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A METHOD OF PREDICTING THE POLLUTION POTENTIAL OF SURFACE MINING BACKFILL

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ABSTRACT

The paper describes a quick and effective method of predicting the acid ferruginous pollution potential of surface mined backfill on sites where the groundwater is likely to rebound through the fill on cessation of mining activity. Continuous cores of the strata to be mined were taken and analysed in the laboratory in order to identify the strata which are potentially acid producing and conversely strata which had a high acid neutralizing capacity which could be used to eliminate acid production. In this way it is hoped that during the mine planning and operational phase steps can be taken to prevent the problem developing. Some of the chemical and physical methods of prevention are also briefly discussed.

INTRODUCTION

With greater excavation depths and strata pollution controls affecting surface coal mining in the United Kingdom some sites have experienced considerable water problems. Many of these problems have now been overcome during the operational phase through the judicious use of advance dewatering techniques[1] resulting from thorough hydrogeological and geotechnical investigation during the mine planning process. However, at some mines once pumping has ceased, the voids are backfilled and the area restored to agriculture there is the possibility, where the original groundwater table was high, of springs appearing at surface formed by water that has passed through the backfill. The breakdown of iron pyrites is greatly increased in the presence of oxygenated water.

Whether these springs will be of acid ferruginous water will depend on a number of coincident factors. Most important of these will be the nature of the backfill material through which the water flows. It is generally agreed[2,3] that the major cause of pollution is the pyrites content of the spoil which reacts with oxygenated water in the following manner :-

$$4\ FeS_2 + 4\ H_2O + 14O_2 \longrightarrow 4\ FeSO_4 + 4\ H_2SO_4$$

Other reactions involving bacterial attack on pyritic minerals also take place and after further oxidation the ferrous sulphate is converted to Ferric hydroxide $Fe(OH)_3$ which gives rise to the familiar red acid discharge at surface. The amount of pyritous material and the physical conditions within the fill will control the amount of pollution of the groundwater which in some instances may already be slightly contaminated by passage through abandoned underground mine workings in the surrounding solid strata.

In order to evaluate the possibility of predicting whether pollution would take place a research project was undertaken at a future surface mine site. Air-flush drilling methods were used to obtain core samples of the full sequence of strata to be excavated. These were then given a full geological description and further sub-divided into samples for analysis in the laboratory. Each sample was analysed for pH, Moisture Content, Acid Neutralising Capacity (A.N.C.) and Sulphur Content.

CORE DIA mm 0 921 | BOREHOLE No 3139 | SHEET 1

ROCK QUALITY DESIGNATION R.Q.D.	THICKNESS (m)	CORE DESCRIPTION	DEPTH (m)	CORE BOX No & RECOVERY %	ANALYSIS SAMPLE No	SAMPLE THICKNESS (m)	ANALYSIS RESULTS: pH	SULPHUR TOTAL %S	POTENTIAL ACID PRODUCING SULPHUR %S	(a) THEORETICAL NEUTRALISING REQUIREMENTS % CaCo3	(b) ACID NEUTRALISING CAPACITY % CaCo3	ACID PRODUCING POTENTIAL a − b (% CaCo3)	EXCESS NEUTRALISING CAPACITY b − a (% CaCo3)
	0 70	PEAT	0·70										
	2 85	BOULDER CLAY	3·55										
	0 70	SOFT SANDSTONE	4·25										
47	1·45	SANDSTONE Coarse Grained Finely Micaceous Moderately Well Sorted Occasional Thin Silty Black Bands Lightly Ironstained	5·70	① 100	1·1	0·50	7·1	0·36	0·32	1·00	1·65	—	0·65
					1·2	0·45	7·3	0·25	0·23	0·72	1·61	—	0·89
					1·3	0·50	7·1	0·04	0·04	0·12	1·58	—	1·46
53	1·80	SANDSTONE Very Coarse Grained Coaly Bands Ironstained	7·50	② 100	2·1	0·95	5·4	0·76	0·73	2·28	0·44	1·84	—
					2·2	1·50	4·8	0·12	0·11	0·34	0·23	0·11	—
86	0·50	SANDSTONE Pale Grey Less Coarse Grained Current Bedded	8·00										
43	1·73	SANDSTONE Firm Medium Grained Pale Grey Soft Friable Bands		③ 100	3·1	1·50	6·4	0·13	0·12	0·37	0·73	—	0·36
					3·2	0·27	4·7	0·22	0·20	0·62	0·65		0·03
	0·04	MUDSTONE Coaly Black Friable	9·77		3·3	0·08	4·8	1·76	1·40	4·37	0·97	3·40	
63	1·23	SANDSTONE Pale Grey Coarse Grained Firm	11·00		3·4	1·06	5·7	0·20	0·18	0·56	0·71	—	0·15
40	1·90	SANDSTONE Coarse Grained at Top Grey Poorly Cemented	12·90	④ 98	4·1	0·77	5·1	0·19	0·17	0·53	0·26	0·27	—
					4·2	1·23	4·2	1·19	1·08	3·37	0·76	2·61	—
	0·20	MUDSTONE Dark Grey Firm Fissile	13·10		4·3	0·28	7·2	0·14	0·13	0·41	3·81		3·40
	0·10	CLAY Stiff Grey	13·20										
100	0·25	SANDSTONE Silty Broken Calcareous	13·48	⑤ 100	5·1	0·51	7·3	0·37	0·33	1·03	5·72	—	4·69
62	1·17	LIMESTONE Hard Grey Calcite on Bedding Sandy to Base	14·65		5·2	0·90	7·5	0·18	0·16	0·50	53·49	—	52·99
100	0·42	LIMESTONE Very Hard	15·07		5·3	1·01	7·4	0·48	0·45	1·40	11·34	—	9·94
56	0·73	SANDSTONE Medium Grained Dark Grey Hard and Plant Remains	15·80		5·4	0·30	7·0	0·62	0·61	1·90	3·37	—	1·47
89	1·13	SANDSTONE Medium/Fine Grained Poorly Sorted Firm Dark Grey	16·93	⑥ 94	6·1	0·65	7·0	0·41	0·37	1·16	5·89		4·73
					6·2	0·26	7·1	0·51	0·51	1·59	5·63		4·04
					6·3	0·22	7·0	0·08	0·07	0·22	3·60		3·38
0	0·21	SANDSTONE As above Ironstained	17·21		6·4	0·27	6·9	0·03	0·03	0·09	3·21		3·12
46	0·28	SANDSTONE Dark Grey	17·49		6·5	0·26	7·0	0·25	0·23	0·72	4·01		3·29
0	0·21	SANDSTONE Broken	17·70		6·6	0·12	7·2	0·83	0·79	2·47	11·24		8·77

Figure 1 Geological section and analysis results for borehole No. 3139 from 0.0m to 17.70m depth.

From these analyses the quantities of potentially acid producing material could be calculated as a proportion of the whole backfill volume. The actual effect of this material is difficult to ascertain as the weathering effect on the different rock types cannot be accurately assessed. Other factors such as the rate of flow of the groundwater, the permeability of the various layers of fill and the geometry of the void will also effect the rate of the chemical process.

DRILLING AND SAMPLING

The site under investigation lies in a hilly district with an average rainfall of 1400mm/annum. The water table in the area to be excavated appears at surface in the form of natural springs which are non-polluting. The groundwater passes through the strata[4] to be excavated via the natural pore spaces in the rock and also through abandoned mine workings in some of the seams to be worked. As these old working spaces are waterlogged then it is assumed that little oxygen is present in the groundwater and that little iron or sulphur is picked up by the groundwater. As the water table level is high then all the strata sampled can be expected to have groundwater flowing through it and possibly issuing at surface.

The strata to be excavated was drilled using air-flush rotary methods and strata cores of 92.1mm diameter were logged with a full geological description in the field. The cores were taken in positions where the strata was considered to be repesentative of the complete strata to be excavated on site. Core recovery averaged over 95% exceptwhere old workings occur. The core was then transported in core boxes to the laboratory where the strata was further sub-divided into sample units based on lithology and a hand specimen assessment of the sulphur content.

The strata concerned is from the Carboniferous System Limestone Group and as can be seen from the sections in Figures 1 to 7 the strata consists of fine to medium grained sandstones, shaley mudstones, coal and seatearths with the occasional limestone.

LABORATORY ANALYSIS

The principles involved in the laboratory assessment were based on those described in Costigan, Bradshaw and Gemmell in[5] their assessment of the acid producing potential of colliery spoil. The acid producing potential of the material, measured by its pyritic content was related to its Acid Neutralising Capacity (A.N.C.) as measured by reaction with hydrochloric acid.

In this way it was hoped to identify not only the strata which are potentially acid producing, but to estimate the theoretical lime dosage required to neutralise any acid products of oxidation. In addition it was hoped to identify any strata, e.g. limestone or dolomite, with a high Acid Neutralising Capacity which could be blended with the potential acid producing strata thus reducing, if not eliminating, the need for inmixing additional lime or limestone.

The samples from the core drilling were split into subsections which were dried and crushed to minus 3mm size particles. Where necessary the samples were then reduced systematically to give a representative weight of not more than 500g for each subsection. These samples were then further crushed to -0.2mm for analysis.

CORE DIA mm 0.921 | BOREHOLE No 3139 | SHEET 2

ROCK QUALITY DESIGNATION R.Q.D.	THICKNESS (m)	CORE DESCRIPTION		DEPTH (m)
93	0.73	SANDSTONE	Medium Fine Grained Calcite Veining and Dark Remains	18.43
0	0.46	MUDSTONE	Silty Dark Grey Firm	18.89
0	1.81	MUDSTONE	Black Finely Micaceous Occasional Pyrite Nodules	20.90
39	1.25	MUDSTONE	Black Firm Silty Iron Rich	21.95
	0.06	IRONSTONE		22.01
0	0.94	MUDSTONE	Black Firm Broken Small Nodules of Ironstone	22.95
0	1.50	MUDSTONE	Dark Grey / Black Silty and Broken	24.45
66	0.49	MUDSTONE	Silty in Parts	24.92
	0.02	IRONSTONE		24.94
22	1.01	MUDSTONE	Black Silty and Firm	25.95
34	1.66	MUDSTONE	Calcareous Black at Top Darker Grey at Base Silty Shell Fragments	27.61
100	0.25	LIMESTONE	Very Impure Moderately Hard Shell Fragments	27.86
13	0.74	MUDSTONE	Calcareous Dark Grey Similar to Above	28.60
100	1.35	LIMESTONE	Hard Grey Shell Fragments Calcite Veins	29.95
44	0.27	LIMESTONE	As above	30.22
0	0.13	MUDSTONE	Calcareous Dark Grey	30.35
33	0.36	LIMESTONE	Hard	30.71
0	0.17	MUDSTONE	Calcareous	30.88
100	0.47	MUDSTONE	Black Silty Firm	31.35
100	0.28	MUDSTONE	Soft Black	31.63
100	0.19	COAL	Broken Bright Clarain	31.82
100	0.63	SANDSTONE	Silty Poorly Sorted Dark Mudstone	32.45
69	0.42	SANDSTONE	Silty Grey Poorly Sorted	32.87
54	1.58	SANDSTONE	Medium Grained at Top Coarser to Base Crossbedded	34.45
0	0.51	MUDSTONE	Grey Silty Firm	34.96
	0.05	MUDSTONE	Coaly Black Firm	35.01
0	0.19	SILTSTONE		35.20
100	0.25	SANDSTONE		35.45

ANALYSIS RESULTS

CORE BOX No & RECOVERY %	ANALYSIS SAMPLE No	SAMPLE THICKNESS (m)	pH	SULPHUR TOTAL % S	POTENTIAL ACID PRODUCING SULPHUR % S	(a) THEORETICAL NEUTRALISING REQUIREMENTS % CaCo3	(b) ACID NEUTRALISING CAPACITY % CaCo3	ACID PRODUCING POTENTIAL a b (% CaCo3)	EXCESS NEUTRALISING CAPACITY b a (% CaCo3)
7 / 100	7.1	0.72	7.0	1.70	1.59	4.96	5.88		0.92
	7.2	0.78	6.9	2.93	2.69	8.40	4.78	3.62	
	7.3	0.90	6.9	2.29	2.14	6.68	4.37	2.31	
	7.4	0.60	6.8	2.73	2.55	7.96	4.83	3.13	
8 / 100	8.1	0.52	6.8	2.82	2.65	8.27	5.13	3.14	
	8.2	0.36	7.1	2.63	2.43	7.59	5.05	2.54	
	8.3	1.00	6.7	2.36	2.19	6.84	4.79	2.05	
	8.4	0.37	6.8	1.36	1.31	4.09	4.32		0.23
9 / 100	9.1	0.95	6.9	0.66	0.63	1.97	4.50		2.53
	9.2	0.53	7.0	0.70	0.65	2.03	4.10		2.07
	9.3	0.64	7.1	0.91	0.86	2.68	4.66		1.98
	9.4	0.88	6.9	0.96	0.87	2.72	4.79		2.07
10 / 100	10.1	1.20	7.0	0.88	0.83	2.59	5.20		2.61
	10.2	0.48	7.1	0.90	0.84	2.62	11.22		8.60
	10.3	0.27	7.1	1.14	1.08	3.37	10.08		6.71
	10.4	0.73	7.0	1.14	1.10	3.43	10.19		6.76
11 / 97	11.1	0.52	7.0	0.09	0.08	0.25	60.36		60.11
	11.2	0.83	7.1	0.05	0.05	0.16	61.62		61.46
12 / 99	12.1	0.80	7.0	0.17	0.15	0.46	60.63		60.17
	12.2	0.30	6.9	1.34	1.24	3.87	45.51		41.64
	12.3	0.40	6.4	2.70	2.51	7.84	12.08		4.24
	12.4	0.26	6.2	3.48	3.13	9.77	5.03	4.74	
	12.5	0.20	6.7	3.29	2.56	7.99	5.14	2.85	
	12.6	0.58	6.7	1.31	1.26	3.93	1.89	2.04	
13 / 97	13.1	0.66	6.3	0.70	0.69	2.15	1.30	0.85	
	13.2	0.86	7.2	0.09	0.08	0.25	4.05		3.80
	13.3	0.56	6.8	0.06	0.05	0.16	2.08		1.92
	13.4	0.52	6.5	0.03	0.03	0.09	0.82		0.73
	13.5	0.18	6.4	0.17	0.15	0.47	0.95		0.48
	13.6	0.22	6.8	0.03	0.03	0.09	2.53		2.44

Figure 2 Geological section and analysis results for borehole No. 3139 from 17.70m–34.45m depth

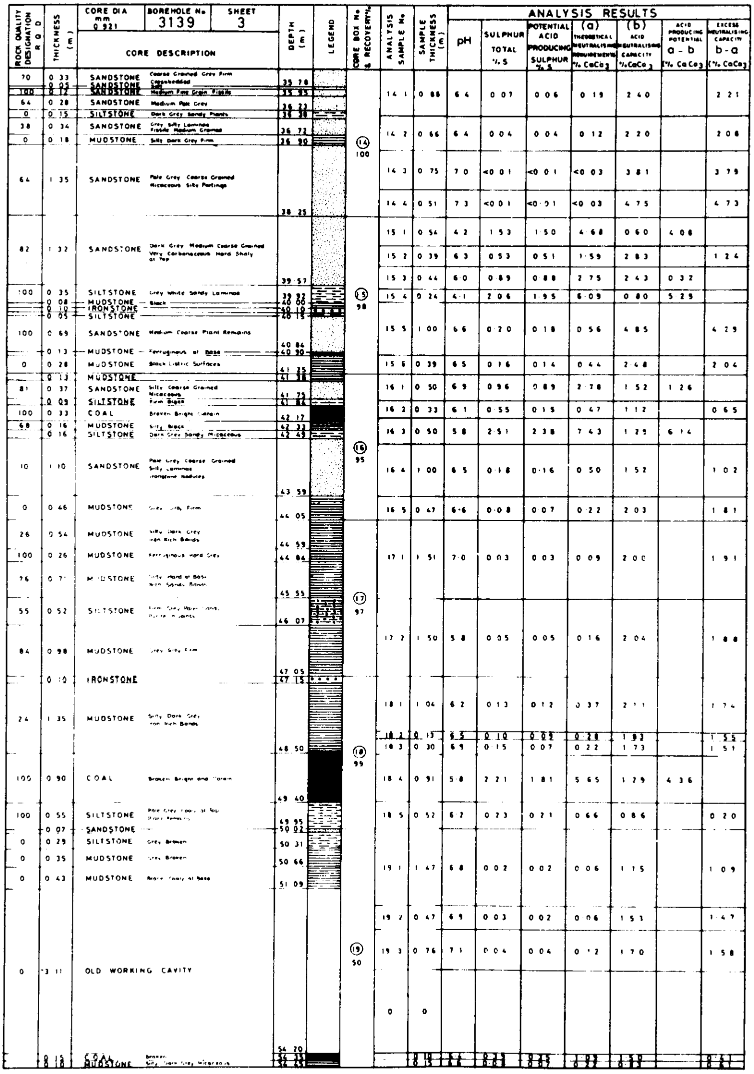

Figure 3 Geological section and analysis results for borehole No. 3139 from 35.4m to 54.45m depth

CORE DIA mm 0·921 | BOREHOLE No. 3139 | SHEET 4

ROCK QUALITY DESIGNATION R.Q.D.	THICKNESS (m)	CORE DESCRIPTION		DEPTH (m)	LEGEND	CORE BOX No. & RECOVERY %	ANALYSIS SAMPLE No.	SAMPLE THICKNESS (m)	pH	SULPHUR TOTAL %S	POTENTIAL ACID PRODUCING SULPHUR %S	(a) THEORETICAL NEUTRALISING REQUIREMENT % CaCO3	(b) ACID NEUTRALISING CAPACITY % CaCO3	ACID PRODUCING POTENTIAL a – b % CaCO3	EXCESS NEUTRALISING CAPACITY b – a % CaCO3
100	0·84	SANDSTONE	Silty Dark Grey Fine Grained Coarser Bands Occasional Ironstone Nodules	55·36		20 / 97	20·1	1·05	3·9	0·03	0·03	0·09	0·83		0·74
100	0·15	SILTSTONE	Dark Grey	55·51											
50	0·28	MUDSTONE	Soft Dark Grey at Top Silty To Base	55·79			20·2	0·30	6·7	0·04	0·04	0·12	0·92		0·80
100	0·84	SANDSTONE	Pale Grey Medium Coarse Grained Silty Micaceous Laminae	56·63			20·3	0·76	7·0	0·01	0·01	0·03	1·10		1·07
100	0·50	SANDSTONE	Pale Grey Coarse Grained	57·13			20·4	0·72	6·8	0·03	0·03	0·09	1·63		1·54
	0·06	SANDSTONE	Soft Ironstained	57·19											
62	0·16	SANDSTONE	Grey Coarse Grained	57·35											
96	2·80	SANDSTONE	Coarse Grained Pale Grey Current Bedded Carbonaceous and Micaceous Laminae	60·15		21 / 98	21·1	0·80	7·0	0·04	0·03	0·09	1·75		1·66
							21·2	0·52	7·5	<0·001	<0·001	<0·003	4·54		4·54
							21·3	1·48	7·1	0·08	0·07	0·22	1·53		1·31
100	2·42	SANDSTONE	Coarse Grained and Ironstained	62·57		22 / 59	22·1	1·37	6·6	0·20	0·18	0·56	2·05		1·49
							22·2	1·06	6·5	0·05	0·05	0·16	1·48		1·32
	1·88	CAVITY		64·45											
	0·05	COAL		64·50			22·3	0·05	7·1	0·06	0·05	0·16	1·33		1·17
72	0·25	SILTSTONE	Dark Grey Micaceous	64·75			22·4	0·27	6·5	0·06	0·05	0·15	0·67		0·51
100	0·28	SANDSTONE	Silty at Top Poorly Sorted	65·03		23 / 76	23·1	0·80	6·8	0·04	0·04	0·12	1·06		0·94
67	1·24	SANDSTONE	Pale Grey Coarse Grained	66·27			23·2	0·75	5·9	0·05	0·05	0·16	1·15		1·35
	0·50	CAVITY		66·75											

Figure 4 Geological section and analysis results for borehole No. 3139 from 54.45m to 66.75m depth

CORE DIA mm	BOREHOLE No	SHEET
0 921	3141	1

ROCK QUALITY DESIGNATION R.Q.D	THICKNESS (m)	CORE DESCRIPTION		DEPTH (m)	LEGEND	CORE BOX No & RECOVERY%	ANALYSIS SAMPLE No	SAMPLE THICKNESS (m)	ANALYSIS RESULTS pH	SULPHUR TOTAL % S	POTENTIAL ACID PRODUCING SULPHUR % S	(a) THEORETICAL NEUTRALISING REQUIREMENTS % CaCo3	(b) ACID NEUTRALISING CAPACITY % CaCo3	ACID PRODUCING POTENTIAL a - b (% CaCo3)	EXCESS NEUTRALISING CAPACITY b-a (% CaCo3)
–	1·30	BOULDER CLAY		1·30											
–	1·00	SANDY BOULDER CLAY		2·30											
–	0·55	SANDSTONE		2·85											
10	1·00	SANDSTONE	Medium Coarse Grained Micaceous Ironstained Hard Well-jointed	3·85		① 100	1·1	2·20	7·0	0·20	0·18	0·56	2·77		2·21
40	1·20	SANDSTONE	Medium Coarse Grained Micaceous Ironstained in Parts Hard One Mudstone Band 0.67 from Top	5·05											
43	0·82	SANDSTONE	Medium Coarse Grained Micaceous Some Ironstaining Coal Traces to Base	5·87		② 100	2·1	0·72	6·9	0·06	0·05	0·16	0·89		0·73
	0·18	COAL	Dark Shaly Ironstained	6·05			2·2	0·93	5·9	0·43	0·39	1·22	0·81	0·41	
	0·05	MUDSTONE	Limestone Soft Clayey												
	0·64	COAL	Mostly Dull Slickensided	6·74											
	0·32	MUDSTONE	Grey Fine Nodules	7·06			2·3	0·32	4·6	0·06	0·05	0·16	0·65		0·49
	0·22	COAL	Bright Dense	7·28			2·4	0·52	5·8	0·92	0·56	1·75	0·94	0·81	
	0·06	MUDSTONE													
	0·23	COAL	Bright	7·57											
	0·25	MUDSTONE	Silty Micaceous Dark Grey	7·82			2·5	0·51	4·5	0·01	0·01	0·03	0·42		0·39
	0·05	SANDSTONE													
100	0·18	SILTSTONE	Dark Grey	8·05											
66	0·72	SANDSTONE	Medium Grained Light Grey Muddy Laminae	8·77		③ 100	3·1	1·82	4·4	0·13	0·12	0·37	1·02		0·65
0	0·15	SANDSTONE	Mudstone Bands Clay Traces	8·92											
81	0·87	SANDSTONE	Medium Grained Off White	9·79											
25	0·40	MUDSTONE	Silty Plant Traces	10·19			3·2	0·38	3·8	0·37	0·33	1·03	0·82	0·21	
	0·29	COAL	Bright Clarain Ironstained	10·48			3·3	0·29	3·6	5·32	4·37	13·64	0·53	13·11	
	0·07	MUDSTONE	Silty												
50	0·22	SANDSTONE	Medium Grained	10·77			3·4	0·40	4·0	0·19	0·17	0·53	1·47		0·94
	0·08	MUDSTONE	Dark Grey Plants												
	0·10	SILTSTONE	Grey [illegible]	10·95											
	3·17	OLD WORKINGS CAVITY		14·12		④ 28									
	0·12	COAL	[illegible]	14·24			4·1	0·37	4·0	1·07	0·74	2·31	0·62	1·69	
59	0·64	MUDSTONE	Silty at Base Coaly at Top	14·88			4·2	1·02	4·4	0·08	0·07	0·22	0·72		0·50
0	0·27	SILTSTONE	Grey Sandy	15·15											
89	0·99	SILTSTONE	Dark Grey, Paler Grey, Coarse Grained Hard Some Ironstone Nodules	16·14		⑤ 98	5·1	2·28	5·6	0·09	0·08	0·25	1·26		1·01
100	0·71	MUDSTONE	Silty Dark Grey Fine Limestone Plant Remains	16·85											
	0·08	MUDSTONE	Dark Grey Brack												
	0·17	MUDSTONE	Silty	17·10											
	0·08	MUDSTONE	Dark Grey Firm												
100	0·57	SANDSTONE	Pale Grey Medium Hard	17·75			5·2	0·57	6·3	0·06	0·05	0·16	1·72		1·56

Figure 5 Geological section and analysis results for borehole No. 3141 from 0.0m to 17.75m depth

Rock Quality Designation R.Q.D.	Thickness (m)	Core Dia mm 0.921 / Borehole No 3141 / Sheet 2 — Core Description		Depth (m)
72	2.23	SANDSTONE	Medium Grained Pale Grey More Silty Bands to Base Oblique joints with Ironstaing	19.98
35	0.34	SILTSTONE	Dark Grey Ironstained in Bedding Firm Sandy at Top	20.32
	0.43	MUDSTONE		20.75
0	1.41	MUDSTONE	Dark Grey Broken at Top	22.16
	0.05	IRONSTONE		
50	0.74	MUDSTONE	Firm Black Silty to Base with Sandy Laminae	22.95
	0.08	SILTY MUDSTONE		
100	0.19	SANDSTONE	Micaceous Carbonaceous	23.22
0	0.30	MUDSTONE	Black Silty Thin Coal Laminae	23.52
10	1.12	MUDSTONE	Grey Silty Sandy to Base Firm Yellow Ironsteining	24.64
0	0.11	SANDSTONE	Pale Grey Coarse Grained Ironstained	24.75
85	2.12	SANDSTONE	Medium Grained Poorly Sorted Sub-vertical Joints	26.87
0	0.53	MUDSTONE	Silty Dark Grey Sub Fissile	27.40
	0.74	MUDSTONE	Dark Grey Silty at Top	28.14
	0.09	IRONSTONE	[illegible]	
0	0.13	MUDSTONE	Firm Black Silty	28.36
	0.07	MUDSTONE	Soft	
0	0.30	MUDSTONE	Firm Black and Silty Lingula Fragments	28.73
	0.12	IRONSTONE		28.85
0	0.36	MUDSTONE	Firm Black & Silty	29.21
	0.15	IRONSTONE	Grey	29.36
	0.64	MUDSTONE	Dark Grey to Black Iron Ribs in Parts Pyrite Pyrite Nodules	
	0.06	MUDSTONE	Firm Black	30.00
100	0.34	SANDSTONE	Hard Fine Medium Grained Grey/Black Laminae	30.40
	0.12	MUDSTONE	Firm Black & Silty	
	0.04	MUDSTONE	Coaly	
	0.20	MUDSTONE	Grey/Buff Black at Base, Listric Surfaces	30.76
	0.09	SHALE	Coaly	
	0.47	COAL	Broken Stick Duller to Base	31.32
100	0.39	MUDSTONE	Silty Black Coaly Dark Grey Listric Surfaces	31.71
	0.04	SANDSTONE		
100	0.66	SANDSTONE	Dark Grey Medium Grained Poorly Sorted Micaceous Plant Remains & Coal Traces	32.41
0	0.22	MUDSTONE	Coaly Silty at Top Black Some Coal Laminae	32.62
0	0.19	COAL	Broken	32.81
100	0.44	SANDSTONE	Dark Grey Silty Plant Remains	33.25
0	0.20	SANDSTONE	Soft and Shaley	33.45
100	0.30	SANDSTONE	Soft	33.75
	0.72	SANDSTONE	Pale Grey Hard Carbonaceous Partings	34.47
100	0.66	MUDSTONE	Black Firm and Silty	35.13
0	0.25	COAL	Broken Dull	35.38
	0.10	MUDSTONE	Coaly Black	
	0.13	COAL	Broken	35.61
	0.14	MUDSTONE	Coaly	35.75
	0.08	COAL		
	0.07	MUDSTONE	Black Coaly Soft	35.90

ANALYSIS RESULTS

Core Box No & Recovery %	Analysis Sample No	Sample Thickness (m)	pH	Sulphur Total % S	Potential Acid Producing Sulphur % S	(a) Theoretical Neutralising Requirements % CaCo3	(b) Acid Neutralising Capacity % CaCo3	Acid Producing Potential a – b (% CaCo3)	Excess Neutralising Capacity b–a (% CaCo3)
6 / 99	6.1	0.42	6.9	<0.01	<0.01	<0.03	4.34		4.32
	6.2	1.05	7.2	<0.01	<0.01	<0.03	5.77		5.75
	6.3	0.85	6.7	<0.001	<0.001	<0.003	2.85		2.85
	6.4	0.65	6.6	0.34	0.31	0.97	2.41		1.44
7 / 100	7.1	0.79	6.5	0.07	0.06	0.19	2.40		2.21
	7.2	0.78	6.7	0.06	0.05	0.16	2.16		2.00
	7.3	0.73	6.2	0.24	0.22	0.69	1.31		0.62
8 / 66	8.1	0.55	5.6	0.25	0.23	0.72	1.70		0.98
	8.2	0.83	6.1	0.65	0.60	1.87	1.33	0.54	
	8.3	0.24	6.1	0.19	0.17	0.53	1.46		0.93
	8.4	0.18	6.2	0.04	0.04	0.12	1.88		1.76
9 / 100	9.1	2.12	6.3	0.16	0.14	0.44	0.75		0.31
	9.2	0.53	6.3	0.16	0.14	0.44	1.12		0.68
10 / 96	10.1	0.74	6.6	0.03	0.03	0.09	1.91		1.82
	10.2	0.18	6.5	0.19	0.17	0.53	2.43		1.90
	10.3	[illegible]	[illegible]	1.24	1.20	3.75	2.04	1.71	
	10.4	0.40	6.5	0.76	0.73	2.28	2.02	0.26	
	10.5	0.14	6.3	0.26	0.23	0.72	1.67		0.95
	10.6	1.05	4.2	2.73	2.56	7.99	2.09	5.90	
11 / 100	11.1	0.46	4.8	3.34	3.10	9.68	0.68	9.00	
	11.2	0.30	6.4	0.45	0.41	1.28	0.80	0.48	
	11.3	0.58	6.5	0.42	0.38	1.19	1.29		0.10
	11.4	0.45	6.3	0.13	0.12	0.37	0.84		0.47
12 / 97	12.1	0.66	4.6	0.18	0.16	0.50	0.27	0.23	
	12.2	0.41	4.4	1.00	0.66	2.06	0.68	1.38	
	12.3	0.49	6.0	0.15	0.14	0.44	0.40	0.04	
	12.4	0.49	6.6	0.05	0.05	0.16	0.35		0.19
13 / 100	13.1	0.73	6.7	0.02	0.02	0.06	2.21		2.15
	13.2	0.43	6.9	0.16	0.14	0.44	2.07		1.63
	13.3	0.13	6.9	0.15	0.14	0.44	1.74		1.30
	13.4	0.77	6.3	0.87	0.48	1.50	1.21	0.29	

Figure 6 Geological section and analysis results for borehole No. 3141 from 17.75m to 35.98m depth

CORE DIA mm 0.921 | BOREHOLE No 3141 | SHEET 3

ROCK QUALITY DESIGNATION R Q D	THICKNESS (m)	CORE DESCRIPTION	DEPTH (m)	LEGEND	CORE BOX No & RECOVERY %	ANALYSIS SAMPLE No	SAMPLE THICKNESS (m)	ANALYSIS RESULTS pH	SULPHUR TOTAL % S	POTENTIAL ACID PRODUCING SULPHUR % S	(a) THEORETICAL NEUTRALISING REQUIREMENTS % CaCo3	(b) ACID NEUTRALISING CAPACITY % CaCo3	ACID PRODUCING POTENTIAL a - b (% CaCo3)	EXCESS NEUTRALISING CAPACITY b - a (% CaCo3)
100	0.18	SILTSTONE Firm Hard Black Dark Grey	36.08											
85	2.62	SANDSTONE Medium to Coarse Grained Silty Micaceous Remains	38.70		(14) 100	14.1	2.80	6.3	0.32	0.29	0.91	1.86		0.95
92	1.32	SANDSTONE Pale Grey Silty Micaceous Shaly & Coaly	40.02			15.1	1.32	5.8	<0.01	<0.01	<0.03	2.71		2.69
	0.41	COAL Broken Stick			(15) 97	15.2	1.58	5.6	1.02	0.63	1.97	0.88	1.09	
	0.06	MUDSTONE Coaly Black Paler	40.43											
	0.61	COAL Clarain												
	0.02	MUDSTONE Coaly	41.10											
	0.58	COAL	41.70											
	0.08	MUDSTONE												
	0.16	SILTSTONE Dark Grey Firm	41.94			16.1	0.24	6.8	0.08	0.07	0.22	1.06		0.84
87	1.44	SANDSTONE Pale Grey Coarse Grained Silty & Micaceous Laminae	43.38		(16) 100	16.2	1.44	7.4	<0.01	<0.01	<0.03	4.72		4.70
66	1.12	SANDSTONE Silty Dark Grey Abundant Plant Remains Silty Micaceous Laminae Sub Vertical Joints	44.50			16.3	1.12	7.0	0.06	0.05	0.16	2.73		2.57

Figure 7 Geological section and analysis results for borehole No. 3141 from 35.09m to 44.5m depth

Analysis

- In order to measure pH 8g of the crushed sample were shaken with 20ml 0.01M $CaCl_2$ for 45 minutes and the pH determined using a glass electrode.

- The moisture content of each sample was determined by drying to constant weight at 105°C under oxygen free nitrogen in a minimum free space oven. All sulphur and A.N.C. results were expressed on a dry basis.

- Acid Neutralising Capacity (A.N.C.) was determined by taking a known weight of the material which was refluxed with 0.25M - HCl and the resultant suspension titrated to pH 8.3 with 0.1M Na OH. The A.N.C.was calculated as the amount of acid, expressed as % $CaCO_3$, neutralised by the sample.

  The blank tests (sample plus water without acid, and acid without sample) described by Costigan, Bradshaw and Gemmell were carried out on a cross section of the samples which had either a higher sulphur content or which gave a lower pH. However the blank values obtained made negligible difference to the final results, possibly due in part to lack of oxidation of any sulphur present. These blank tests were accordingly omitted for the rest of the samples in order to minimise the laboratory work-load. [4]

- The total sulphur content of each of the samples was determined using a Leco SC32 Sulphur Analyser (See Note below). "Forms of Sulphur" were then determined on a cross section of the samples as follows :

- In order to assess Organic Sulphur about 2g of sample, weighed accurately was refluxed with 100ml boiling 2M - HNO_3 for 30 minutes to extract both sulphate and pyritic sulphur. After extraction the suspension was cooled, filtered, and washed through a weighed glass fibre filter under vacuum, the remaining solids then being dried and weighed. The sulphur content of the dried solids was then determined on the Leco SC32 and the result calculated to the original basis, allowing for loss in weight during the acid extraction.

- Organic plus pyritic sulphur - the above procedure was repeated, this time 5g of sample being refluxed with 50ml 5M - HCl to extract the sulphate sulphur. The remaining pyritic plus organic sulphur was determined on the Leco SC32, corrections again being made for loss in weight during the extraction.

  For samples containing no or low amounts of carbonaceous matter it is essential to add about 1 - 2g V_2O_5 powder (see Leco SC32 instruction manual) to ensure full release of the Sulphur.

The most effective procedure was found to be:-

1. Spread on thin layer of V_2O_5 over the bottom of the combustion boat.
2. Weigh sample into boat and thoroughly mix with about 1g V_2O^5
3. Spread a thin layer of V_2O_5 over the sample mixture
4. Note total weight of V_2O_5 used in order to apply correction for its inherent sulphur content.

These were indications in tests carried out and two of the samplers that the use of V_2O_5 was not essential on the acid extracated residues in the "Forms of Sulphur" analyses, but this has yet to be confirmed.

The individual "Forms of Sulphur" were then obtained as follows :-

(i)	Total Sulphur	-	determined directly.
(ii)	Sulphate Sulphur	-	Total Sulphur - (Organic and Pyritic Sulphur).
(iii)	Pyritic Sulphur	-	(Organic and Pyritic Sulphur) - Organic Sulphur.
(iv)	Organic Sulphur	-	determined directly after extraction.

As stated above "Forms of Sulphur" were estimated on a cross-section of the samples[6]. From these samples it was seen that the sulphate content was consistently low, even where some oxidation might have been expected.

Number of Sulphate determination - 20.
Range of Sulphate content - Nil - 0.06.

% Sulphate Sulphur	No. Samples
NIL	5
0.01	5
0.02	5
0.03	1
0.04	2
0.05	1
0.06	1

Table 1
Distribution of Sulphate Sulphur Sample Analysis

Because of the large number of samples involved it was accordingly decided that no further sulphate estimations be carried out. Also, because of the workload involved it was decided that, in addition to the samples already analysed, organic sulphur would only be determined where the total sulphur was 0.5%, and that the ratio of organic to total sulphur be calculated. This ratio was found to be 0.1 and it was then assumed that the pyritic sulphur was (0.9 x Total Sulphur) for all samples with total sulphur contents of less then 0.5%. It was also assumed that all the pyritic sulphur would be oxidised to sulphuric acid and the % $CaCO_3$ required to neutralise this acid was calculated.

$$4\,FeS_2 + 4\,H_2O + 14\,O_2 \rightarrow 4\,FeSO_4 + 4\,H_2SO_4$$

$$4\,FeSO_4 + 2\,H_2SO_4 + O_2 \rightarrow 2\,Fe_2(SO_4)_3 + 2\,H_2$$

$$2\,Fe_2(SO_4)_3 + 12\,H_2O \rightarrow 4\,Fe\,(OH)_3 + 6\,H_2SO_4$$

$$4\,FeS_2 + 14\,H_2O + 15O_2 \rightarrow 4\,Fe\,(OH)_3 + 8\,H_2SO_4$$

i.e. 1g sulphur would produce 3.059g H_2SO_4 which would then require 3.121g $CaCO_3$ for neutralisations (i.e. 1% Sulphur = 3.121 A.N.C.). The following table shows the values obtained for pH, sulphur and A.N.C. values, together with the figure taken for Potential Acid Producing Sulphur. This latter figure is also shown as the theoretical % $CaCO_3$ required for neutralisation.

Where this figure is greater than the A.N.C., the difference between them is taken as the "Acid Producing Potential". Where the A.N.C. is greater than the % $CaCO_3$ required for neutralisation of the acid products the difference is taken as the "Excess Neutralising Capacity".

Although these average figures show that there is a theoretical overall excess of Neutralising Capacity, examination of the individual results shows that for BH.3139 there are 12.41m and for BH.3141, 5.22m of potentially acid producing strata. Coal subsections or part sections were excluded from the calcualtions as it was assumed all coal would be excavated and not used for backfilling.

B.H. No.	Average Potential Acid Producing Sulphur %S	(a) Average Theoretical Neutralisation Requirement %CaCO3	(b) Average Acid Neutralising Capacity - A.N.C. %CaCO3	Average Excess Neutralising Capacity (b - a) %CaCO3
3139	0.52	1.63	6.12	4.49
3141	0.26	0.82	1.90	1.08

Table 2 - overall average values, in proportion to sample thickness, for the potential acid producing sulphur, theoretical neutralisation requirement, acid neutralising capacity and excess neatralising capacity.

B.H. No.	Total Thickness (m) (excluding coals)	Average Potential Acid Producing Sulphur %S	(a) Average Theoretical Neutralisation Requirement %CaCO3	(b) Average Acid Neutralising Capacity - A.N.C. %CaCO3	Average Acid Producing Potential (a - b) %CaCO3
3139	12.41	1.43	4.46	2.26	2.20
3141	5.22	1.01	3.42	1.16	2.26

Table 3 - potential acid producing strata - average values in proper-tion to sample thickness.

SUMMARY OF RESULTS

The average theoretical Acid Producing Potentials of these particular strata on their own are greater than those which are known to give severe acid ferruginous pollution.

Assuming that the thickness found in the borehole core samples are representative of the site as a whole then this represents 124,100m^3 of potentially acid producing material per hectare of site surface area identified in BH.3139 and 52,200m^3 potentially acid producing material per hectare identified in BH.3341. Assuming an in situ bulk density of between 1.8 and 2.0 tonnes/m^3 for the strata then there could be between 223,400 and 248,000 tonnes of material with an average Acid Producing Potential of 2.20% as $CaCO_3$ and between 93,960 and 104,440 tonnes with an average Acid Producing Potential of 2.26% as $CaCO_3$, per hectare of site area.

The total $CaCO_3$ equivalent required to neutralise these tonnages could therefore be between about 7,000 and 7,800 tonnes per hectare of site surface area (this is equivalent to the production of between about 6,800 and 7,600 tonnes sulphuric acid per hectare of site surface area).

However, strongly neutralising strata were also identified, particularly in BH.3139, where there were 5.96m with individual Excess Neutralising Capacities greater than a pH of 6.0. The average of these, in proportion to sample thickness was 35.66% as $CaCO_3$. Of this 5.96m, 3.35m had an average Excess Neutralising Capacity of 56.89% as $CaCO_3$. Assuming an in situ bulk density of 2.0 tonnes/m^3 for these strata this gives a total $CaCO_3$ equivalent of 42,500 tonnes/-hectare for the 5.96m strata and 38,120 tonnes/hectare for the 3.35m strata on its own.

Even this latter, lower, figure is theoretically more than sufficient to neutralise the total amount of acid which could be produced. Ochreous deposits on large pieces of limestone would seal off all but the thin surface layer and render the remainder ineffective.

In order to ease the workload on the laboratory, and to produce the results fairly quickly several assumptions were made at various stages, the principle being:-

- That in samples of 0.5% of total sulphur, the pyritic sulphur was 0.9 x Total Sulphur.
- That all "pyritic" sulphur would be oxidised.
- Similarly, that the theoretical A.N.C. obtained in the laboratory would be achieved in practice.
- Average results were taken in porportion to sample thickness, the specific gravity of the materials not being protaken into account.
- Similarly the bulk densities the in-situ matmaterial were assumed.
- In addition no allowance could be made at this stage to the Acid Neutralising Capacity for the effect of long term exposure to possibily slightly acid, peaty water which could occur on site.

However it is felt that these assumptions were reasonable within the context of the exercise and do not invalidate the results which have not only identified potentially acid producing material but have shown possible methods of treatment, should it not prove possible to dispose of this potentially polluting material in such a way as to eliminate contact with water.

CONCLUSIONS

The results of the particular site under analysis have shown that, although there are individual strata which have a high pollution potential, the average analysis for the full strata sequence to be excavated show an excess of neutralising capacity i.e. the resultant backfill should not be polluting. The possibility of acid ferruginous springs forming at this particular site if the groundwater table rebounded to surface on cessation of mining is therefore remote. The strata with the highest acid producing potential were the ironstone bands usually containing both siderite and iron pyrites. Ironstone bands are quite common in coal-bearing strata and at mines where they predominate in the sequence then a quite high overall acid producing potential can result. Quite often the major iron bearing strata has been worked in the past using pillar and stall underground mining methods. The workings allow oxygenated air to circulate round the iron rich cavity walls and pillars resulting in acid ferruginous groundwater flow within the voids that may connect through high walls in the surface mine.

Where a pollution potential has been identified from laboratory analyses then remedial measures will need to be planned for in the mining process. These remedial measures can take the form of either preventing the groundwater from rising through the backfill or physically affecting the fill so that it becomes non-polluting. Much more research is needed in this respect and to be effective should be large-scale, on-site investigations of the different methods available.

Usually the pavement of the excavation area is a fireclay or seatearth occuring below the lowest seam to be worked and this would be naturally impermeable as long as it was not severely disrupted by blasting or vehicular movement. A possible method of reducing pollution would be to induce the groundwater springs to issue at surface either before it reaches the backfilled void or after it has only passed through a small part of it. This could be done by raising the final surface contours on restoration of the site with an impermeable layer of drift superimposed on the fill. However, it is important not to inhibit the flow within the fill by too much as this slower rate would give the groundwater a greater opportunity to pick up polluting chemicals from the material.

Bactericides have been used on a small scale in the United States [7] but the authors do not think the method would be cost effective in larger surface coal mining environments.

It would appear that the best method of success would be a permutation of some or all of the above methods and each mine environment would need to be treated as a separate entity.

The research project as outlined in this paper has shown that it is possible to analyse the pollution potential of strata at a proposed future mine site and that the determination of the pyritic content of the material to be excavated can be applied as a matter of routine. Once further research into cost effective remedial matters has been completed then it should be possible to eliminate the possibility of pollution on groundwater rebound by judicious mine planning.

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