KEYSBROOK MINERAL SANDS PROJECT, KEYSBROOK, WESTERN AUSTRALIA: ACID SULFATE SOILS ASSESSMENT

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PREPARED FOR

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1. INTRODUCTION

The proposed Keysbrook mineral sand mine is located within the Peel Harvey catchment portion of the Swan Coastal Plain. The acid sulfate soils (ASS) map of Western Australian Planning Commission Planning Bulletin 64 (2003) shows most of the mine area as moderate to low risk of acidity, with two specific areas shown as high risk. A larger high risk site is located outside the mine area and will not be disturbed.

The Department of Environment (DoE) (2003) describes ASS as the common name given to naturally occurring soil or sediment containing iron sulfides over extensive low-lying areas under waterlogged (i.e. anaerobic) conditions. These soils may be found close to the natural ground level but may also be found at depth in the soil profile. When sulfides are exposed to air, oxidation takes place and sulfuric acid is produced where the soil's capacity to neutralise the acidity is exceeded.

In Western Australia, ASS are known to have formed in estuarine areas and coastal lowland areas such as mangroves, tidal flats, salt marshes and swamps, wetland areas, saline inland areas and near mining operations.

Particular areas of concern in Western Australia include:

- Estuarine, floodplain and wetland areas between Perth and Busselton, such as the Peel-Harvey estuarine system and the Vasse River area;
- The northern coastline, including the Pilbara and Kimberley coasts;
- The Scott River Plain, including Toby Inlet; and
- Parts of the Wheatbelt where land salinisation has occurred.

The Environmental Protection Authority (EPA) objective is to maintain the integrity, ecological functions and environmental values of the soil and landform.

2. BASELINE ACID SOIL ASSESSMENT

A meeting was held with DOE representatives on 24 October 2005 to determine the scope of soil assessment to be conducted over the mine site. It was determined to undertake an initial survey over a range of different soil types, focusing on the low-lying landforms that are the most likely sources of potentially acid sulfate soils (PASS). If this initial investigation identified high PASS in the mining area, further sampling may be required to quantify the extent of potential acid forming locations at a more detailed level.

The resource drilling indicated the heavy minerals are located within the superficial sand layer, generally no deeper than two metres below surface within the low-lying profiles. Testing for PASS extended to one metre below the resource/excavation zone as required in the DoE Identification and Investigation of ASS (October 2004).

Testing was conducted on 23 November 2005 by drilling holes to three metres below surface at selected locations (Figure 1).

Field samples were collected every 0.25 metre down each hole. For laboratory analysis, sub samples of two field samples were bulked to produce a sample of each 0.5 metre profile within each hole. Table 1 describes the soils from the locations sampled over the mine area.

Table 1: Description of Soils Sampled over the Mine Area

Site	Soil Type	Description	ASS Risk Category[4]
1	P8[2]	Broad imperfectly to poorly drained flats and ill defined stream channels with moderately deep to deep sands over mottled clays; acid grey and yellow duplex soils to uniform bleached pale brown sands over clays	Moderate-Low
2	P8[2]	As above.	Moderate-Low
3	B6[2]	Sand plain similar to B4 with imperfectly drained soils.	Moderate-Low
4	B4[2]	Broad poorly drained sand plain with deep grey siliceous sands or bleached sands, underlain at depths generally greater than 1.5 metres by clay or less frequently a strong iron organic pan.	High
	Sp2[3]	Peat Sand. Fine to medium grained quartz sand with much brown to black organic material, grades to peat of, of lacustrine origin.	
5	P1b[2]	Gently undulating plain with deep acid mottled duplex yellow soils having sand to sandy loam surfaces and generally moderately deep topsoil over clay subsoil.	High
6	B6[1]	Sand plain similar to B4 with imperfectly drained soils.	Moderate-Low

Notes:

1. Van Gool (1990) Land Resources in the Northern Section of the Peel-Harvey Catchment, Swan Coastal Plain, WA.
2. Wells (1989) Land Resources of the Mandurah-Murray Region WA.
3. Geological Survey of Western Australia (1986) Environmental Geology Series: Serpentine.
4. Western Australian Planning Commission. Planning Bulletin No. 64. Acid Sulfate Soils. (November 2003).

In the field, samples were stored in eskies in accordance with the DoE Identification and Investigation of ASS (October 2004). The samples were transferred to a deep freezer within four hours of collection and frozen. The samples were delivered to the Chemistry Centre of Western Australia for analysis in a frozen state.

3. LABORATORY ANALYSIS AND REPORT

SAMPLE IDENTIFICATION

The samples of soils were provided to the Chemistry Centre of WA on 25/11/05. On receipt the samples were identified and allocated a Laboratory Number.

TEST METHODS

The test methods of the Acid Sulfate Soils Laboratory Methods Guidelines manual were used in this work, specifically Method Code 23 – SPOCAS (Suspension Peroxide Oxidation Combined Acidity and Sulfate) formed the basis of this work.

The SPOCAS method is a standardised set of procedures useful in assessing the environmental impact of soils suspected of containing pyrite and other iron sulfides which might lead to an acid sulfate soil problem if disturbed.

SAMPLE PREPARATION

After drying at 85°C for a minimum of 48 hours, sub samples of the milled homogenised material were then subjected to chemical tests. All results are reported on a dry weight basis.

TEST PROCEDURES

Step 1: Determination of Potassium Chloride Extractable Sulfur (S_{KCl}), and Titratable Actual Acidity (TAA)

In this procedure the sample is extracted with potassium chloride solution. The extraction with potassium chloride is used to determine soluble and absorbed sulfur (non-sulfidic sulfur) and the titratable actual acidity of the sample (**TAA**).

The pH, acidity, and extracted sulfur of the resultant solution are reported as **pH_{KCl}, TAA_{KCl},** and **S_{KCl}** respectively.

Step 2: Determination of the Peroxide Oxidation Sulfur (S_P) and Titratable Peroxide Acidity (TPA)

This step involves oxidation of the sample with hydrogen peroxide to produce maximum acidity from any reduced sulfidic material. The sulfur content (**S_P%**), the Titratable Peroxide Acidity (**TPA**), and pH (**pHox**) of the oxidised solution are determined. **S_P%** will include the soluble, absorbed, and sulfide, sulfur species.

Step 3: Determination of Retained Acidity

Existing acidity in acid sulfate soils includes **'actual'** acidity (TAA) and **'retained'** acidity (acidity stored in largely insoluble iron and aluminium sulfate minerals). A dilute HCl extraction performed on the washed soil residue after peroxide digestion will give the residual acid soluble sulfur (**S_{RAS}**) from which the retained acidity can be calculated. This acidity is expressed as **a-S_{RAS}**. For soil samples with $pH_{KCl}<4.5$ the S_{RAS} **must** be determined.

Step 4: Determination of the excess Acid Neutralising Capacity (if applicable)

This determination is optional depending on the peroxide solution pH.
If the solution pH after the peroxide step is >6.5, the material may have an acid neutralisation capacity. The excess acid neutralizing capacity may be lower than the neutralising capacity calculated from the reacted calcium and magnesium since some of the inherent neutralizing capacity may have been consumed by peroxide generated acidity.

Step 5: Peroxide Oxidisable Sulfur (S_{POS})

This step involves calculating the differences between the extracts from Step 2 and Step 1. The peroxide oxidisable sulfur is used to predict the potential acid risk from non-oxidised sulfur compounds.

Peroxide oxidisable sulfur: $S_{POS} = (S_P - S_{KCl})\%$

If it assumed that all the Spos is a result of pyrite oxidation then Spos can be converted to acidity units:

Spos(%S) x 624 =equivalent mol H^+/t

RESULTS

Table 2 shows the results of the laboratory analysis.

Table 2: Laboratory Analysis Results

Test Site	Lab No. 05A282	Depth	Soil Type	Description	pH KCl	pHox	SKCl	Sp	Spos	ANC	TPA	TAA	TPA Action Criteria for Sand
							%	%	%	moles H+/tonne			
1:H2	001	0-0.5	P8	Broad poorly drained flats and stream channels. Moderately deep sands over mottled clays.	5.3	4.7	<0.01	<0.01	<0.01		6	<2	18
	002	0.5-1			5.1	4.3	0.01	0.01	<0.01		15	4	18
	003	1-1.5			5.1	4.5	<0.01	0.01	0.01		15	5	18
	004	1.5-2			5.4	4.4	0.01	0.01	<0.01		12	5	18
	005	2-2.5			5.5	4.7	0.01	0.01	<0.01		8	3	18
	006	2.5-3			6.2	5.6	0.02	0.02	<0.01		<2	<2	18
2:H2	007	0-0.5	P8	Broad poorly drained flats and stream channels. Moderately deep sands over mottled clays.	4.9	4.9	0.01	0.01	<0.01		3	6	18
	008	0.5-1			5.1	4.5	0.01	0.02	0.01		5	4	18
	009	1-1.5			4.9	4.4	0.02	0.03	0.01		13	8	18
	010	1.5-2			4.8	4.2	0.03	0.04	0.01		20	13	18
	011	2-2.5			4.8	4.3	0.02	0.03	0.01		19	12	18
	012	2.5-3			5.3	4.5	0.01	0.02	0.01		9	<2	18
3:H4	013	0-0.5	B6	Broad poorly drained sandplain with deep grey siliceous sands, underlain at depths generally greater than 1.5 metres by clay.	5	4.7	<0.01	0.01	0.01		6	4	18
	014	0.5-1			5.4	4.4	<0.01	0.01	0.01		4	5	18
	015	1-1.5			5.5	4.7	0.01	0.02	0.01		5	2	18
	016	1.5-2			5.7	5.5	0.03	0.03	<0.01		<2	<2	18
	017	2-2.5			5.6	4.8	0.02	0.02	<0.01		7	3	18
	018	2.5-3			5	5	0.01	0.01	<0.01		4	6	18
4: H4	019	0-0.5	B4	Broad poorly drained sandplain with deep grey siliceous sands, underlain at depths generally greater	5.5	5	<0.01	0.01	0.01		<2	3	18
	020	0.5-1			5.1	4.4	0.01	0.01	<0.01		8	4	18
	021	1-1.5			5	4.4	<0.01	0.01	0.01		6	8	18

Test Site	Lab No. 05A282	Depth	Soil Type	Description	pH KCl	pHox	SKCl	Sp	Spos	ANC	TPA	TAA	TPA Action Criteria for Sand
							%	%	%	moles H+/tonne			
	022	1.5-2			4.7	4.4	0.01	0.01	<0.01		8	5	18
	023	2-2.5			4.7	4.6	0.01	0.01	<0.01		5	9	18
	024	2.5-3			4.6	4.6	0.01	0.01	<0.01		8	6	18
5:H4	025	0-0.5	P1b	Flat to gently undulating plain with deep acidic mottled yellow duplex soils comprising moderately deep pale sand to sandy loam over clay. Cs (Clayey sand) unit on Environmental Geology Maps and High Risk ASS on DoE map.	5.6	4.3	<0.01	<0.01	<0.01		5	<2	18
	026	0.5-1			5.5	4.5	<0.01	0.01	0.01		4	2	18
	027	1-1.5			5.9	4.5	<0.01	<0.01	<0.01		3	<2	18
	028	1.5-2			5.8	4.7	<0.01	0.01	0.01		3	<2	18
	029	2-2.5			5.5	4.5	0.01	0.01	<0.01		10	3	18
	030	2.5-3			5.4	5.4	0.01	0.01	<0.01		5	<2	18
6:H2	031	0-0.5	B6	Broad poorly drained sandplain with deep grey siliceous sands, underlain at depths generally greater than 1.5 metres by clay.	4.8	4.4	<0.01	<0.01	<0.01		15	6	18
	032	0.5-1			5.1	4.7	<0.01	<0.01	<0.01		4	3	18
	033	1-1.5			4.6	5.7	0.01	0.02	0.01		<2	8	18
	034	1.5-2			4.5	6.5	<0.01	0.03	0.03	12	<2	12	18
	035	2-2.5			4.5	6.5	0.01	0.02	0.01	9	<2	10	18
	036	2.5-3			4.7	6.5	<0.01	<0.01	<0.01	11	<2	9	18

ACID BASE ACCOUNTING (ABA)

The acid base accounting approach is used to predict net acidity from the oxidation of sulfidic material. The SPOCAS method is in essence a self contained ABA. The **TPA** result represents a measure of the net acidity, effectively equivalent to the sum of the soil's potential sulfidic activity and actual acidity **(TAA)** less any neutralising capacity of the sample. Where the pH_{KCl} is <4.5 then the residual acid soluble sulfur (S_{RAS}) component of SPOCAS should be done, since the TPA does not measure **retained acidity**. In soils that are self neutralising (ie TPA=0), then the HCL titration step in SPOCAS allows calculation of the **excess acid neutralising capacity** (ANC_E).

GUIDE TO INTERPRETATION OF SPOCAS TESTWORK

Interpretation of results from SPOCAS test methods involve comparison of the test results with published action criteria. Table 3 shows the NSW ASSMAC published Action Criteria.

Table 3: NSW ASSMAC Action Criteria

Type of Material		Action Criteria, <1,000 tonnes		Action Criteria, >1,000 tonnes	
Texture	Approx Clay Content (%<0.002 mm)	Sulfur Trail S_{POS} %	Acid Trail TPA mole H^+/t	Sulfur Trail S_{POS} %	Acid Trail TPA mole H^+/t
Coarse eg sands	□5	0.03	18	0.03	18
Medium eg loams/light clays	5 – 40	0.06	36	0.03	18
Fine clays/silts	□40	0.1	62	0.03	18

According to the NSW ASSMAC, exceedance of the action criteria indicates risk of an acid sulfate soil issue and the need for an acid sulfate soil management plan with development approval.

INTERPRETATION OF RESULTS OF SPOCAS TESTS FROM THIS WORK

No single method, including SPOCAS, will provide all the answers to the complex chemistry involved in reactions of acid sulfate soils. However results from SPOCAS test procedures will provide guidance to identification of potential ASS issues. The following comments are provided on the samples tested in this work.

The majority of the samples are within the guideline values for sand. Samples 05A282-010 and 011 exceed the TPA guideline for sand. The anomalous behaviour of samples 05A282-033 to 036 with TAA>TPA was reproducible. The reason for this behaviour is unknown.

RECOMMENDATION

Soils exceeding the Action Limits criteria of the NSW Acid Sulfate Soil Manual should be managed in accordance with that manual.

REFERENCES

1. **Acid Sulfate Soils Laboratory Methods Guidelines** manual, Acid Sulfate Soils Management Advisory Committee (ASSMAC, NSW), August 1998.

2. **Acid Sulfate Soils Laboratory Methods Guidelines 2003**, Department of Natural Resources and Mines, Queensland, August 2003.

4. REVIEW BY DEPARTMENT OF ENVIRONMENT

The Chemistry Centre report was submitted to DOE representatives for review and comment. The following comments were received:

- While the majority of the results are below action criteria levels, there is variation within the sampled locations that indicate some acid formation potential exists.
- The implication for management is highest if water is to be discharged from site into the surrounding environment. While all water from the pit dewatering is utilised within the process and contained on site, there is minimal impact to surrounding systems.
- Implementing a monitoring programme is recommended as a proactive strategy to detect any changes that may occur.
- Implementing proactive action at a normal operational level, such as lining of the water dam with limestone, to produce additional acid neutralising capacity (ANC)/buffering potential is a positive step.
- The preparation of an ASS management plan may be required at a later date, if monitoring results show a trend towards acidification that requires action.

A further meeting was held with the DOE on 12 June 2006. Even though the initial sampling recorded low values in the two high risk sites nominated on the DOE acid soils map (sites 4 and 5 in Table 2), a re-sampling program was advised to provide a more intense sampling pattern, to provide greater certainty in these two areas. A proactive strategy could then be developed to manage the soils in these two areas, in the event the detailed sampling confirms elevated levels that were not recorded in the first survey. Trigger levels were also identified for comparison against the monitoring data, so that management measures can be developed and implemented in a timely manner, if threshold values are recorded.

5. CONCLUSION

The results of the initial sampling indicate the soil profiles in the mine area have a low risk of acid formation. The results indicate an ASS management plan is not required to be prepared at the present time.

Monitoring is recommended to detect any changes that may occur as the project is implemented.

The preparation of an ASS management plan and the implementation of management actions to mitigate acidic impacts will be undertaken if monitoring shows threshold (trigger values) is recorded.

6. REFERENCES

Department of Environment (2003). General Guidance on Managing Acid Sulfate Soils.

Department of Environment (2004). Identification and Investigation of Acid Sulfate Soils. Acid Sulfate Soils Guideline Series.

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