies and the percentages of sulphides include: Granite <1%, Sedimentary units up to 10%, ultramafics 2-5% (pyrite, pyrrhotite), @ Lancefield, basalt footwall <1%, basalt hanging wall<1% (.5% pyrite) Ore and cherty sedimentary unit 10-15% sulphides. Alteration includes extensive carbonitisation associated with a regional carbonatisation event. These carbonates, principally a ferroan dolomite have generally given the waste products here a high neutralising capacity. The Leinster Nickel tailings which have been identified as acid producers are included in the tailings at Windarra, so it will be important to assure the 7 MM tonnes of Leinster tails are isolated at the completion of operations. The Windarra tails include S @ 3%, but also include considerable carbonate, whereas the Leinster tails include> 10% S. Tailing material from the gold processing includes abundant carbonate..

Tuesday November 29,1994 warm and windy. At Harbour Lights immediately north of Leonora operations are winding down as they will be closing within the next week. They have been treating ore from Butcher Well, having stopped mining on site in January of 1993. No testing was done on the ore or waste material, and most waste dumps were reclaimed in 1993. in the pit, which is surprisingly close to the WMC nickel loadout facilities, the west wall of the pit is a schistose greenstone unit. Oxidation varies from extensive to near surface at the south end with considerable variability in the depth of oxidation. The two ends of the pit are filling with groundwater, pH measured at 7.4 and 7.7. Sample 94-11-29-1 is from the north end of the pit adjacent to the small pond. It is a green schistose medium fine grained rock consisting of chlorite and albite. No visible pyrite was noted. On some surfaces a bright green mineral (fuchsite??) was noted. Carbonate (ankerite??) was noted in fractures and joints. Sample 94-11-29-2 was taken at the south end of the pit. Similar to sample 1 above with the exception of some minor sulphides (<1%). Sample 94-11-29-3 is from oxidised material. Sample 94-11-29-4 is from the west edge of TD 4

Tarmoola: Met with Peter Matviev, Stuart Brown (Mine Superintendent) and Arie Schaap (Sr. Mine geologist) Sulphides are minimal at Tarmoola (their interpretation...) Oxidation is highly variable but generally extends to 40m. The depth of the pit will be 230 m. The orebody includes a granitoid dome, with the ore being present in both the greenstone schists and the granite. Granite is present at the pit bottom and is generally a "true" granite, light coloured, low in mafic minerals and generally lacking in visible sulphides. Sample 94-11-29-5 is from the granite. Measured pH at the bottom of the pit was 8.0. Basalt and ultramafics...the basalt is fairly typical of the greenstone belt units, weak to moderate schistosity, some quartz veining with carbonate (calcite and ankerite) present. Sulphides can constitute up to 5% Of the greenstone. Sample 94-11-29-7 is the basalt greenstone. Also present in the bottom of the pit is a breccia of uncertain origin, presumably related to the emplacement of the granitics (??) sample 94-11-29-6 is the breccia. The breccia is very low in sulphides. A small quantity of BIF also occurs in the pit, carrying gold but with little sulphides. Sample 94-11-29-8 is the BIF. The BIF is less than 1% of the waste rock volume.

Teutonic Bore: I stopped briefly at Teutonic Bore, hoping to get to the bottom of the pit to get a pH reading at least. However, after driving in as far as I could in the sedan, and hiking down into the pit, I was unable to figure out a safe route to the bottom of the pit to get either a water or a rock sample. I collected a sample from a waste rock bund prior to departing the site.

Leinster: I met with Don Ferguson at the site. Leinster has 2 open pits w associated waste. All UG waste remains underground. Surface waste material is mostly oxidised, breaking down to a clay which can be used for rehab work. (Don's discussion...) Don discussed Tailing Impoundment II leak and plume. Also reviewed the new impoundment.

Mt. Keith: I met with Phil Davidson (Environmental Officer) touring the site until dark, as Phil was flying out in the AM. We looked at waste dumps, tailing impoundments and pit. Phil discussed the waste dump construction. There are some problems with grade control and berming along the dump crests which could cause problems with surface water control. The new tailing line had problems with heat expansion at the joints resulting in several leaks of tailing and a substantial repair bill. The tailing impoundment, 4 - 100 hectare cells, is constructed of prepared clay with a PVC lined section at the decant tower.

Wednesday, November 30, 1994 Sunny fine hot... Returned to Mt Keith for some additional discussions with Phil and the Geologist, John Hicks. While there, I copied some of the preliminary work on waste characterisation and some other miscellaneous geology info.

Discussing geology with John Hicks we had an extensive discussion of the carbonitisation and related alteration. Also examined hand specimens of some of the samples displaying relict igneous textures, which have subsequently been altered to serpentine minerals. There is a pyritic chert unit present in the footwall (?), but it constitutes less than 1/2% of the waste. In general the rocks here contain less than 2% sulphide.

Following this I headed for Wiluna..where I met with Colin Patterson. We toured the Wiluna Gold site starting with an active dump to review some of the most recent waste. The waste rock here consists of mostly miscellaneous basalts/greenstones and ultramafic rocks. There are some interbedded sedimentary units present as well, but they generally constitute an inconsequential percentage of the waste rock stream (<1/2%). The waste examined generally lacked visible sulphides, which where present form small blebs totalling less than 1% of the rock. Following this we stopped at the North Pit to examine the ore and waste in the pit. In the pit there is extensive carbonate veining, consisting predominantly of carbonate and lesser ankerite. An extensive suite os samples was taken here. Oxidation can extend to 75-80 metres in the ore/shear zones with frequent bleaching in the ore zone associated with extensive carbonate/sericite alteration. We also stopped at the Happy Jack South pit where I took soma additional samples. Following this I departed for Meekathara arriving at 1700.

Thursday, December 1, 1994 warm, mostly cloudy and muggy.

I met with Russel Coles at Dominion Mining and toured the area to the west of the main office, reviewing waste dump construction and the Haveluck in pit tails.

Dominion is backfilling several pits and is considering backfilling the in pit tails as well. Russ is trying to maximise up front planning for final reclamation, emphasising the cost benefits. Dominion is attempting to maximise direct haul topsoil salvage and placement.

The Haveluck in pit tails have been decommissioned for approximately 5 years. They are still not stable due to groundwater flux through the tails and the generally slow drying of the tails.

Following this I Drove down the road to St. Barbara where I met first with Robin Campbell and then with Greg Knox who has recently gone from being an exploration geologist to being the Sr. Mine Geologist. We went into the South Junction Pit to examine the different lithologies at the bottom of the pit. Oxidation is variable but generally quite deep. The bottom of the pit includes the usual greenstone type assemblages, and a quartz albite porphyry as well. Ore is hosted in quartz carbonate veining, + or - fuchsite. At the upper levels of the pit the porphyry is entirely altered to clays and iron oxides. Water, which is of good quality, is a problem operationally and all dewatering reports to the mill as process water. The pH of water ponded at the bottom of the pit was 7.8. The greenstone unit at the bottom of the pit consisted of chlorite-albite with some talc. Sulphides were estimated at 2-4%. The quartz-albite porphyry unit includes < 1% pyrite, and this may be associated with alteration/weathering as fresher hand specimens of the porphyry seemed to have less sulphides. The Bluebird pit to the east of the highway was more extensively oxidised, probably because it hasn't reached the same depth as the South Junction Pit. The Bluebird pit includes a dolerite dike which has accessory sulphides, but it was not sampled due to blasting. It does not constitute a significant percentage of waste.

Friday, December 2, 1994 Warm, going to hot, partly cloudy early

Following the early morning drive down to Big Bell I met with Peter Bilby and Lee-Anne Stewart (Environmental Officer) Lee-Anne said Placer, from whom Posiedon had acquired the property had done some work on the waste rock. There have been some problems with tailings, and also problems with historic tailings which include low pH and Hg. Currently there is no open cut mining at Big Bell, all mining being underground. All waste rocks in surface dumps is oxidised (?), with all sulphide bearing waste being returned either underground or into the disused pit. Groundwater has salinity of 10-15K TDS, pH 4.2 -6.0 (this seems low....based on other deposits) heavy metals are consistently below detection limits. Depth to GW is approximately 25 metres. Dewatering is at 40-85 m^3 / hour. I visited with Sara Box, a geologist, on the general geology of the deposit before heading out to look at the sites with Lee_Anne. Within the ore zone sulphides are predominantly pyrite/pyrrhotite, while outside of the ore zone the percentage of the two minerals is reversed. There is also some marcasite. The primary alteration in the deposit is a potassic enrichment evidenced by biotite and K-feldspar alteration. Generally there is very little quartz or carbonate, with what little carbonate there is being minor fracture or joint filling.

We started the site visit by going to the north dam of the impoundment. There are numerous seeps below the impoundment. The tailing material is deposited on an unprepared surface of weathered granitic rock, with the decant basically at the high point in the impoundment, consequently it works rather poorly as a decant system as near as I could tell. Measured pH of one of the numerous seeps was 7.8, most likely reflecting the limited retention time in the impoundment. I sampled the old tailings, which could be seen to have oxidised (photo). Separate samples of both oxidised and unoxidised material were taken. Following this, samples were taken of fresh rock being dumped into the pit and weathered rock from an old dump being used for impoundment construction. The fresh rock was an amphibolite -> biotite schist with minor sulphides <3%, associated with minor quartz veining sub-parallel to schistosity.

Golden Crown Met briefly with Dave Richards and collected samples of both waste and ore from the underground operation. The ore is hosted in an altered dolerite with only minor associated quartz veining and carbonate bleaching (?). There is an associated black graphitic shale with some pyrite, but it constitutes only a minor portion of the waste...< 2%.

At WMC's Hill 50 operation I met with Trevor McKenzie and toured the entire area extensively. WMC inherited a considerable amount of disturbance when they acquired various pieces of the property. They have been slowly whittling away at these older disturbances. Where possible sulphide wastes have been encapsulated in oxide waste. Smaller pits are generally all in oxidised material. Groundwater in the area can be anywhere from 5-25 metres, though in the area of operations it of course is altered by extensive dewatering. TDS is generally in the range of 10k. Samples were taken from a dump crest and a low grade stockpile. We went to the bottom of the Boomer pit and collected a sample. The pH of a pond at the bottom of the pit was 7.9. Rock was a light green to dark green altered basalt which had a fairly strong HCl fizz, although it was difficult to tell exactly what was fizzing...?? Numerous photos.

Saturday December 3, 1994 Pleasant, fine and sunny

Mt. Gibson After some confusion I met with Richard Fare (?) one of the mine geologists for a tour of the site. The deposits at Mt. Gibson are a fairly common greenstone hosted sequence including the usual greenstones, shearing, some BIF, some felsic sediments, chert as well as some small quartz porphyry units associated with granitic material. We visited several pits and sampled a representative range of waste material. Sumps in the pits had pH ranges from 6.9 to 7.3, with a pH of 6.7 measured at a seep with some Fe oxide staining.

Field Notes
January 4, 1995 - January 13, 1995

January 4, Departed Perth at 0715 for Forestania (nickel) with David Bills. We arrived at the site in mid-afternoon, meeting with Seppo Rantanen. Forestania involves three different mine sites: Flying Fox, which we drove by, but did not visit, Cosmic Boy, where we met with the staff and collected waste samples from the dump and tailings, and Diggers Rock where we collected additional samples from the dump. Ore is interpreted as primary dissemination of pyrrhotite, pentlandite in ultramafic rocks lying on a Banded Iron Formation. The associated rocks include the UM series, metasedimentary rocks either derived or associated with volcanics and or ultramafics. This general sequence of lithologies repeats itself and currently only the "basal lode" is being mined. Characteristic of the alteration associated with mineralisation is extensive carbonate enrichment featuring siderite, ankerite with minor associated talc. There are asbestiform minerals, tremolite/actinolite and minor chrysotile, present. The bulk of the produced waste will remain underground and will be BIF. Some UM are produced currently as the decline develops. The BIF includes very few sulphides. There is a 10 m band of pyrite rich UM at the base of the sequence.

Diggers Rock is an ultramafic/greenstone flow complex which includes pods of SG (?) massive sulphides. There is also a thin BIF with sulphides. Weathering here follows the deposit, being depressed in the center of the deposit. (photo)

January 5 Cool and cloudy in the AM...We travelled to Bounty and met with Paul Weedon. Bounty (Gold) includes two pits, now exhausted, North Bounty and Bounty. Currently most waste is retained UG, though there are surface waste dumps as UG haulage gets organised. The HW here is basalt/gabbro with limited sulphides, generally present only as pyrite/pyrrhotite in minor shears. Ore is associated with pyrrhotite and minor pyrite, with some marcasite in the upper levels of the deposit. The FW sequence is a series of high Mg basalts, komatiites, and peridotite basalts. There is minor pyrite/pyrrhotite within 10-15 metres of the contact. Also present are minor cherts with sulphides slightly more distal. Exploration has uncovered some zones of massive sulphides which include nickel mineralisation, but this is only preliminary work. Minor quartz feldspar porphyry above the ore zone also includes minor sulphides (< .5%). Carbonate alteration in the HW can include massive calcite. Samples of a representative suite of rocks were collected from the interim waste rock dump.

January 5, 1330 Yilgarn Star Yilgarn Star is situated in the Yilgarn Star greenstone belt (!!). Generally the metamorphic grade is higher here, amphibolite facies in basalts and associated metasediments. Mineralisation is structurally controlled along shears. Mineralisation being:

1) quartz "reefs" up to metre thick, 2) thin QVs, cms thick 3) carbonate (generally ankerite) and magnetite veins. Ore is associated with pyrrhotite and minor pyrite (py 1-4% in metaseds). There are minor sulphides in the FW rocks. Samples were collected from the pit. pH of sump @ 6.5 and 7.0

Nevoria Similar to YS above, higher grade rocks, amphibolite facies. The main sulphide here is pyrrhotite which is what Gold mineralisation is associated with. A pegmatite cuts across the structure. The general geology is similar: BIF, amphibolites, metaseds, probably of similar parentage to many of the other deposits visited. There is some pyrite, and minor chalcopyrite in the BIF. Some anomalous antigorite and chrysotile is also present. Two samples of WR were collected. Pyrite was not common in WR, generally < 1%. pH at sump @ 7.0

January 6 1995 Warm to Hot. Copperhead Copperhead is located at the eastern edge of the greenstone belt with one of the granitoid to the east of the pit. There are two distinct ore zones here The north zone is hosted in an altered dolomite, while the southern zone is hosted in BIF. The S series includes UM altered to talc schist and the N series includes mafics altered to amphibolite. The S series has very little carbonate alteration. Sulphides present include galena, pyrrhotite, chalcopyrite with limited pyrite. S series has the Cpy and Pyrr, while the N has the Gln as well. The saddle in between includes Py and Cpy. Carbonate present is all dolomite. pH @ adit @7.9.

PM Mt Dimer Mt Dimer is something a little different. It is a polymetallic deposit hosted in one of the granitoids. It is extensively weathered, though the weathering can be quite variable. There are some GS/UM close by. There is minor carbonate associated with mineralisation. Sulphides include: Py, Sph, Gln, Cpy, Brn, all altered to carbonates and oxides in the upper portions of the deposit. Gold mineralisation is structurally controlled. A basalt unit cuts across the structure/pit. There is some carbonate associated with mineralisation (ankerite/dolomite). Waste rock samples collected include granite and sheared material from adjacent to the ore zone.

January 8, Teutonic Bore Hot and Windy. After circumnavigating the pit I figured it would be possible to access the haul road below the point it had washed out. I took along a Gatorade bottle to sample the water from Lake Teutonic. The pH of the lake ranged from 6.7 at the adit to 7.1 at the "beach". I estimated the flow from the adit @ 10-20 GPM which is probably little more than a SWAG. There is little fresh rock at the bottom of the pit to sample, (and what there was , was hotter than hell...) so I collected a sample of fresh rock from along the haul road. There is abundant massive sulphides all along the road. Mineralisation includes Cpy, Py, Gln and Sph (??). The lithology is a fairly typical looking GS assemblage. I saw only limited carbonate veining (some siderite/qtz ...). The extensive dump complex is characterised by essentially random dumping of sulphidic waste along the top and margin of the dump. Extensive series of photos...
At the coarse ore stockpile (??) I sampled a small pond resulting from the previous days thundershower @ 3.2. A small puddle by the old office building sampled @ 3.0. There appears to have been offsite impacts from tailing runoff as well. More photos.....

January 9 Jubilee. Jubilee and New Celebration are mining the same deposit. It is a series of Qtz feldspar porphyries in a fairly typical GS assemblage of rocks. Calcite was fairly common throughout this area, both in the porph units and in the HW and FW rocks. Sulphides are generally associated with dolerite dikes and can include Py, Aspy, Pyrr, Cpy, and Sph. New Celebration of course is much the same...

January 10 Three Mile Hill With Hugh Jones This deposit is unusual in two respects: 1) it is hosted in a gabbro sill, and 2) fresh rock extends virtually to surface. There is very little carbonate associated with the deposit. Ore is ass'd with fine disseminated Pyrr. Aspy is present and is taken as an indicator of lower grade. we also visited the Tindals pit where ore is asso'd with a complex porphyry swarm intruded into UM. UM do not include Sulphides. Porphyry can include Pyrr, Py, Sph, Gln, Cpy, with very limited carbonates. Marcasite is common on fracture surfaces. pH in pit @ 7.6 - 7.7.

KCGM/Superpit With Hugh and Mark Cannon AGC/Woodward Clyde did some work here. This is mostly an oxide deposit, but they are getting into sulphides. Ore is generally hosted in the dolerites and can include 1-2% sulphides, most commonly

Py, very limited Pyrr. Cpy and Aspy can be present locally, but they are uncommon. There is extensive carbonate alteration ass'd with the deposit, mostly in the form of ankerite. There is a shale unit present, but it composes only 2% of the waste, no estimate on sulphides in the shale... Two samples were taken, both of which fizzed w/ weak HCl.

PM With Hugh and Mark visited Bardoc to examine in pit tails disposal.

January 11 Kambalda With Hugh Extensive discussion of Geology with Colin Woolard. The deposits generally do include sulphides, but are always associated with extensive carbonate alteration. We looked at some very innovative rehab work prior to departing the site.

Kanowna Belle With John Robinson Another slight variation....this deposit is hosted in what KB calls a "grit" HW is a Grit and Qtz feldspar Porph., FW is a conglomerate. Extensive carbonate alteration (ankerite and calcite) and limited sulphides. Sulphides present include Py and minor Aspy.

January 12, Nepean Hugh and I This is a quasi abandoned nickel property, there is a watchman on site, but little else. It looks to be a fairly standard greenstone assemblage with the unusual feature of associated a fairly clean pegmatite and granite in the waste rock dump. The waste rock dump took us a while to find it, since it is quite a distance from the shaft. The host rock was apparently a dolerite with generally limited sulphides, <1% mostly Py w/ some Cpy. Carbonates are present but didn't appear widespread. We found water seeping through the ore bins at the shaft, and equally interesting, water seeping from below the dump. Water at the old heavy media separation plant measured pH of 5.4 and 4.3 . The seep below the dump was 6.5. Most of the more massive chunks of sulphide in the dump were extensively oxidised.

PM Visit to Gidgi Roaster with Hugh and Mark. The roasting process destroys essentially all the sulphides. What reports to the tailing is .4-.5% Sulphide S but apparently tied up in silica.

January 13 Coolgardie Gold With Hugh Lindsays Pit Basalt is the host rock here, mineralisation is associated with Aspy. There is extensive minor quartz veining with associated calcite. Sulphides in the "transitional ore are estimated to be 1-2%. The low grade material includes considerable calcite and a fairly coarse Aspy. At the Greenshields pit there is more Aspy but lower Au, some minor Pyrr as well. Host rock here is a dolerite containing extensive quartz calcite veins

PM Visited Hopes Hill to review another in pit tails disposal system.

Appendix C

Sample Preparation Details

GEOLOGICAL CHARACTERISTICS OF MINE WASTE
SAMPLE PREPARATION and HANDLING

1.0 Sample Preparation

1.1 Waste Rock Samples

: Dry waste rock samples will usually be submitted in the form of grab samples, diamond drill core or RC drill cuttings. The grab samples will comprise either weathered materials or "whole rock" samples of varying size.

: Both the weathered and the unweathered rock samples are to undergo the preparation steps indicated below.

:Between 0.5 and 2.0 kilograms of waste rock will usually be submitted for testwork.

NOTE: All steps are to be supervised by qualified laboratory staff.

Crushed Samples

: The as-received samples are to be crushed to a nominal 2 mm average particle size and appropriate cleaning of the crusher unit is to be carried out between samples.

Pulverised Samples

: Random sub-samples (usually 200 grams) of the crushed samples are to be taken by means of a riffle (or other) splitter, and pulverised to a nominal 75 µm average particle size.

: Quartz "washes" of the chrome-free, hardened bowl are to be undertaken between samples.

1.2 Moist Solid Samples

: These samples will usually be cores or grab samples of moist tailing material collected from inactive tailing storage facilities. The samples will typically be loose and either in plastic or calico sample bags.

: The moisture content of the samples will vary considerably. The moisture content (based on oven drying at 105 degrees C for 24 hours) of the samples will need to be determined on representative subsamples for moisture corrections in subsequent testwork.

NOTE: The whole mass of the as-submitted samples must not be oven dried.

: Depending on the moisture retention characteristics of the samples, it may also be possible to express a small quantity of porewater from the samples using the filter press. The yield of porewater from the samples will probably not exceed 50% of the entrained porewater in the samples. The need to express porewaters from such samples will be decided by qualified laboratory staff on a case-by-case basis.

: The moist solid samples for use in the filter press may also comprise soil or crushed waste rock samples which have been moistened with deionised water for the isolation water extracts.

2.0 pH AND ELECTRICAL CONDUCTIVITY (EC)

- The determination of pH and electricity conductivity (EC) are to be performed on slurries prepared using samples of crushed waste rock, as received tailings solids or soil materials.

- Deionised water should be used at a solid:water ratio of approximately 1:2 (w/w). The as-received solids should be used directly in these tests.

- Approximately 20 grams of sample should be thoroughly mixed with 40 mL of deionised water and the mixture left to age for 24 hours. During aging, the slurries should not be agitated and should be left in contact with the air.

- The pH should be recorded to within 0.1 pH unit, and the EC should be reported in μS/cm to no more than 2 significant figures.

- Any pronounced colour and/or odour formation in the test slurries should be noted and recorded on the laboratory report.

3.0 ACID-NEUTRALISATION CAPACITY (ANC)

3.1 Determination of 'Fizz' Rating

- To determine the amount and concentration of HCl to be used in the acidification step, the sample is initially subjected to the 'fizz' test.

- To approximately 0.5 gram of the as-received sample, 1 to 2 drops of 1:3 HCl (approximately 8% HCl) should be added. The following ratings apply to the effervescence or fizz observed upon HCl addition:

Reaction	*Fizz Rating*	*HCl Molarity*	*HCl Volume (mL)*	*NaOH Molarity (M)*	*Sample Weight*
no reaction	0	0.1	25	0.1	5.0
slight reaction	1	0.1	25	0.1	5.0
moderate reaction	2	0.1	25	0.1	2.0
strong reaction	3	0.5	25	0.5	1.0
very strong	4	1.0	25	1.0	1.0

The above ratings are used for the selection of the test work conditions employed below.

3.2 Acidification Step

- Based on the results of the fix test, appropriate weights of the as-received sample are placed into a 250 mL flask or beaker and to this the required amount and concentration of HCl added, as indicated by the above table. Also, 20 mL of deionised water should be added.

  Note: Any evolution of gasses (eg. H_2S) observed during the acidification step should be noted and recorded on the laboratory report.

- Place the flasks on a hot plate (or in a water bath) and heat to 80 to 90 °C. The flasks should be covered (eg. watch glass) and swirled occasionally over 1 to 2 hours until reaction is complete.

  Note: Reaction is complete when no evolution of gas is evident and when the solid particles readily settle out upon agitation of the flasks.

  NOTE: DO NOT ALLOW EVAPORATION TO DRYNESS OCCUR. IF SO, THEN REPEAT TESTS.

- The flasks are allowed to cool to room temperature then measure pH to 0.1. Deionised water is then added to give a total volume of approximately 125 mL and the pH of the mixture to within 0.1 pH unit.

- M = sample weight (in grams).

- Z = conversion factor
  = 49 where ANC expressed in H_2SO_4 / tonne equivalent units.
  = 5.0 where ANC expressed in % $CaCO_3$ equivalent units.

- ANC = (Y x [HCl] x Z)/M

  Note: Concentration in M.

NOTE: The ANC reporting limits should be < 1 kg H_2SO_4 / tonne or < 0.1% $CaCO_3$

3.7 Intrinsically Acidic Samples

- Samples of strongly oxidised sulphidic materials will usually be strongly acidic, so that more NaOH is added during the back titration than the HCl added originally. In this case, the results of the NaOH titration should be reported as a net acidity determined to pH 7, after correcting for the added HCl.

- This net acidity should also be reported in kg H_2SO_4 / tonne on a dry weight basis.

3.8 Reporting

- The occurrence of effervescence under ambient conditions and/or after warming should be indicated on the laboratory report.

- The ANC results should be reported on an oven-dry basis and in kg H_2SO_4 / tonne units. Where moist samples are tested (eg. filter cakes of tailings solids), this should be indicated on the report, but with the results reported on the dry basis.

3.8 Reporting

- The occurrence of effervescence under ambient conditions and/or after warming should be indicated on the laboratory report.

- The ANC results should reported on an oven-dry basis and in kg H_2SO_4 / tonne units. Where moist samples are tested (eg. filter cakes of tailings solids), this should be indicated on the report, but with the results reported on dry basis.

- Add 250 mL of the freshly prepared 15 % $H_2 O_2$ solution and record the time addition of the $H_2 O_2$.

- Record the nature of any immediate reaction (viz. degree of effervescence) and record observations made as the reaction progresses, especially whether the reaction generates enough heat to boil the suspension. Note the time at which the sample boils.

- Allow samples to continue reaction until all effervescencing has ceased. This may require the samples to be left overnight.

Note: *Droplets of condensation on the sides of the flask in the morning indicates that boiling occurred during the overnight stand. The occurrence of significant droplets should be noted and reported.*

- At the completion of reaction , boil the suspensions until all effervescence has ceased (viz. excess $H_2 O_2$ decomposed).

Note: *Do not allow the suspensions to boil to dryness - add deionised water if necessary.*

- Allow the suspensions to cool to room temperature and then add deionised water to give a total volume of approximately 250 mL for the measurement of pH and EC.

- Report the pH value to 0.1 pH unit and the EC value to no more than 2 significant figures.

Note: *Any significant coloration (<u>other than Fe staining</u>)* of the reacted *suspensions should be noted.*

5.3 NaOH-Titration Step

- If the pH of the NAG suspensions is 7 or greater, then no titration is carried out. In this case, the NAG value is less than the reporting limit of 0.5 kg H_2SO_4 / tonne.

- If the pH of the NAG suspensions is less than 7, then the suspensions are to be titrated with a standard NaOH solution to pH 7.0 with constant stirring. The molarity of the standard NaOH solution is based is the NAG pH as follows:

NAGpH	*[NaOH]*
less than 2	*0.5 M*
greater than 2	*0.1 M*

5.4 Blanks and Duplicates

- A blank using acid-washed silica sand must be performed with each batch of samples tested.

- Duplicate NAG tests should be carried out on every 5th sample in a given batch. For batch sizes less than 5, a duplicate NAG test should also be carried out.

5.5 NAG Calculation

- NAG = (49 x V x M)/W

  Where:

  V = volume of NaOH dilution used in titration (in mL).
  M = molarity of NaOH solution used in titration (in moles/L).
  W = weight of sample reacted, corrected for moisture content (in grams).

- The above calculation gives NAG in kg $H_2 SO_4$ / tonne on a dry weight basis.

5.6 Reporting

- The sample weight, NAG pH, NAG EC and NAG values are to be reported for each sample, together with comments on the nature of the reaction observed.

- The results of all blanks and duplicates are to be reported.

5.7 Modification for Multielement Analyses on NAG Solutions

- When the multielement composition of the NAG test solutions is required, the following modifications apply to the test conditions and NAG calculation.

- After allowing the reacted NAG suspensions to cool to room temperature, make up the suspensions to approximately 250 mL using deionised water. Thoroughly mix the suspensions and measure NAG pH and NAG EC. These steps are the same as those described in the NAG test above.

- Prior to carrying out the NaOH titration (ie. NAG pH less than 7), approximately 50 mL of the NAG solutions should be removed. This step should also be carried out if the NAG pH is greater than 7.

- Where required, the remaining NAG suspensions are to be titrated to pH 7 and the NAG calculated after taking into account the reduced sample volume (viz. approximately 200 mL instead of 250mL).

- The 50 mL aliquot of the removed NAG solution should be filtered through a 0.45 um membrane filter and the filtrate acidified to pH less than 2 using AR HNO_3. The filtrate should then be made up to 200mL using deionised water.

- The dilution factor employed in preparing the 200 mL of preserved filtrate should be indicated on the report.

- The preserved NAG test solutions should be clearly labelled with the appropriate Sample Number and the descriptor 'NAG' included.

5.8 Reference

The above NAG test is based on a method described by Finkelman RB and Giffin DE, 1986, "*Hydrogen Peroxide Oxidation: An Improved Method for Rapidly Assessing Acid-Generating Potential of Sediments and Sedimentary Rocks*", Recreation and Revegetation Research, 5:521 to 534.

Appendix D

Sample List

Sample #	New #	Description of Sample
94-11-1	YO 1	Sample of "granite" from Youanmi
94-11-2(s)	same	Material from backhoe trench below Scuddles tailing impoundment
94-11-3(s)	same	material from backhoe trench below the road, adjacent to the site above
94-11-4(t)	same	sample of tailing material directly above sample 2(s)
94-11-5	Sc 1	sample of waste rock from surface waste rock storage at Scuddles
94-28-11-1	Pa 1	shale unit at the bottom of Paddington I pit
94-28-11-2	Pa 2	oxidised portion of shale unit from the Paddington II pit
94-11-28-3(t)	Pa 3	tailing material from the NE corner of tailing impoundment
94-11-29-1	HL1,11,12	greenstones from the north end of the pit at Harbor Lights
94-11-29-2	HL 2, 21, 22	greenstones from the more southerly portion of the pit at HL
94-11-29-3	HL 3	oxidised portion of the greenstone from the north end of the HL pit
94-11-29-4	HL 4t	tailing from the west edge of TD 4 HL
94-11-29-5	Tr 5	granitic rock from the bottom of the Tarmoola pit
94-11-29-6	Tr 6	breccia from the Tarmoola pit adjacent to granite above
94-11-29-7	Tr 7	greenstone unit from more southerly portion of the pit
94-11-29-8	Tr 8	banded iron formation from upper portions of pit
94-11-29-9	Tb 1	from a waste rock bund at Teutonic Bore
94-11-30-1	Wln 1	Wiluna north pit ore zone
94-11-30-2	Wln 2	Wiluna north pit slightly distal FW greenstone
94-11-30-3	Wln 3	Wiluna north interbedded sedimentary rocks
94-11-30-4	Wln 4	Wiluna north grab sample
94-11-30-5	Wln 5	Wiluna north from a 5-10 cm sheared zone with blebby pyrite
94-11-30-6	Wln 6	Wiluna north greenstone unit
94-11-30-7	Wln 7	Wiluna north sedimentary zone
94-11-30-8	Wln 8	Wiluna north small intrusive unit
94-11-30-9	Wln 9	Wiluna north hanging wall ore
94-11-30-10	Wlh 10	Wiluna Happy Jack S ore zone (low carbonate?)
94-11-30-11	Wlh 11	Wiluna Happy Jack S oxidised material
94-11-30-12	Wlh 121, 122	" " " hanging wall low Mg basalt
94-12-1-1	Sb 6, 7	St. Barbara S Jct. Pit contorted greenstone unit
94-12-1-2	Sb 2, 3	Same quartz albite porphyry
94-12-1-3	Sb 4, 5	Same quartz/carbonate/fuchsite vein
94-12-1-4	Sb 1	Same sl. farther north talc schist
94-12-2-1t	Bbt 1	Big Bell tailing, north side of impoundment
94-12-2-2t	Bbt 2	Same old tailing material..Unox (?)
94-12-2-3t	Bbt 3	Same Same site ...Oxidised (?)

94-12-2-4	Bb 10,11	Big Bell, from waste dump..sample 11 is less oxidised highly weathered amphibolite schist
94-12-2-5	Bb 1	Same from UG waste currently being dumped in the south end of the disused pit
94-12-2-6	Gg 2	Golden Crown waste from UG
94-12-2-7	Gg 1	Same ore zone
94-12-2-8	H 55,56, 57	Hill 50 dump crest, greenstone unit
94-12-2-9	H51, 52, 53, 54	Hill 50 decline, similar lithology
94-12-2-10	H 501, 502, 503 504	Boomer pit, greenstone unit at the bottom of the pit
94-12-3-1	Mg 11, 12, 13	Mt. Gibson Orion II pit, adjacent to shear zone
94-12-3-2	Mg 21, 22, 23	Same, Donkey pit metamorphosed to partial biotite schist
94-12-3-3	Mg 31, 32 33	Same more ox, 32 greenstone, 31 pink w/white flecks, 33 brn oxidised rock
Ra 1		Ravensthorpe
Ra 2		Same
Ra 3		Same
Ra 4		Same
Frs-1t		Tailing sample
Frs-2		BIF from WRD
Frs-3		Meta sed iment, mostly amphibolite
Frs-4		GS/UM
DR-1		Digger's Rock BIF-oxidised
DR-2		UM no visible sulphides
Bo-1		Bounty...Basalt no visible sulph.
Bo-2		FW pods material
Bo-3		BIF
Bo-4		Tailing
Ys-1		Yilgarn Star Schist unit, chlorite,minor Py on Schist/planes
Ys-2		GS altered metabasalt, Qtz,calc vns
Nv-1		Nevoria Amphibolite, some minor Qtz vning
Nv-2		same w/ minor Pyrr
Ch-1		Copperhead BIF, Mgn,Pyrr,Qtz/chert
Ch-2		Talc Chl schist
Ch-3		ultramafic @ saddle
Ch-4		Dolomite lode in CH North
Md-1		Mount Dimer Granite from WRD
Md-2		Shear adj to
Md-3		Tailing
Tb-2		Teutonic Bore from waste along haul road at bottom of pit
Tb-3		Sample of intermediate process adj to ore stkple
Tb-4		Solidified tails

Jb-1		Jubilee Fw side of ore zone, Talc/Chl schist w/Calcite
Ti-1		Three Mile Hill Qtz Bio Porph @ Tindal Pit
Ti-2		Ultramafic
Kc-1		Superpit Subgrade w/Calcite
Kc-2		" Marginal Weak fizz
Kb-1		Kanowna Belle "grit" or greywacke unit (??) w/Calcite
Kb-2		low grade from oxidised portion of the pit
Ne-1		GS/UM from S of shaft
CG-1		Coolgardie Gold low grade w/ coarse Aspy Lindsay's pit

Appendix E

Laboratory Reports

MOD Tests pH, EC, Sulphurs .						
CCWA ID	Client ID	pH	EC	Comments on	Total S	SO4
UNITS			uS/cm	slurries.	%	%
1310/1	Bb1b	8.0	3100		0.05	0.01
1310/2	Bb1T	7.2	7300		0.98	0.32
1310/3	Gg2	8.7	3700		0.27	0.01
1310/4	H502	8.7	3200		0.07	0.01
1310/5	H504	8.3	3600		0.46	0.01
1310/6	H51	8.2	520		1.87	0.02
1310/7	H54	8.7	230		0.17	<0.01
1310/8	HL12	8.6	520		0.11	<0.01
1310/9	HL21b	8.6	550	Frothy cream, yellow colour	0.23	0.01
1310/10	HL2b	8.5	560	Dark grey	0.3	0.01
1310/11	HL3b	9.0	~400	semi gelled	0.02	0.02
1310/12	Mg13	7.8	3800.		7.52	0.03
1310/13	Mg13-2	7.4	~1000	Semi gelled	<0.01	0.03
1310/14	Mg23b	8.2	670	light brown, semi gelled	4.47	0.04
1310/15	Mg32b	8.4	N/A	dark grey	0.06	0.02
1310/16	Mg33b	7.0	~700	reddish brown	0.01	0.02
1310/17	Pa1b	8.0	6300		0.45	0.03
1310/18	Pa2b	8.2	2000		0.06	0.18
1310/19	Ra1b	7.5	3800		0.1	0.21
1310/20	Ra2b	5.5	19000		0.27	0.81
1310/21	Ra3b	7.5	2900		4.44	1.02
1310/22	Ra4b	7.8	9000	reddish brown	0.13	0.47
1310/23	Sb2b	8.8	1200		<0.01	0.01
1310/24	Sb4	9.0	520		<0.01	<0.01
1310/25	Sb6	8.6	N/A	high suspended solids, semi gelled	0.3	<0.01
1310/26	Sb7	8.9	460		0.11	<0.01
1310/27	Sc1b	9.2	270	high suspended solids	1.09	0.01
1310/28	Tb1b	8.4	440		3.9	0.03
1310/29	Tr5b	9.1	450		0.18	<0.01
1310/30	Tr6b	9.1	410		0.1	<0.01
1310/31	Tr7b	8.8	360		1.66	0.01
1310/32	Tr8b	8.0	200	reddish brown	0.02	0.03
1310/33	Wlh11b	8.7	560	semi gelled	0.01	0.04
1310/34	Wlh122	9.6	690		0.03	0.01
1310/35	Wn1b	9.2	3400		0.09	0.01
1310/36	Wn2b	9.6	550		0.01	0.01
1310/37	Wn3b	8.5	3700	dark grey	0.09	0.07
1310/38	Wn5b	7.4	5700	dark grey	10	0.53
1310/39	Wn6	9.3	540		2.02	0.01
1310/40	Wn8b	9.3	410		0.15	0.01
1310/41	Wn9b	8.8	1000		1.8	0.02
1310/42	Yo1b	8.9	480		3.36	0.02
1310/43	Sb3b	8.1	1500		<0.01	0.01

NAG tests - MOD. Data from RM, transcribed by DJI.

Sample 94E 1310	Weight g	pH	NaOH Molarity	NaOH Vol, mLs	NAG kgH2SO4/tonne dry wt.	Observed effervescence, hydrogen peroxide step
1	1.294	8.1	N/A		N/A	slight
2	1.268	2.6	0.097	4.5	16.9	moderate
3	1.269	7.9	N/A		N/A	moderate
4	1.273	8.9	N/A		N/A	moderate
5A	1.309	8.8	N/A		N/A	moderate
5B	1.308	9	N/A		N/A	moderate
6	1.294	7.4	N/A		N/A	moderate
7	1.3	8.7	N/A		N/A	moderate
8	1.265	8.8	N/A		N/A	moderate
9	1.268	9.2	N/A		N/A	moderate
10A	1.272	8.8	N/A		N/A	moderate
10B	1.289	9	N/A		N/A	moderate
11	1.309	6.8	0.097	1.5	5.4	slight eff after 5 hrs at 200oC
12	1.302	2	0.097	21.5	78.5	moderate with heat
13	1.268	5.9	0.097	0.6	2.2	slight eff after 5 hrs at 200oC
14	1.253	2.1	0.097	16.9	64.1	moderate with heat
15A	1.325	7.1	N/A		N/A	slight
15B	1.309	7	N/A		N/A	slight
B1	1.262	2.9	0.097	3.5	13.2	moderate eff after 5 hrs at 200oC
16	1.287	6.1	0.097	1.1	4.1	slight with heat
17	1.268	6.4	0.097	0.1	0.4	slight
18	1.285	10	N/A		N/A	moderate, gentle boil
19	1.297	6.3	0.097	0.1	0.4	moderate with heat
20A	1.292	6	0.097	0.15	0.6	slight
20B	1.291	6.1	0.097	0.15	0.6	slight
21	1.254	2	0.097	8.5	33.3	moderate with heat
22	1.291	7.3	N/A		N/A	moderate with heat
23	1.326	5.8	0.097	4.9	17.6	slight eff after 5 hrs at 200oC
24	1.263	8.7	N/A		N/A	slight
25A	1.257	8.7	N/A		N/A	slight
25B	1.25	8.9	N/A		N/A	slight
26	1.263	9.1	N/A		N/A	slight
27	1.311	2.1	0.097	6.3	22.8	moderate
28	1.288	2	0.097	10	36.9	moderate with heat
29	1.271	9	N/A		N/A	moderate
30A	1.304	8.8	N/A		N/A	slight
30B	1.314	9.3	N/A		N/A	slight
B2	1.272	3	0.097	1.9	7.1	moderate eff after 5 hrs at 200oC
31	1.255	9.3	N/A		N/A	moderatre
32	1.28	6.1	0.097	1	3.7	moderatre
33	1.294	7.5	N/A		N/A	moderatre
34	1.28	10.3	N/A		N/A	moderatre
35A	1.273	10.4	N/A		N/A	slight
35B	1.31	10.4	N/A		N/A	slight
36	1.261	8.8	N/A		N/A	moderate
37	1.292	8	N/A		N/A	slight
38	1.297	1.6	0.097	7.8	28.6	moderate with heat
39	1.254	10.3	N/A		N/A	moderate
40A	1.323	11.3	N/A		N/A	moderate
40B	1.297	11.3	N/A		N/A	moderate
41	1.288	10.3	N/A		N/A	moderate
42	1.27	1.8	0.097	3.5	13.1	moderate
43	1.304	5.9	0.097	3.5	12.8	slight eff after 5 hrs at 200oC
B3	1.272	2.7	0.097	5.1	19.1	moderate eff after 5 hrs at 200oC
1R	1.253	7.6	N/A		N/A	slight eff after 5 hrs at 200oC
2R	1.257	2.3	0.097	4.7	17.8	moderate
3R	1.275	10.5	N/A		N/A	moderate with heat, gentle boil
6R	1.252	8.1	N/A		N/A	moderate with heat, gentle boil

NAG = (49 * V * M)/W

ANC tests - MOD. Data from RM, transcribed by DJI.

Sample	Weight	HCl	HCl	Observations,	pH	NaOH	NaOH	Observations	ANC
94E 1310	g	Molarity	Vol, mLs	Acidification		Vol, mLs	Molarity	Back titration	kg H2SO4/t
									dry wt.
1	2.001	0.1	25	H2S evolved	2.1	17.2	0.097	Green colour	19
2	5.080	0.1	25		2.8	13.8	0.097		11
3	1.040	0.5	25	H2S evolved	1.0	22	0.490	Green/brown	71
4	1.104	0.5	25		1.5	14	0.490	Green colour	244
5A	1.033	0.5	25		1.5	10.1	0.490	Green colour	353
5B	1.011	0.5	25		1.5	10.7	0.490	Green colour	347
6	1.001	0.5	25	H2S evolved	1.2	20.6	0.490	Green/red-brown	108
7	1.020	0.5	25		1.2	19.4	0.490	Green	135
8	1.031	0.5	25		1.5	11.3	0.490	Green	326
9	1.024	0.5	25		1.5	13.7	0.490	Green/orange-brown	270
10A	1.020	0.5	25		1.3	16.7	0.490	Green/orange	199
10B	1.043	0.5	25		1.3	16	0.490	Green/orange	211
11	5.109	0.1	25		2.2	11.8	0.097		13
12	5.042	0.1	25	H2S evolved	3.3	17.8	0.097		7
13	5.038	0.1	25		1.8	22.6	0.097		2
14	5.083	0.1	25		3.3	18.6	0.097		6
15A	5.157	0.1	25		2.0	15.1	0.097		9
15B	5.106	0.1	25		2.1	15.4	0.097		9
16	5.022	0.1	25		1.9	22.4	0.097		3
17	5.058	0.1	25		3.7	5	0.097		19
18	1.043	0.5	25		1.6	9.4	0.490		366
19	5.182	0.1	25		2.2	18.3	0.097	Green	6
20A	5.057	0.1	25		2.3	22.4	0.097		3
20B	5.022	0.1	25		2.4	21.1	0.097		4
21	5.090	0.1	25		2.8	14.7	0.097		10
22	5.016	0.1	25		2.1	16.4	0.097		10
23	5.124	0.1	25		2.0	21.3	0.097		4
24	1.033	0.5	25		1.3	23.8	0.490		28
25A	1.020	0.5	25		1.5	19.2	0.490	Green/orange-brown	139
25B	1.021	0.5	25		1.5	19.4	0.490	Green/orange-brown	134
26	1.003	0.5	25		2.1	2.9	0.490	Green/orange-brown	540
27	5.161	0.1	25	H2S evolved	2.6	12.7	0.097		12
28	5.056	0.1	25		3.5	9.6	0.097		15

29	5.059	0.1	25	H_2S evolved	5.2	3.1	0.097		21
30A	2.025	0.1	25		2.0	8.6	0.097	Orange-brown	40
30B	2.036	0.1	25		2.0	8.5	0.097	Orange-brown	40
31	1.014	0.5	25		1.3	14.3	0.490	Green to brown	259
32	5.034	0.1	25		1.9	22.9	0.097		2
33	5.028	0.1	25		2.4	13.4	0.097		11
34	1.018	0.5	25		1.5	20.2	0.490	Green	116
35A	1.004	0.5	25		1.5	19.1	0.490	Green	144
35B	1.013	0.5	25		1.5	18.8	0.490	Green	150
36	5.114	0.1	25		3.0	9.3	0.097	Green	15
37	5.026	0.1	25		3.1	5.8	0.097		19
38	5.034	0.1	25		2.0	14.9	0.097		10
39	1.017	0.5	25		1.5	19	0.490	Light green	145
40A	1.020	0.5	25		1.5	20.8	0.490	Light green-orange brown	101
40B	1.005	0.5	25		1.6	21.5	0.490	Light green-orange brown	85
41	1.008	0.5	25		1.7	16.3	0.490	Light green	211
42	5.000	0.1	25		3.6	3.6	0.097		21
43	5.031	0.1	25		2.0	21.6	0.097		3
Blank		0.1	25			25.5	0.097		
Blank		0.5	25			25.4	0.490		

C = constant = ([HCl] * HCl Vol blank) /([NaOH] * Vol NaOH blank)
C = (0.1 * 25) / 0.097 * 25.5) = 1.0 for 0.1 M acid
C = (0.5 * 25) / 0.49 * 25.4)   = 1.0 for 0.5 M acid

Y = Vol of HCl consumed by sample = (vol HCl added) - (Vol NaOH * C)

Z = 49 if ANC expressed as H_2SO_4/tonne equivalents
Z = 5.0 if ANC expressed as % $CaCO_3$ equivalents

ANC = (Y * [HCl] * Z) / M where M is sample weight in grams.

NAG tests - MOD. Data from RM, transcribed by RSS.

Repeats from batch

Sample	Weight	pH	NaOH	NaOH	NAG	Observed effervescence,
94E 1310	g		Molarity	Vol, mLs		hydrogen peroxide step
11	1.282	6.9	0.097	0.8	3	slight
16	1.286	6	0.097	2.6	9.6	slight
32	1.296	5.9	0.097	3	11.0	slight
43	1.266	6	0.097	3.9	14.6	slight

NAG = (49 * V * M)/W

CHEMISTRY
CENTRE

Your Ref : 94E1422
Our Ref :
Enquiries to : R.S.Schulz
Telephone : 222 3018

Department of Minerals and Energy
Mining Operations Division
Mineral House
100 Plain Street, WA 6004
Attention: M Rowe / RD Williams

Waste Characterisation Analyses

Report on 13 samples of waste rock and 1 sample of water received on December 17, 1994.

All results are presented in the attached spreadsheet format. Please note that the electrical conductiviy results are in µS/cm (as requested), not mS/m as is usually the case in CCWA reports.

Peta

PB McCafferty
Chemist and Research Officer
Environmental Chemistry Laboratory
Cost: $ 2755.00

MOD Tests pH, EC, Sulphurs .						
Results on a dry wt. basis						
CCWA ID	Client ID	pH	EC	Comments on	Total S	SO4
UNITS			uS/cm	slurries.	%	%
1422/1	Kb-1	8.8	580		<0.01	<0.01
1422/2	Kb-2	7.5	3500		0.10	0.04
1422/3	Kc-1	8.3	1400		1.08	0.04
1422/4	Kc-2	8.4	8200		0.39	0.02
1422/5	Ne-1	8.9	200		0.01	0.01
1422/6	Tr-1	7.7	1100		2.16	0.16
1422/7	TB-2	7.8	370		0.62	0.07
1422/8	Tb-3	6.2	10000		7.21	2.9
1422/9	Tb-4	3.0	28000		18.1	17.0
1422/10	Ti-2	8.1	-	gelled	0.40	0.11
1422/11	Jb-1	9.0	120		<0.01	<0.01
1422/12	3mi-1	8.6	350		0.02	0.02
1422/13	CG-1	8.4	350		0.55	0.03
1422/14	Water	6.7*	2480*		0.05	-
	*results direct on sample (no slurry).					

ANC tests - MOD. Data from RM, transcribed by RSS.

Sample 94E 1422	Weight g	HCl Molarity	HCl Vol, mLs	Observations, Acidification	pH	NaOH Vol, mLs	NaOH Molarity	Observations Back titration	(as received) ANC kg H2SO4/t
1	2.067	0.1	25		5	4.2	0.097	orange brown	49
2	5.007	0.1	25	trace H2S	2.3	23.4	0.097		2
3	2.002	0.1	25		6.1	1.5	0.097		58
4	1.043	0.5	25		1.7	18	0.49	green -red brown	164
5A	5.030	0.1	25		2.8	16.4	0.097	pale green	8
5B	5.067	0.1	25		2.8	16.5	0.097	pale green	8
6	5.008	0.1	25		3.1	14.9	0.097		10
7	5.011	0.1	25	trace H2S	4	17	0.097	green	8
8	5.039	0.1	25		5.2	11.8	0.097		13
9	5.016	0.1	25		2.3	115.5	0.097	green	-88
10A	5.044	0.1	25		3.2	16.2	0.097	green	9
10B	5.024	0.1	25		3.2	16	0.097	green	9
11	5.012	0.1	25		5.5	1.9	0.097	pale green	23
12	5.002	0.1	25		3.5	9.1	0.097	green	16
13	1.018	0.5	25		1.6	19.3	0.49		137
(3 R)	1.012	0.5	25		1.5	14	0.49	green - red brown	266
(11 R)	2.009	0.1	25		3	4.5	0.097	pale green	50
Blank		0.1	25			25.5	0.097		#VALUE!
Blank		0.5	25			25.4	0.49		#VALUE!

C = constant = ([HCl] * HCl Vol blank) /([NaOH] * Vol NaOH blank)
C = (0.1 * 25) / 0.097 * 25.5) = 1.0 for 0.1 M acid
C = (0.5 * 25) / 0.49 * 25.4) = 1.0 for 0.5 M acid

Y = Vol of HCl consumed by sample = (vol HCl added) - (Vol NaOH * C)

Z = 49 if ANC expressed as H2SO4/tonne equivalents
Z = 5.0 if ANC expressed as % CaCO3 equivalents

ANC = (Y * [HCl] * Z) / M where M is sample weight in grams.

NAG tests - MOD. Data from RM, transcribed by RSS.

Sample 94E1422	Weight g	pH	NaOH Molarity	NaOH Vol, mLs	NAG	Observed effervescence, hydrogen peroxide step
1	1.258	10.7	N/A	N/A	N/A	moderate
2	1.265	3.8	0.097	0.5	1.9	slight
3	1.263	9.6	N/A	N/A	N/A	moderate
4	1.282	9.8	N/A	N/A	N/A	strong
5A	1.265	7.6	N/A	N/A	N/A	moderate
5B	1.286	7.7	N/A	N/A	N/A	moderate
6 Tr 1	1.267	2.7	0.097	11.4	42.8	strong
7 TB2	1.252	5	0.097	3.5	13.3	moderate
8 TB3	1.256	5.6	0.097	4.8	18.2	strong
9 TB4	1.283	2.6	0.097	28.3	104.8	very strong
10A Ti2	1.291	4.1	0.097	1.2	4.4	moderate
10B Ti2	1.285	1	0.097	1.1	4.1	moderate
11 JB1	1.267	9.2	N/A	N/A	N/A	moderate
12 3mi	1.308	9.4	N/A	N/A	N/A	slight
13 C6	1.275	11.3	N/A	N/A	N/A	slight
Blank	1.277	3.8	0.097	1.4	5.2	N/A

NAG = (49 * V * M)/W

Analabs

Analabs Pty. Ltd.
ACN 004 591 664
50 Murray Rd. WELSHPOOL
WESTERN AUSTRALIA 6106
P.O. Box 210, BENTLEY
WESTERN AUSTRALIA 6102
Tel: (619) 458 7999
Fax: (619) 458 2922

Facsimile Transmission

To: Dept of Mines	From: Alf Larcher
Attn: David Williams	Analabs Perth
Fax N°: 325 2280	Date: 25/1/94
N° Pages including this one: 7	Re: Progressive Results

David,

Please find progressive results.

Methods as per quote.

Remaining results will be available later today or Friday.

Alf

kg H2SO4/tonne

SAMPLE	ANC	Initial Effervescence	Effervescence on Warming	pH before Titration
Bb 1a	19.51	Slightly Reactive	Nil	2
Bb 10	4.22	Slightly Reactive	Nil	1.9
Bb 11	137.12	Very Reactive	Slight	0.9
Gg 1	289.25	Very Reactive	Slight	0.9
H 52	228.16	Very Reactive	Slight	0.9
H 53	354.14	Very Reactive	Slight	0.9
H 55	504.40	Extremely Reactive	Moderate	0.9
H 56	381.19	Very Reactive	Moderate	1
H 57	402.41	Very Reactive	Slight	0.9
H 501	279.12	Very Reactive	Slight	0.9
H 502a	292.86	Very Reactive	Slight	1
H 503	96.27	Very Reactive	Slight	0.9
HL 2a	339.76	Very Reactive	Slight	1
HL 3a	19.03	Slightly Reactive	Nil	1.8
HL21a	373.37	Very Reactive	Nil	0.8
HL 41	17.93	Slightly Reactive	Nil	1.9
Mg 11	40.93	Slightly Reactive	Nil	2.2
Mg 12	26.09	Slightly Reactive	Nil	2.6
Mg21	28.89	Slightly Reactive	Nil	2.5
Mg 22	84.70	Very Reactive	Slight	0.9
Mg 23a	23.83	Slightly Reactive	Nil	3.3
Mg 31a	6.37	Slightly Reactive	Nil	1.8
Mg 32a	10.00	Slightly Reactive	Nil	2
Mg 33a	7.26	Slightly Reactive	Nil	1.8
Pa 1a	6.74	Slightly Reactive	Nil	1.8
Pa 2a	403.03	Very Reactive	Slight	0.9
Sb 1	27.01	Slightly Reactive	Nil	6.8
Sb 2a	4.61	Slightly Reactive	Nil	1.8
Sb 3a	7.24	Slightly Reactive	Nil	1.8
Sb 5	88.62	Very Reactive	Slight	0.9
SCIa	64.32	Very Reactive	Slight	0.9
Tr 5a	91.76	Very Reactive	Slight	0.8
Tr 6a	80.68	Very Reactive	Slight	0.8
Tr 7a	46.01	Very Reactive	Slight	5.8
Tr 8a	3.04	Slightly Reactive	Slight	1.9
Wn 1a	191.93	Very Reactive	Slight	0.9
Wn 2a	144.97	Very Reactive	Slight	0.9
Wn 5a	55.85	Very Reactive	Slight	0.9
Wn 7	105.44	Very Reactive	Slight	0.9
Wn 8a	226.58	Very Reactive	Slight	0.9
Wn 9a	234.69	Very Reactive	Slight	0.8
Wln 10a	305.60	Very Reactive	Slight	0.8
Wln 10b	281.37	Very Reactive	Slight	0.9
Wln 11a	16.99	Slightly Reactive	Nil	2
Wln121	260.99	Very Reactive	Slight	0.9
Yo1a	56.86	Very Reactive	Slight	0.9
94-11-4t				
RPT H53	361.31	Slightly Reactive	Slight	1
RPTYo1a	46.97	Slightly Reactive	Slight	0.8

kg H_2SO_4/tonne

SAMPLE	ANC	Initial Effervescence	Effervescence on Warming	pH before Titration
Bb2T	24.10	Slight	Nil	1.54
Bb3T	13.01	Slight	Nil	1.55
Ra1a	37.30	Slight	Nil	1.84
Ra2a	29.10	Slight	Nil	1.7
Ra3a	40.80	Slight	Nil	2.13
Ra4a	19.85	Slight	Nil	1.5
Pa3(t)	95.61	Slight/moderate	Nil	5

②

NET ACID GENERATION "NAG"				
JOB No. :	23286			
DATE :	17.1.95			
ANALYST :	KD			
SAMPLE	pH	EC uS/cm	NAG H2SO4/tonne	OBSERVATIONS
Bb 1a	8.1	328	<0.5	Slight Effervescence Initially
Bb 10	2.8	1196	16.8	Moderate Effervescence Initially
Bb 11	8.4	372	<0.5	Moderate Effervescence Initially
Gg 1	8.2	405	<0.5	Moderate Effervescence Initially
H 52	8.3	427	<0.5	Moderate Effervescence Initially
H 53	7.4	663	<0.5	Moderate Effervescence Initially
H 55	8.4	193	<0.5	Moderate Effervescence Initially
H 56	8	208	<0.5	Moderate Effervescence Initially
H 57	8.6	221	<0.5	Moderate Effervescence Initially
H 501	8.6	207	<0.5	Moderate Effervescence Initially
H 502a	8.5	189	<0.5	Moderate Effervescence Initially
H 503	8.2	269	<0.5	Moderate Effervescence Initially
HL 2a	8.5	311	<0.5	Moderate Effervescence Initially
HL 3a	7.3	182	<0.5	Moderate Effervescence Initially
HL21a	8.4	190	<0.5	Moderate Effervescence Initially
HL 41	8.2	265	<0.5	Moderate Effervescence Initially
Mg 11	4.3	358	2	Moderate Effervescence Initially
Mg 12	2.9	904	132.7	Very Reactive, Boiled Overnight
Mg21	2.8	1123	109.1	Very Reactive, Boiled Overnight
Mg 22	3.5	318	28.2	Moderately Reactive, Ceased by Morning
Mg 23a	3.5	473	36.3	Moderate Effervescence Initially
Mg 31a	6.8	184	1.3	Slightly Reactive
Mg 32a	7.8	378	<0.5	Moderate Effervescence Initially
Mg 33a	6.8	154	4.8	Moderate Effervescence Initially
Pa 1a	3.4	538	7.7	Moderate Effervescence Initially

SAMPLE	pH	EC uS/cm	NAG H2SO4/tonne	OBSERVATIONS
Pa 2a	8.6	518	<0.5	Moderate Effervescence Initially
Sb 1	6.5	160	2.5	Moderate Effervescence Initially
Sb 2a	6.9	130	<0.5	Moderate Effervescence Initially
Sb 3a	6.6	136	3.6	Moderate Effervescence Initially
Sb 5	8.2	346	<0.5	Moderate Effervescence Initially
SC1a	3	1117	18.6	Moderate Effervescence Initially
Tr 5a	8.4	250	<0.5	Moderate Effervescence Initially
Tr 6a	8.5	217	<0.5	Moderate Effervescence Initially
Tr 7a	8.4	203	<0.5	Moderate Effervescence Initially
Tr 8a	6.4	82.6	3.8	Moderate Effervescence Initially
Wn 1a	8.6	121	<0.5	Moderate Effervescence Initially
Wn 2a	7.9	280	<0.5	Moderate Effervescence Initially
Wn 5a	2.7	1366	155.1	Very Reactive, Boiled Overnight
Wn 7	3	682	50.5	Slightly Reactive Initially
Wn 8a	8.2	129.7	<0.5	Slightly Reactive Initially
Wn 9a	9	215	<0.5	Slightly Reactive Initially
Wln 10a	8.5	199	<0.5	Slightly Reactive Initially
Wln 10b	7.6	153	<0.5	Slightly Reactive Initially
Wln 11a	7.9	275	<0.5	Slightly Reactive Initially
Wln121	8.4	184	<0.5	Slightly Reactive Initially
Yo1a	2.4	3440	82.6	Very Reactive Initially
94-11-4t	2.4	2490	479.9	Very Reactive Initially, Boiled Overnight
Bb2T	8.1	787	<0.5	Slightly Reactive Initially
Bb3T	2.8	936	55.4	Reactive Initially
Ra1a	7.2	106	<0.5	Slightly Reactive Initially
Ra2a	7.3	127	<0.5	Slightly Reactive Initially
Ra3a	3.1	545	73.4	Moderate Effervescence Initially
Ra4a	7.7	420	<0.5	Slightly Reactive Initially
Pa3(t)	8.4	769	<0.5	Slightly Reactive Initially
Bb2T-RPT	2.8	815	47.9	Moderate Effervescence Initially
Bb3T-RPT	2.7	1009	53.6	Slightly Reactive Initially

Appendix F

Summary of the Chemistry of Acid Rock Drainage

Sulfide Oxidation in a nutshell...

Sulfide minerals are typically formed during the latter stages of igneous activity. They are often related to late stage magmatic fluids consisting mostly of water at high temperatures and are generally not stable in the weathering environment. Historically, prospectors have looked for weathering products of sulfide minerals, the "gossan" or "iron cap", as indicators of mineralized areas. All sulfides suffer from the same geochemical tendencies, however some are more common and reactive than others. Because iron sulfide is the most common sulfide and is also the most easily subjected to chemical attack in a weathering environment, this discussion will focus on this mineral. Iron sulfide can occur as FeS_2 either as pyrite, or less commonly as the polymorph marcasite. Iron sulfide also occurs as pyrrhotite ($Fe_{1-x}S$). Evidence suggest both marcasite and pyrrhotite are more susceptible to oxidation than pyrite. Pyrite can exist either as a coarsely crystalline variety, common in many base and precious metal mines, or as a cryptocrystalline variety known as framboidal pyrite. Framboidal pyrite is generally much more susceptible to weathering.

In the initial weathering reaction, these minerals are oxidized producing dissolved iron, sulfate, acid and heat. This initial reaction is commonly expressed as:

$$FeS_2 + 7/2O_2 + H_2O \ <\!-\!> \ Fe^2+ + 2SO_4^{2-} + 2H^+$$

In the natural environment this reaction is generally considered to be electrochemical. Virtually all the products of this initial reaction result in negative impacts to the receiving environment. Compounding this, the reaction products themselves can have an autocatalytic effect. The dissolved iron, increased acidity and temperature all can accelerate the subsequent oxidation of additional pyrite. The second phase of the oxidation reactions involves the oxidation of ferrous iron (Fe_{2+}) to ferric iron (Fe^{3+}).

$$Fe^{2+} + 1/4\ O_2 + H^+ \ <\!-\!> \ Fe^{3+} + 1/2\ H_2O$$

This reaction takes place within the range of pH values expected in the weathering environment. At a pH above 3-4 ferric iron is insoluble and precipitates as ferric oxyhydroxide.

$$Fe^{3+} + 3H_2O \ <\!-\!> \ Fe(OH)_3 + 3H^+$$

The precipitation of ferric oxyhydroxide does reduce Fe^{+3} in solution but it also produces additional acid which can then aid in the subsequent oxidation of additional pyrite. Ferric iron in solution is important because it can serve to oxidize additional pyrite by the reaction below.

$$FeS_2 + 14\ Fe^{+3} + 8H_2O \ <\!-\!> \ 15\ Fe^{+2} + 2SO_4^{2-}$$

The pH range between 5 and 3 is important because there are several potential factors which enter into this rather complex weathering reaction. As the pH drops below 5, pyrite dissolution increases markedly as bacteria which catalyze the oxidation reaction become important. As noted above, the lower end of this pH region is important because ferric iron will remain in solution, where it acts to oxidize additional pyrite. As the pH drops below 3.5 the importance of bacterial activity is greatly increased further accelerating the oxidation of pyrite.

Of course most sulfide assemblages include a variety of minerals other than iron sulfides. The presence of additional mineral components only serves to further complicate the oxidation reactions. The dissolved iron present resulting from the initial pyrite oxidation reaction can promote the oxidation of other sulfide minerals. While these minerals may not be important contributors to the overall acid present, often the metals are kept in solution by the reduced pH, and galvanic interactions amongst the minerals and dissolution products can further promote oxidation of the non-pyrite portion of the mineral assemblage.