GEOCHEMICAL CHARACTERIZATION OF SPOIL MATERIAL TO ASSESS SUITABILITY FOR USE AS A COVER IN TAILINGS REHABILITATION[1]

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Abstract.   Twenty-four samples of waste rock material from the Mt. Micke stockpile were collected for chemical characterization. Mount Micke is spoil that was removed from the Wonga pit gold mine in Stawell, Western Victoria, Australia.   Tentative plans at the Stawell mine are to use this material as a rehabilitative cover in conjunction with other materials to prepare the mine tailings for revegetation. The objective of this study was to assess the chemical properties of the Mt. Micke spoil to establish future land use potential and investigate the possibilities for future environmental problems. The following elements were targeted for ICP-MS/AES analysis following a nitric:perchloric acid digest: Al, As, Ca, Cd, Co, Cr, Cu, K, Mg, Mn, Mo, Na, Ni, P, Sb, Se, Sn and Zn. Total C and S were also determined. Acid-base accounting (ABA) was used to identify samples with significant acid producing potential (APP). Results indicate most samples have a low APP and are not prone to acid mine drainage. Three of the samples did have high total sulfur concentrations between 0.1-0.18 % and some APP, but the buffering capacity was sufficiently high to neutralize the potential acidity. The composition of transition metals is also relatively low, with ranges typically $<500 \mu g \ kg^{-1}$ in all samples. Interestingly, there were elemental concentration variations between the samples, which are attributed to the distinct regions in the open pit from where the material was originally mined. To accurately assess the characteristics of the spoil, it is essential to sample the different mined zones and not assume the stockpile is homogenous. A nutrient analysis for plant growth should be completed before any attempt is made at rehabilitation. Laboratory data revealed the Mt. Micke material is relatively low in P. Applications of biosolids and commercial fertilizers or the planting of low P tolerant plants will enhance success of rehabilitation on these tailings by compensating for the low P in these materials. Waste Rock from Mt. Micke should not pose any significant environmental problems and should be a beneficial cover supplement to the tailings rehabilitation.

Additional Key Words: Stawell, gold, Victoria, Australia.

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Introduction

Investigations of mine spoil materials often focus on specific environmental impacts such as erosion or acid mine drainage (AMD), however it is also important to understand and evaluate the potential of the material as a future resource. Field and laboratory techniques have been developed to assess specific problems such as potential acidity or neutralizing capacity of overburden materials (Smith et al., 1974), but a more rounded evaluation approach is often ignored. Reclamation of mine sites using overburden is a common practice. Chemical characterization of the material to be used is essential for successful rehabilitation.

Due to the nature of mining materials being excavated from different zones and placed together, contrasting chemical properties can evolve side by side ensuring a much more dynamic chemical environment than the undisturbed material. Weathering of the waste rock will continue to release beneficial and/or hazardous compounds into the environment. The unique physical and chemical properties of mine spoil materials set it apart from other undisturbed soils, regolith and rock materials. For this reason it is essential to describe, study, map and place mine soil in a scheme for future land use planning (Ammons et al., 2000).

Tentative plans to use spoil material as a rehabilitative cover in conjunction with other materials to prepare mine tailings for revegetation have been developed by the Stawell Gold Mine (SGM) in western Victoria, Australia. The spoil material is known as "Mt. Micke" and is constructed of waste rock and regolith removed from the Wonga open-pit gold mine in Stawell.

The Stawell Gold Mine is located approximately 230 km northwest of Melbourne (Fig 1). The mean annual rainfall in Stawell is 575.6 mm with a mean daily temperature of 19.7°C and 8.4°C maximum and minimum, respectively (Commonwealth Bureau of Meteorology, 2003). The elevation is approximately 260 m above sea level and natural vegetation is dry sclerophyll forest and native grasses. Most of the area however is used for agricultural.

Geologically, the region is on the boundary of the Ballarat Trough and Murray Basin in the Lachlan fold belt (Douglas and Ferguson, 1976). The Stawell district is underlain by a NW plunging antiformal culmination of Cambrian mafic volcanic rocks, structurally inserted into a sequence of mudstones and wackes of Cambro-Ordovician age. The regional metamorphic grade is lower greenschist facies, overprinted by a metamorphic aureole (Quick, 1990).

Figure 1. General location of Stawell, Victoria.

The Stawell gold mine (SGM) is a major Victorian goldfield. As of 1990, the mine had produced 82 t of gold with 61 t from primary sources and 21 t from alluvial gold (Woodall, 1990; Phillips and Hughes, 1996). The production of gold in Victoria peaked in 1856 at 96 t y^{-1} and then rapidly decreased to only 5 t y^{-1} in 1918. Production was typically around 1 t y^{-1} until more recent times, where in the last decade gold production has climbed to approximately 4 t y^{-1}, with the Stawell gold mine being the major contributor with 2 t y^{-1} (Phillips and Hughes, 1996).

Gold in the region is mined in either quartz veins or volcanogenic massive sulfides (VMS). There are two distinct ore zones, with oxidized material reaching depths to 100m and reduced sulfide ore below this depth. The mineral composition of the veins is dominated by quartz (>95%) (Cox et al., 1991), which contains chlorite, mica, sulfides, antimonides, carbonates, albite, rutile and zircon (Solomon and Groves, 1994). The content of sulfides varies greatly in the region between 2% and 60%; the Stawell region contains about 50% sulfides (Whiting and Bowen, 1976). Of the sulfide minerals, arsenopyrite and pyrite are the most common with chalcopyrite, galena, sphalerite, pyrrhotite, stibnite, bournonite and boulangerite being other common minerals (Solomon and Groves, 1994).

Mt Micke comprises a mixture of both oxidized and unoxidized material. Significant levels of sulfides, particularly pyrite, indicate AMD from the spoil could become a potential environmental hazard. The objective of this study is to assess the chemical properties of the Mt. Micke spoil to establish future land use potential and investigate possible future environmental problems.

Materials and Methods

Twenty-four samples of waste rock material from the Mt. Micke stockpile were collected for chemical characterization. The approximate location of Mt. Micke is 37°04'13" S and142°48'24" E. Six samples were collected from each of three profiles excavated to depths of approximately 6 metres on the surface of the stockpile. A further 6 samples were collected from a profile excavation in the toe of the stockpile (Fig. 2). The samples were collected systematically every meter in all profiles. Approximately 4 kg of sample from each depth were collected and placed in sealed plastic bags for transport to the laboratory. Sampled material was passed through a 10 mm screen at the sampling site and later air dried and sieved to various size fractions. The <250 μm fraction was used for further analysis. Soil pH (McClean, 1982), EC and moist color (Munsell, 1988) were recorded for all samples. Total C and S content were determined using an Eltra-CS 2000 Analyser and Acid Producing Potential (APP) calculated mathematically based on the Total S minus a readily-soluble sulfate correction. Readily-soluble sulfate was determined by weighing 2.000 g of sample into a 250 ml plastic bottle, adding 100 ml deionised water and tumbled for 6 hours. The solution was filtered using Whatman 40 grade filter paper, and analyzed on a Dionex 4500I Ion Chromatograph. Acid Neutralization Capacity (ANC) was carried out on a select few samples in accordance with the method described by Sobek et al., (1978). The following elements were targeted for ICP-MS/AES analysis following a nitric:perchloric acid digest: Al, As, Ca, Cd, Co, Cr, Cu, K, Mg, Mn, Mo, Na, Ni, P, Sb, Se, Sn and Zn. Micro and trace elements were analyzed by ICP-MS, while major cations were analyzed by ICP-AES.

Results and Discussion

The profiles sampled do reflect some variation in chemistry. This pattern is more evident between profiles and not sampling depths. Table 1 indicates the mined rock characteristics of each profile. Fig. 2 provides a visual element to the location of the material zones.
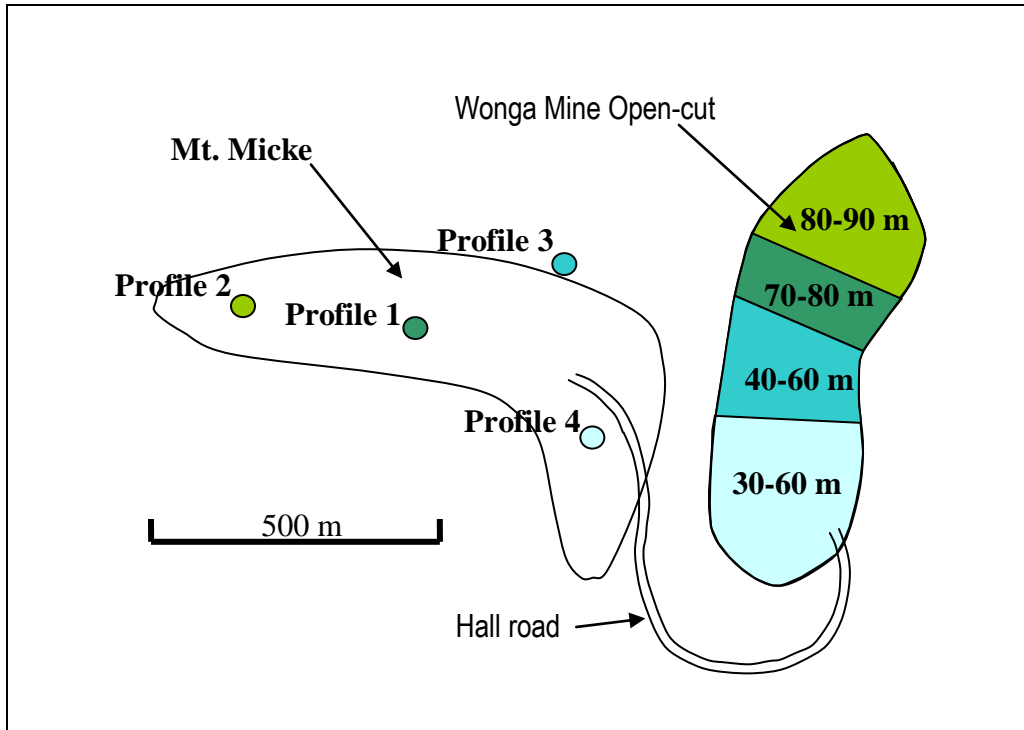
Figure 2. Location of the profiles. Colors indicate the approximate source area in the Wonga open-cut of the waste rock material at each sampling locality (Brian Myles, *pers. comm.* 2001).

Table 1. Generalized source rock material and zones of origin for the four profiles investigated.

Profile	Rock characteristics	Wonga Pit Mined Depth (m)
1	Reduced Wonga Schist (relatively fresh rock)	80 – 90
2	Reduced Wonga Schist	70 – 80
3	Oxidized to semi-oxidized rock	40 – 60
4	Reduced Wonga Schist with some clay	30 – 60

The Mt. Micke material is fairly inert when compared to many other mining spoil materials. The material is neutral to slightly alkaline, with EC between 20 and 250 μS cm^{-1} (Table 2). Profile 3 is slightly acidic and has consistently lower EC values. The lower pH indicates the difference between the oxidized and reduced overburden. Profile 3 minerals such as pyrite have been oxidized and have generated some acid, although not enough to be considered an environmental concern. Total C and S analysis revealed the spoil material was low in both elements (Table 3). Visually there are signs of pedogenesis and the formation of distinct

minesoil horizons. This is more likely to be stratification during the depositional construction of Mt. Micke, rather than pedogenesis. The lack of pedogenesis is identified in homogenous C data, with the exception of profile 3 with the much higher C content in the surface sample and decreasing in a characteristic pedogenic melanization curve. The higher C content from profile 3 is probably an anomalous occurrence of some carbonate minerals, since total C is a combination of organic C and carbonates in this environment.

Acid producing potential (APP) is not considered to be a problem at this location, with the maximum acid production of 9.38 H_2SO_4 kg t^{-1} (Table 4). Profile 3 had the highest APP and significantly higher levels of readily-soluble sulfate, so neutralization potential was determined for some selected samples and the net balance indicates the buffering capacity is larger than the APP (Table 3 and 4), with the exception of the 1-2 m sample. The value for this sample is 0.36 H_2SO_4 kg t^{-1}, which is still very low, and given the excess neutralizers in the surrounding material AMD is not likely to occur. The buffering capacity may be attributed to the large quantities of chlorite and the associated CEC within much of the waste rock material, although this was not determined. Profile 3 is typically different to the other profiles and this is reflective of the different composition and oxidation state of the waste rock material.

Transition metals and metalloids were low throughout the spoil, including As which is an environmental concern in the area given the larger quantities of As that are found in the mineralised rock and the tailings material (Table 5). The highest As content was approximately 500 μg kg^{-1}, while most elements of environmental concern had a maximum of 100 μg kg^{-1} (Table 5). Again the oxidized profile 3 had higher concentrations of As, as well as Mn and Ca. The increase in these elements is due to the liberation of these metals through oxidation and the slightly more acidic conditions. The increased Ca concentrations also correlates well with the increased C contents providing further evidence of an anomalous increase of carbonate materials in this profile.

Table 2. Munsell® color, pH and EC of the samples studied.

Profile	Depth (m)	Color (moist)	pH	EC (μS cm^{-1})
1	0 - 1	Moderate yellowish brown 10 YR 5/4	7.5	90
	1 - 2	Moderate olive brown 5 Y 4/4	7.9	110
	2 - 3	Light olive grey 5 Y 5/2	6.4	131
	3 – 4	Greyish olive 10 Y 4/2	8.0	100
	4 – 5	Moderate yellowish brown 10 YR 5/4	7.3	150
	5 - 6	Dark yellowish orange 10 YR 6/6	7.8	140
2	0 – 1	Dark yellowish brown 10 YR 4/2	7.9	45
	1 - 2	Dark yellowish brown 10 YR 4/2	7.4	20
	2 – 3	Olive grey 5 Y 3/2	8.2	20
	3 – 4	Olive grey 5 Y 3/2	8.1	25
	4 – 5	Dark yellowish brown 10 YR 4/2	7.9	20
	5 - 6	Olive grey 5 Y 3/2	7.9	40
3	0 – 1	Dark yellowish brown 10 YR 4/2	6.3	110
	1 - 2	Olive black 5 Y 2/1	5.3	66
	2 – 3	Dark yellowish brown 10 YR 4/2	6.4	100
	3 – 4	Olive grey 5 Y 3/2	6.0	60
	4 – 5	Dark yellowish brown 10 YR 4/2	7.0	54
	5 - 6	Olive grey 5 Y 3/2	6.2	70
4	0 – 1	Moderate yellowish brown 10 YR 5/4	7.8	80
	1 - 2	Moderate olive brown 5 Y 4/4	7.3	114
	2 – 3	Moderate yellowish brown 10 YR 5/4	8.1	130
	3 – 4	Dark yellowish brown 10 YR 4/2	8.3	160
	4 – 5	Moderate yellowish brown 10 YR 5/4	7.5	128
	5 - 6	Dark yellowish brown 10 YR 4/2	6.7	250

Table 3. Total C and S, as well as readily-soluble sulfate values for the four profiles.

Profile	Depth (m)	% Total S	Readily-soluble SO_4^{2-} (mg kg^{-1})	% Total C
1	0 - 1	0.30	320	0.02
	1 - 2	0.02	381	0.03
	2 - 3	0.03	355	0.03
	3 – 4	0.02	468	0.02
	4 – 5	0.02	438	0.03
	5 - 6	0.03	322	0.03
2	0 – 1	0.02	461	0.03
	1 - 2	0.05	285	0.02
	2 – 3	0.02	-	0.02
	3 – 4	0.02	340	0.02
	4 – 5	0.03	-	0.02
	5 - 6	0.02	580	0.02
3	0 – 1	0.18	4310	0.11
	1 - 2	0.11	2190	0.07
	2 – 3	0.16	4200	0.08
	3 – 4	0.07	-	0.03
	4 – 5	0.05	1066	0.03
	5 - 6	0.06	813	0.03
4	0 – 1	0.07	256	0.02
	1 - 2	0.02	146	0.03
	2 – 3	0.01	667	0.02
	3 – 4	0.01	387	0.02
	4 – 5	0.01	-	0.03
	5 - 6	0.03	363	0.03

Table 4. Acid Base Accounting values for profile 3.

Depth (m)	S as SO_4^{2-}	APP	Sulphide APP	ANC	Net APP
	mg kg^{-1}	---------------- H_2SO_4 kg t^{-1} ----------------			
0 – 1	1439	5.63	1.13	8.30	
1 – 2	731	3.44	1.15	0.79	0.36
2 – 3	1402	5.00	0.62	24.01	
3 – 4	-	2.19	-	-	-
4 – 5	356	1.56	0.45	-	-
5 - 6	271	1.88	1.03	-	-

Table 5. Selected trace element concentrations of the Mt. Micke material †.

Profile	Depth (m)	Al	As	Co	Cr	Cu	Mn	Ni	Pb	Zn
		------------------------------------- µg kg^{-1} -----------------------------------								
1	0 - 1	14252	123	8	122	19	217	21	22	14
	1 - 2	13842	99	11	80	24	281	28	21	18
	2 - 3	13738	100	9	85	22	254	25	23	16
	3 – 4	13523	105	10	87	25	281	27	23	17
	4 – 5	13426	135	10	73	28	283	29	22	17
	5 - 6	13292	179	9	131	27	247	28	23	16
2	0 – 1	14130	148	14	77	23	320	33	14	21
	1 - 2	14241	277	12	77	24	273	35	18	21
	2 – 3	13797	195	11	91	29	284	37	17	23
	3 – 4	13593	325	15	76	29	316	41	17	23
	4 – 5	14000	319	17	83	25	285	46	13	21
	5 - 6	13759	378	17	94	25	315	50	14	21
3	0 – 1	6974	277	13	43	23	678	25	10	13
	1 - 2	7021	492	9	39	17	243	18	9	10
	2 – 3	6978	467	10	37	17	360	20	9	11
	3 – 4	6937	344	17	39	19	263	30	8	13
	4 – 5	6963	243	12	31	14	179	24	8	11
	5 - 6	6902	331	14	37	16	210	28	8	13
4	0 – 1	6929	79	4	51	8	83	15	9	8
	1 - 2	6866	86	4	48	10	75	15	10	8
	2 – 3	6892	77	3	43	10	61	14	9	7
	3 – 4	6709	118	4	50	13	81	16	11	8
	4 – 5	6772	118	4	41	11	77	15	10	8
	5 - 6	6738	149	4	39	11	105	13	8	10

† Values for the following elements were ≤ 1 µg kg-1: Cd, Mo, Sb, Se and Sn.

Generalized macronutrient analysis indicated that K is the dominant cation, with Mg, Na and Ca decreasing, respectively (Table 6). In terms of plant fertility, the Mt. Micke material contains sufficient nutrients to sustain long-term vegetation. The exceptions could be Mo and P, which may prove deficient in future remediation efforts, particularly if N is also low. Phosphorus values reported are total P. Plant available P would be significantly lower. Nitrogen was not measured and will have to be assessed prior to remediation efforts. Plant health problems would escalate significantly if pH were to drop below 5.5 where Al toxicity can occur. Aluminum would occupy an increasing proportion of the exchange sites replacing the polyvalent cations, such as Mg and Ca that are already in lower quantities than the other base cations. The Al would simultaneously act as a strong adsorber of Mo and P increasing the impact on nutrient availability. Fortunately the Mt. Micke material only exhibits a pH of 5.5 or less in one sample and is not likely to be detrimental to revegetation. Applications of biosolids and commercial fertilizers or the planting of low P tolerant plants will enhance success of rehabilitation on these tailings by compensating for the low P in the Mt. Micke material. Some Australian native plants are adapted scavengers of P, so a remediation plan using selected natives would probably prove more successful than using exotic plant species.

Table 6. Macronutrient analysis of the spoil material.

Profile	Depth (m)	Ca	K	Mg	Na	P
		---------------------------- mg kg^{-1} ----------------------------				
1	0 - 1	280	14900	10100	920	280
	1 - 2	90	20500	14200	1360	240
	2 - 3	90	19400	12980	1240	240
	3 – 4	90	20600	13700	1280	320
	4 – 5	110	16900	10840	1360	240
	5 - 6	90	15700	9780	1280	240
2	0 – 1	890	24800	18580	1000	440
	1 - 2	690	21000	16600	1080	400
	2 – 3	670	22600	17220	1400	440
	3 – 4	750	22400	18140	1160	480
	4 – 5	1220	21500	18900	1220	600
	5 - 6	1480	21800	20000	1280	640
3	0 – 1	2305	9000	7450	220	360
	1 - 2	2085	8700	7970	300	400
	2 – 3	2305	9000	8440	360	380
	3 – 4	1525	10500	9470	440	400
	4 – 5	1055	9950	8900	420	280
	5 - 6	1285	10400	9500	480	320
4	0 – 1	50	7700	6240	420	120
	1 - 2	70	7200	6180	480	120
	2 – 3	60	6550	5520	480	140
	3 – 4	185	7000	5600	600	160
	4 – 5	160	6900	5440	560	180
	5 - 6	170	10100	7690	640	160

Conclusions

By conducting a study of four profiles in the Mt. Micke spoil, the following conclusions are presented.

1. Mt. Micke spoil would make a successful substrate for the remediation of the SGM tailings, providing a supplement of P and N can be made available, possibly in the form of biosolids or commercial fertilizers.

2. The material is not likely to generate acid mine drainage and is unlikely to require the addition of neutralizing agents.

3. Arsenic and other environmentally concerning elements are in very low and safe concentrations.

4. Most micronutrients are available in adequate concentrations to sustain long-term vegetation.

5. The stockpile was not homogenous. The oxidized material in the spoil was significantly different to the fresh rock materials indicating it is essential to sample the different mined zones to accurately assess the characteristics of the spoil prior to use.

Acknowledgements

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