

Hydrometallurgical options for the extraction of (glaucanite) green sands

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Commercial in Confidence

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EXECUTIVE SUMMARY

HYDROMETALLURGICAL OPTIONS FOR EXTRACTION OF (GLAUCONITE) GREEN SANDS

Robbie McDonald and Coby Jeffery

A short program of experiments was conducted for Tracker Geoservices under Consulting Services Agreement #2015020497 to assess the extraction of potassium from a glauconite concentrate. In particular the use of citric acid as an extractant was assessed and compared with sulphuric acid. An additional test was conducted to determine if lime roasting promotes leaching.

Glaucosite concentrate was milled to $-25\ \mu\text{m}$ to prepare feed material for leaching. A portion of this was additionally ring milled to determine if this further enhances extraction. Leaching with 4 M citric acid at $95\ ^\circ\text{C}$ for 10 h using a 10% w/w pulp produced 11% potassium extraction. In comparison, after ring milling the final extraction of potassium increased to 41%. Of particular interest here was that the extraction after 1 h was almost 32% while it was not known how quickly during that time that the potassium was released. Comparison of the XRD patterns for the feeds suggests ring milling reduced the crystallinity of the concentrate and generated “amorphous” material which is more readily leached. Further work to determine the extent to which glauconite concentrate can be “mechanically activated” for leaching and, the conditions under which leaching occurs, is indicated.

For comparison with citric acid leaching, the use of 2.5 M sulphuric acid at $95\ ^\circ\text{C}$ for 8 h using a 10% w/w pulp resulted in 76% potassium extraction. In all acid leaching tests the extractions of leachable metals hosted in the glauconite, Al, Fe, K and Mg, followed similar trends. The data also suggested that the extent of leaching is somewhat higher for the metals hosted predominantly in octahedral sites of the glauconite lattice, *i.e.* Al and Mg.

The glauconite concentrate contains accessory apatite. In each of the acid leaching tests this mineral dissolves rapidly to release calcium and phosphate. In the presence of sulphuric acid most of the calcium re-precipitates as gypsum.

Lime roasting without the addition of salt generates a product that cannot be leached in water. XRD analysis indicates that several calcium aluminosilicates are formed. In comparison it is expected that potassic aluminosilicates were also formed though no such minerals commonly found in nature could be identified.

1 INTRODUCTION

Following an initial approach to CSIRO by John Canaris (Tracker Geoservices Pty Ltd) and Dennis Gee (Independent Mining and Metals Professional) a project to examine a concept proposed to CSIRO involving the use of citric acid to leach glauconite was developed for the client. It was agreed that the following topics should be addressed by the proposal:

1. The effectiveness of high concentration citric acid for the extraction of potassium from glauconite (from concentrate);
2. Comparison of citric acid with sulphuric acid, which is known to be effective for extraction;
3. Leaching under atmospheric conditions at a temperature of 90-95°C, and relatively low pulp density, to optimise the extent of leaching;
4. Use of fine grind size feed, -25 microns, including examination of the effect of mechanical activation via milling upon extraction;
5. The impact of pre-roasting upon extraction.

A series of four tests were designed to address these topics and the results of these tests are described in this brief report.

2 EXPERIMENTAL

A sample of glaucanite concentrate generated from ore collected from the Daly River region in the Northern Territory was provided by the client for this project. The proposed work program consists of four tests as described in Table 1 below. The solubility of (anhydrous) citric acid is high increasing from 117 g per 100 mL water at 10°C to 148 g per 100 mL water at 20°C right up to 548 g per 100 mL water at 100°C; the concentration of citric acid that can be produced for leaching is therefore high (PubChem Open Chemistry Data Base). A saturated ~4 M citric acid solution was prepared at room temperature for the tests using this lixiviant and this is consistent with a reported citric acid mole fraction of a saturated solution as 0.1224 at 20°C (Oliveira *et al.*, 2013). Citric acid solubility data have also been presented by Apelblat (2014).

The milling of the glaucanite concentrate to -25 µm was conducted using a ceramic ball mill on bottle roller over a period of several days to minimise the impact upon the crystallinity of the product. A portion of the product was employed for ring-milling via a Labtechnics unit with checks of the crystallinity of the material using XRD after 15 min and 27 min of milling.

Table 1 Description of experiments conducted to examine the extraction of potassium from a glaucanite concentrate.

Test No.	Conditions
G1	Concentrated (4 M) citric acid, 95°C, 10% w/w pulp density, -25 µm concentrate, 10 h leaching, with sampling (five samples).
G2	Concentrated (4 M) citric acid, 95°C, 10% w/w pulp density, ring milled concentrate, 8 h leaching, with sampling (five samples).
G3	Moderate strength (2.5 M) sulphuric acid, 95°C, 10% w/w pulp density, -25 µm concentrate, 10 h leaching, with sampling (five samples).
G4	Use of glaucanite concentrate roasted with lime (CaO) at 1150°C for 2 h. This was followed by water leaching of the calcine, 95°C, 10% w/w pulp density, 6 h leaching, with sampling (five samples).

Sub-samples collected during the leaching tests were filtered, the solids washed and dried, and solids and liquids sent for assay via ICP-OES; here Sigma 12:22 lithium borate flux was employed for fusion of the solids. The elements analysed were Al, Ca, Fe, K, Mg, P and Si. The density and pH of the leach liquors were also recorded. Samples of -25 µm and ring-milled concentrate were submitted for laser sizing via a Malvern Hydro 2000G instrument.

The particle size analysis data for the glaucanite concentrate feed samples and, the mass balance spreadsheet summaries for the leaching tests described in Table 1, are presented in Appendices A and B, respectively.

3 RESULTS AND DISCUSSION

Elemental analyses of the glauconite concentrate sample milled to $-25\ \mu\text{m}$ and the ring milled sample are given in Table 2. Notably there are differences in the analyses of the two samples; however, these are within the combined sub-sampling variation and analytical error for the analysis method.

Table 2 Elemental analyses of glauconite concentrate milled to $-25\ \mu\text{m}$ and the ring milled sample.

Sample	Elemental analysis (% w/w)						
	Al	Ca	Fe	K	Mg	P	Si
$-25\ \mu\text{m}$	3.68	3.52	14.5	6.09	2.28	1.07	22.0
Ring milled	3.60	3.04	14.3	5.95	2.24	0.98	22.0

XRD analysis of the glauconite concentrate samples indicated that the primary minerals in the sample were apatite ($\text{Ca}_5(\text{PO}_4)_3(\text{F},\text{Cl},\text{OH})$), glauconite ($(\text{K},\text{Na})(\text{Fe}^{3+},\text{Al},\text{Mg})_2(\text{Si},\text{Al},\text{Fe}^{3+})_4\text{O}_{10}(\text{OH})_2$) and quartz (SiO_2). The molar ratio of calcium in these samples is estimated from the analysis data to be 2.4-2.5 which is somewhat higher than the expected value of 5/3, if all of the calcium is hosted in the apatite.

Particle size analysis data for the $-25\ \mu\text{m}$ and the ring milled samples is given in Appendix A. The P_{80} value for the $-25\ \mu\text{m}$ fraction is $14.2\ \mu\text{m}$ whereas that for the ring milled fraction is only marginally smaller, $11.3\ \mu\text{m}$, indicating that ring milling did not significantly reduce the volume weighted particle size though there is a noticeable reduction in the proportion of larger particles. It is also notable that particles of size above $25\ \mu\text{m}$ were detected and this suggests that, although a dispersant and sonication was employed prior to measurement, a small fraction of the sample may still have remained agglomerated.

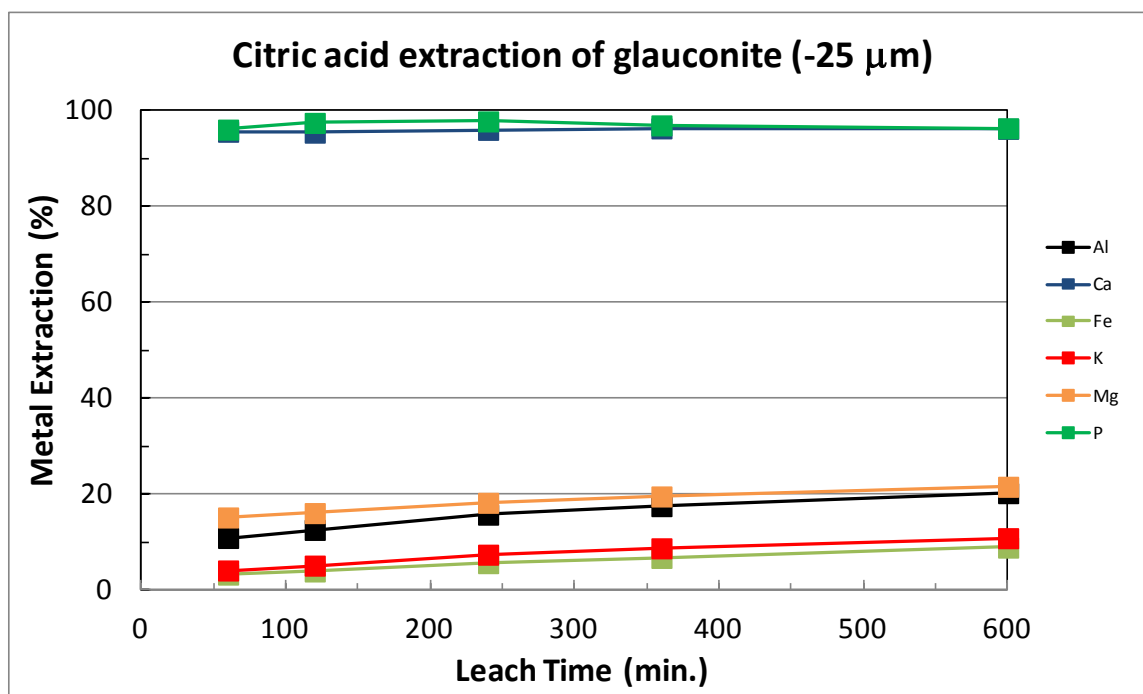


Figure 1 Extraction of metals by 4 M citric acid from a glauconite sample milled to $-25\ \mu\text{m}$ at $95\ ^\circ\text{C}$ (10% w/w pulp density).

Citric acid leaching of the $-25\ \mu\text{m}$ sample generated the extraction data shown in Figure 1. The extractions of Ca and P are high indicating dissolution of the apatite and inferring that little, if any of the calcium, is hosted by glauconite. The rate at which these elements are extracted is uncertain and shorter sample times are required. In contrast, the extractions of elements expected to be associated with the glauconite, K, Fe, Al and Mg, is both much slower and significantly less. In particular around 4% of the potassium is extracted after 1 h increasing to around 11% after 10 h. Furthermore, as the Al and Mg extractions are somewhat higher and virtually no Si is extracted, this indicates that the leaching is incongruent; furthermore, leaching from the octahedral (compared to the tetrahedral) site in the structure has lower activation energy. Overall, however, milling the sample to below 25 microns was insufficient to facilitate glauconite leaching by concentrated citric acid solution.

The dissolution of glauconite by mineral acids under atmospheric conditions is well known and is discussed in various articles (*e.g.* Yadav and Sharma, 1992; Yadav *et al.*, 2000). While it was found that hydrochloric acid is more efficient for potassium extraction, sulphuric acid was chosen in the present study since, based upon price, it would be the cheapest acid lixiviant for glauconite leaching. Furthermore, it is the lixiviant of choice for the K-Max process currently being developed by Potash West.

In contrast to the study of Yadav *et al.* (2000) who used a feed with larger particle size ($-152, +125\ \mu\text{m}$) a sulphuric acid concentration of 6 M and pulp density of 2.5% w/v over 6 h, the present experiment employed a smaller particle size, lower acid concentration with higher pulp density over a longer time frame. Even after 8 h leaching the extractions of Al, Fe, K and Mg were continuing to increase, indicating that the formation of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) does not interfere with leaching of the glauconite. A potassium extraction of 76% was reached at this time; note here that issues beyond the control of the researchers meant that this experiment was terminated after 8 h. The pH of the solution, -0.07 , was consistent with residual acid remaining to continue to drive the reaction which becomes increasing slower as metals need to diffuse through an increasingly thicker layer of silica-rich material.

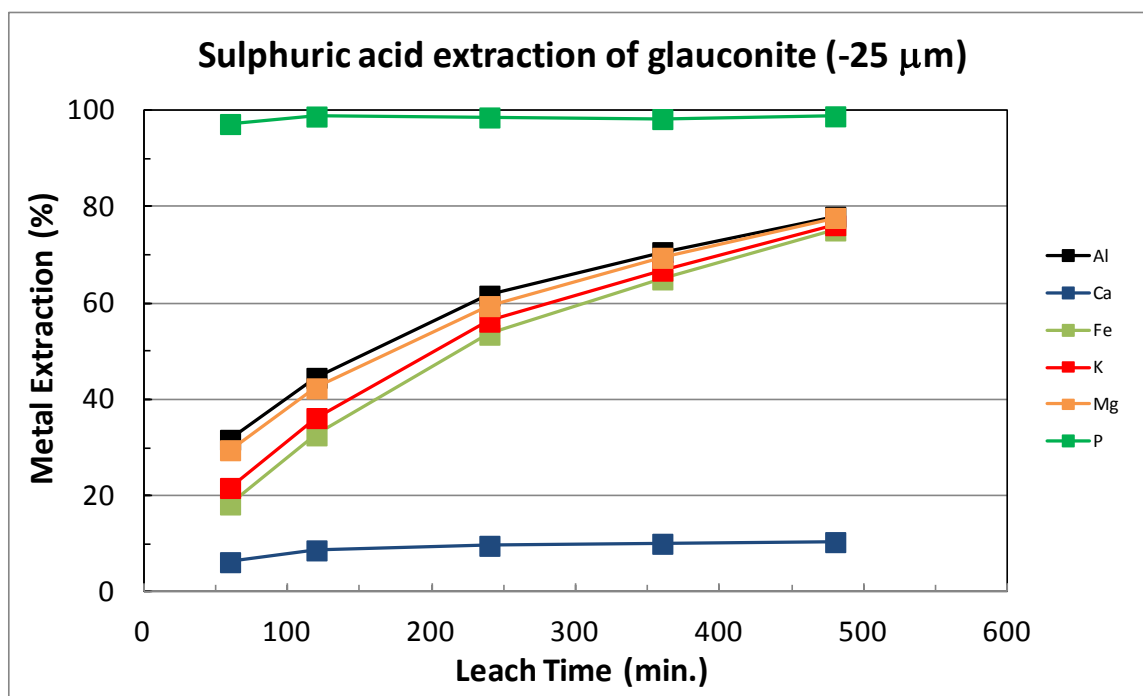


Figure 2 Extraction of metals by 2.5 M sulphuric acid from a glauconite sample milled to $-25\ \mu\text{m}$ at $95\ ^\circ\text{C}$ (10% w/w pulp density).

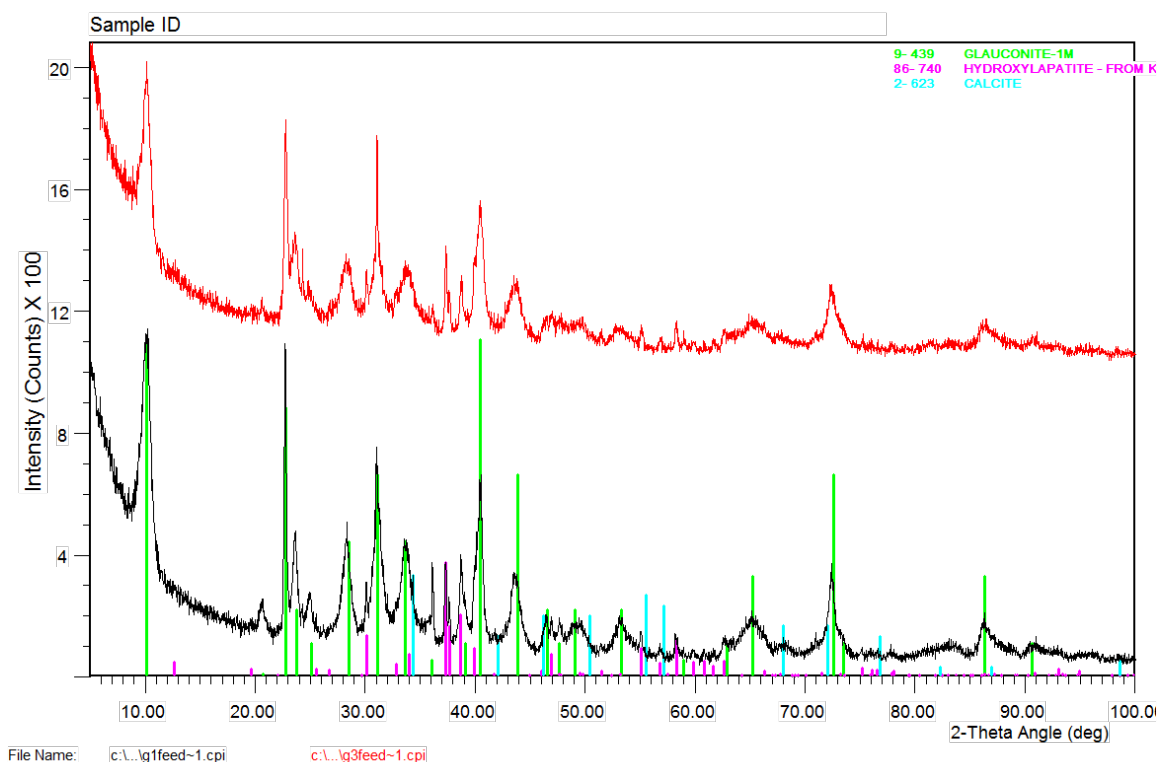


Figure 3 XRD patterns for the glaucosite feed materials used in the test work. The bottom trace corresponds to the $-25\ \mu\text{m}$ feed and the upper trace to the ring milled feed.

Although ring milling produced a small reduction in particle size (see Appendix A), the product was suggested from the XRD trace to be less crystalline. From Figure 3 it appears that the height of the peaks due to the glaucosite is reduced by roughly one third though this may simply correspond to “amorphization” of the sample. The generation of “amorphous” material, however, is suggested by the decreasing peak resolution for the peaks with diffraction angles close to $25^\circ\ 2\theta$ though this is contributed to by general broadening of the glaucosite peaks. Although not shown here there was little difference between snapshot XRD traces obtained after 15 and 27 minutes of ring milling suggesting a limitation in the extent to which this technique is able to reduce the crystallinity of the glaucosite.

Citric acid extraction of the ring milled feed gave higher extractions of Al, Fe, K and Mg while again, the high extractions of Ca and P in the first sub-sample demonstrate the faster leaching of the apatite (Figure 4). While the extractions of the former elements only increased by around 10% between the first and final sub-samples, the extractions in the first sample indicated a faster initial release, ~30% for Al, K and Mg, of the metals hosted by glaucosite. This is ascribed to “mechanical activation” of the sample due to ring milling notwithstanding that a slightly smaller particle size of the feed is also produced. Enhancement of leaching by ultrafine grinding has been noted for other difficult to leach minerals such as talc (Temuujin *et al.*, 2002). As suggested from the work of Temuujin *et al.* (2002) there may be potential to produce a high purity porous silica product which may have commercial value from the leaching of glaucosite. It is, however, beyond the scope of the present work to assess whether such a product, if generated, has a market value.

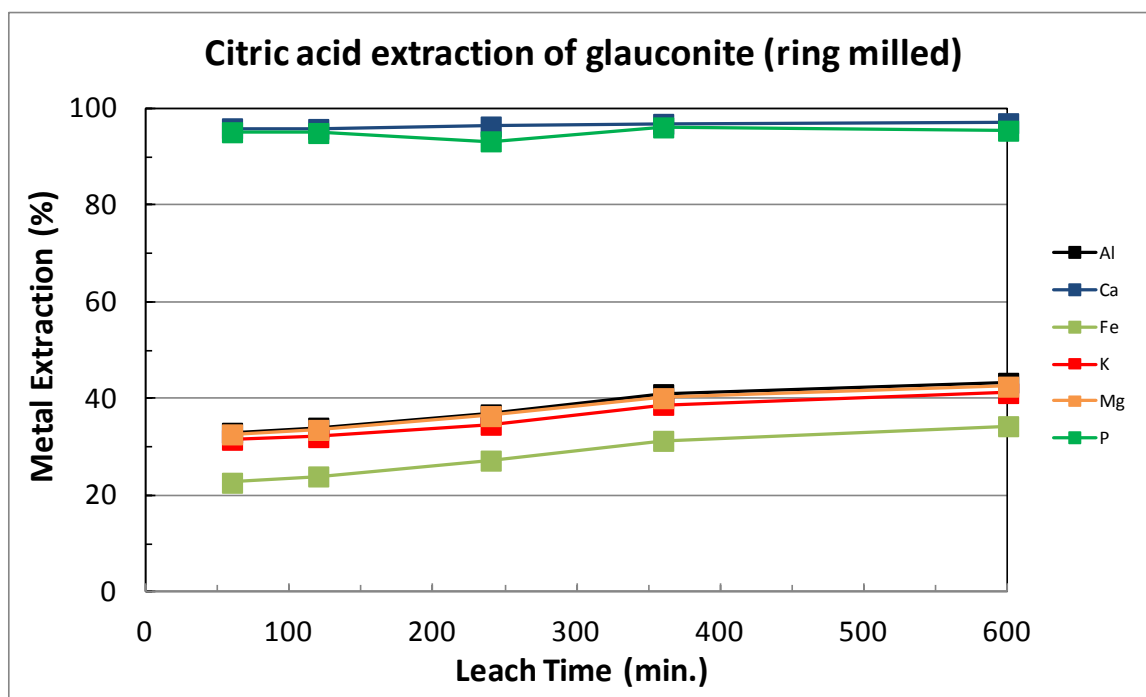


Figure 4 Extraction of metals by 4 M citric acid from the ring milled glauconite feed at 95 °C (10% w/w pulp density).

Based on the present results, further work is required to determine (1) how fast the metals are initially leached, (2) if a weaker lixiviant can be used for leaching and (3) whether further mechanical activation of the sample can be achieved, using a different type of mill, *e.g.* attrition, jet, oscillation, planetary or vibration.

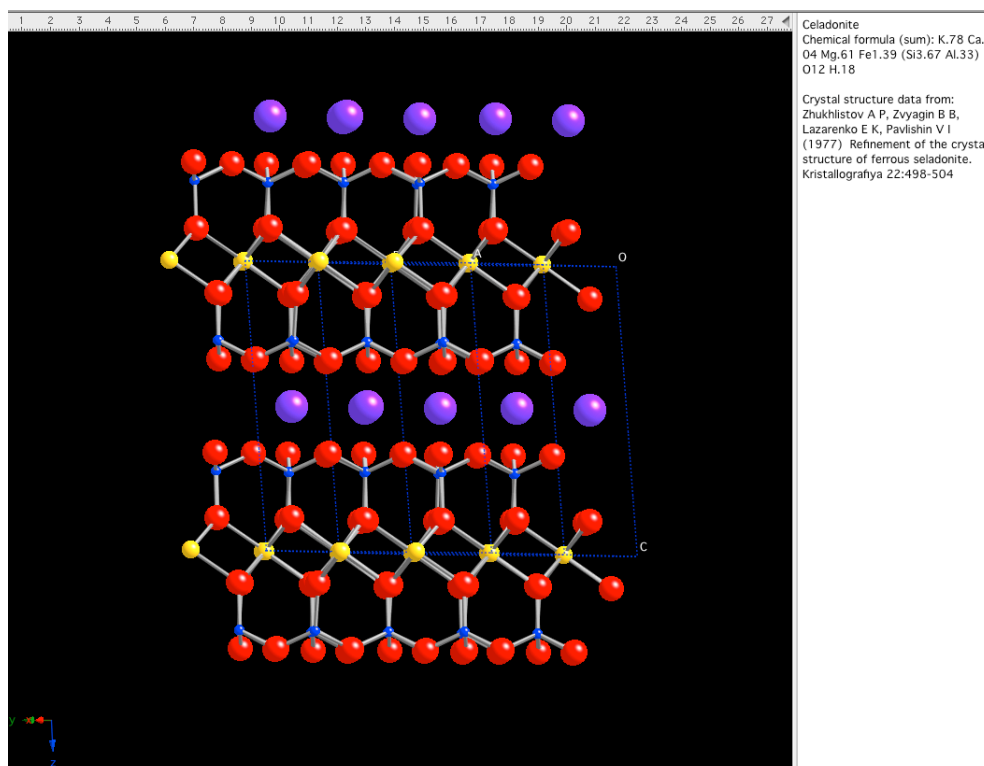


Figure 5 Crystal structure of celadonite, a mineral that is isostructural with glauconite. The atoms shown in this structure are potassium (purple), silicon (blue), magnesium/iron/aluminium (yellow) and oxygen (red) (Reference: <http://clay.uga.edu/courses/8550/CM09.html>)

The crystal structure shown in Figure 5 helps to illustrate the difficulties in leaching mica minerals, and particularly those that are not ion-exchangeable such as muscovite. First, these minerals exhibit perfect cleavage along the [001] direction, *i.e.* parallel to the c-axis, which is also that of the interlayer hosting the potassium ions. The leaching of potassium from these layers is a diffusion controlled process and therefore, to reduce the time to access all of these ions, it is necessary to either disrupt those structural features that stabilise the bonding of the potassium or, to cleave the crystals perpendicular to their natural cleavage plane, which is not energetically favourable. The purpose of mechanical activation, here using ring milling, was to disrupt the crystal structure and thereby reduce the binding energy of the potassium. It is disruption of the crystal structure that is associated with “amorphization”, and which improves accessibility of a lixiviant to the more weakly bound leachable metal ions.

A final test to examine the lime roasting of the glauconite was undertaken for which just lime and a higher temperature, 1150 °C, was employed compared with the conditions used for the Tschirner process (Tschirner, 1919) which uses a lower temperature, 800 °C, and salt (NaCl) in addition to a calcium additive (*e.g.* limestone). Leaching was conducted in water with around 15 mg/L potassium leached after 6 h confirming that a readily soluble potassium salt was not formed during roasting. It was not determined if the product could be leached with acid as has been shown for the lime roasted material produced by the invention underpinning the ThermoPotash process (Ladeira, 2014). Examination of the XRD pattern for the roasted product from this work suggested the formation of hematite and various calcium silicates that include an akermanite-gehlenite solid solution, wollastonite, and augite. Although it is not clear whether potassic aluminosilicates formed this is certainly possible. Furthermore, a test to determine the leachability of potassium from the roasted product with acid could be considered as part of future work.

4 CONCLUSION

The current study indicated that (high strength) citric acid leaching of glauconite (P_{100} -25 μm) under atmospheric conditions is slow and around 11% of the potassium is leached over a 10 h period at 95 °C. In comparison the leaching of the accessory mineral apatite is fast and 96% of both the calcium and phosphorus were found to be dissolved in the first sub-sample taken (after 1 h). Mechanical activation of the sample via ring milling results in the rapid initial release of around 30% of the potassium under the same conditions. It is suggested, however, that this milling technique is not optimum for mechanical activation of the sample and that other techniques could be considered in future work. In addition, the rate of potassium extraction and conditions required for extraction from “activated” materials requires closer consideration. The present work does not indicate how fast the metals were initially extracted from the ring milled sample nor is it known whether a weaker lixiviant can be employed, whether this is citric or a mineral acid.

In comparison to leaching with citric acid, sulphuric acid leaching released 76% of the potassium after 10 h with the data indicating that further extraction was possible. For all leaching tests with either acid, other metals associated with glauconite, Al, Fe and Mg, were leached to similar extents as potassium.

Lime roasting in the absence of salt generated a product from which potassium could not be leached by de-ionised water. It is suggested that the potassium may be associated with aluminosilicates formed during the roasting test, and although these may be leachable under acid or alkaline conditions, the leach liquor could contain other contaminants such as Al, Ca and Mg. In contrast, iron appears to be associated with hematite and would be expected to leach slowly, if at all.

5 ACKNOWLEDGEMENTS

The authors would like to thank Shaun O'Donnell for the particle size distribution data, Sophia Surin for measurement of the XRD patterns and, Tuyen Pham and Milan Chovancek for provision of the analytical data.

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APPENDIX A:
**PARTICLE SIZE DISTRIBUTION DATA FOR THE GLAUCONITE
CONCENTRATE FEEDS**

Analysis Report



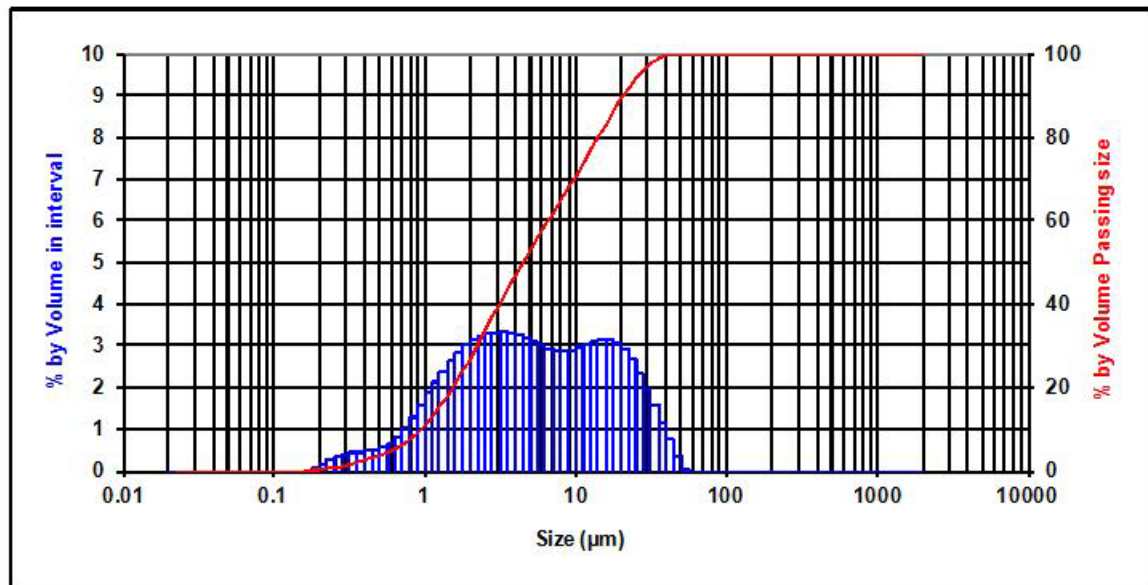
CSIRO

Particle Analysis Service

Sample Name: G1 FEED
 Batch No: R1514224
 PAS ID No: P80223

Dispersant: Water RI/ABS: 2.74 / 1
 Additives: 10 ml Calgon Analysis Model: General purpose (spherical)
 Sonication: 20 minutes in ultrasonic bath Result units: Volume

Concentration: 0.0037 % vol Vol. Weighted Mean D[4,3]: 8.049 µm d(0.1): 0.953 µm
 Obscuration: 14.13 % Surface Weighted Mean D[3,2]: 2.198 µm d(0.5): 4.483 µm
 Weighted Residual: 0.491 % Specific Surface Area: 2.73 m²/cc P80: 14.173 µm
d(0.9): 20.746 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1002	10.84	7.096	61.95	50.238	100.00	355.656	100.00
0.022	0.00	0.159	0.00	1.125	12.98	7.962	64.83	56.368	100.00	399.052	100.00
0.025	0.00	0.178	0.05	1262	15.38	8.934	67.73	63.246	100.00	447.744	100.00
0.028	0.00	0.200	0.19	1416	18.01	10.024	70.69	70.983	100.00	502.377	100.00
0.032	0.00	0.224	0.46	1589	20.85	11247	73.72	79.621	100.00	563.677	100.00
0.036	0.00	0.252	0.79	1783	23.84	12619	76.82	89.337	100.00	632.466	100.00
0.040	0.00	0.283	1.20	2.000	26.97	14.159	79.97	100.237	100.00	709.627	100.00
0.045	0.00	0.317	1.66	2.244	30.20	16.887	83.12	112.468	100.00	796.214	100.00
0.050	0.00	0.356	2.11	2.516	33.49	17.825	86.20	126.191	100.00	893.367	100.00
0.056	0.00	0.399	2.57	2.825	36.82	20.000	89.12	141.589	100.00	1002.374	100.00
0.063	0.00	0.448	3.06	3.170	40.17	22.440	91.80	158.666	100.00	1124.683	100.00
0.071	0.00	0.502	3.61	3.567	43.49	25.179	94.16	178.250	100.00	1261.915	100.00
0.080	0.00	0.564	4.27	3.991	46.76	28.251	96.13	200.000	100.00	1415.892	100.00
0.089	0.00	0.632	5.09	4.477	49.96	3.1698	97.71	224.404	100.00	1588.656	100.00
0.10	0.00	0.710	6.12	5.024	53.08	35.666	98.87	251.785	100.00	1782.502	100.00
0.112	0.00	0.796	7.42	5.637	56.11	39.905	99.64	282.508	100.00	2000.000	100.00
0.126	0.00	0.893	8.99	6.325	59.06	44.774	99.99	316.979	100.00		

28/05/2015

Analysis Report

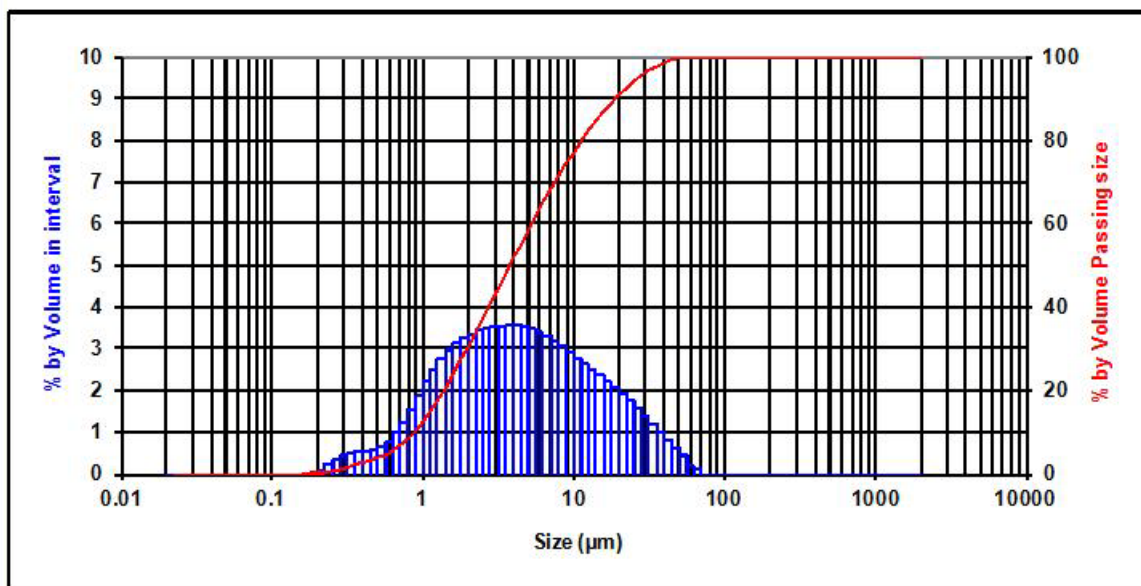


Particle Analysis Service

Sample Name: G3 FEED
 Batch No: R1514224
 PAS ID No: P80224

Dispersant: Water RI/ABS: 2.74 / 1
 Additives: 10 ml Calgon Analysis Model: General purpose (spherical)
 Sonication: 20 minutes in ultrasonic bath Result units: Volume

Concentration: 0.0039 % vol Vol. Weighted Mean D[4,3]: 7.293 µm d(0.1): 0.881 µm
 Obscuration: 15.86 % Surface Weighted Mean D[3,2]: 2.024 µm d(0.5): 3.802 µm
 Weighted Residual: 0.708 % Specific Surface Area: 2.96 m²/cc P80: 11.344 µm
d(0.9): 18.877 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1002	12.44	7.096	68.41	50.238	99.70	355.656	100.00
0.022	0.00	0.159	0.00	1.125	14.94	7.962	71.46	56.368	99.91	399.052	100.00
0.025	0.00	0.178	0.02	1262	17.70	8.934	74.37	63.246	100.00	447.744	100.00
0.028	0.00	0.200	0.08	1416	20.68	10.024	77.16	70.963	100.00	502.377	100.00
0.032	0.00	0.224	0.32	1589	23.82	11247	79.81	79.621	100.00	563.677	100.00
0.036	0.00	0.252	0.67	1783	27.09	12619	82.32	89.337	100.00	632.466	100.00
0.040	0.00	0.283	1.11	2.000	30.45	14.159	84.70	100.237	100.00	709.627	100.00
0.045	0.00	0.317	1.61	2.244	33.87	16.887	88.94	112.468	100.00	796.214	100.00
0.050	0.00	0.356	2.12	2.516	37.34	17.825	89.02	126.191	100.00	893.367	100.00
0.056	0.00	0.399	2.66	2.825	40.85	20.000	90.94	141.589	100.00	1002.374	100.00
0.063	0.00	0.448	3.21	3.170	44.38	22.440	92.69	158.866	100.00	1124.683	100.00
0.071	0.00	0.502	3.85	3.567	47.94	25.179	94.26	178.250	100.00	1261.915	100.00
0.080	0.00	0.564	4.62	3.991	51.49	28.251	96.64	200.000	100.00	1415.892	100.00
0.089	0.00	0.632	5.59	4.477	55.02	3.1698	96.82	224.404	100.00	1588.656	100.00
0.10	0.00	0.710	6.83	5.024	58.51	35.666	97.82	251.785	100.00	1782.502	100.00
0.112	0.00	0.796	8.37	5.637	61.92	39.905	98.63	282.508	100.00	2000.000	100.00
0.126	0.00	0.893	10.24	6.325	65.22	44.774	99.25	316.979	100.00		

28/05/2015

APPENDIX B: MASS BALANCE SPREADSHEET DATA FOR THE LEACHING EXPERIMENTS

CLIENT NAME :			Tracker Geoservices Pty Ltd			TEST CONDITIONS:					
JOB NUMBER:			G			Ore (g):	76.69				
SAMPLE:			Glauconite Concentrate			Water (g):	0				
TEST NO. :			1			Solution (mL):	532				
DATE :			20-April-2015			Solution (g):	691.1	Temperature °C:	95		
						Solution Density (g/mL):	1.299				
						Pulp Density, % (w/w):	10.0				
SOLIDS											
Sample mins	Sample wt., g		Solid Analysis, %*								
	Slurry	Solid (dry)	Al	Ca	Fe	K	Mg	P	Si		
Feed Solid	764.1	76.7	3.68	3.52	14.5	6.09	2.28	1.07	22.0		
60	43.9	3.8	3.94	0.195	15.4	6.39	2.21	0.061	24.5		
120	31.2	2.7	3.86	0.192	15.4	6.44	2.19	0.036	24.8		
240	46.7	4.0	3.78	0.174	15.3	6.30	2.17	0.031	25.2		
360	42.6	3.7	3.69	0.157	15.2	6.21	2.13	0.040	25.4		
480	61.8	5.3	3.62	0.162	14.9	6.05	2.10	0.042	25.6		
Final	517.8	47.0	3.57	0.180	14.8	6.04	2.08	0.044	25.5		
LIQUORS											
Sample mins	Liquor				Liquor Analysis, mg L ⁻¹						
	FA gL ⁻¹	pH	Eh mV Ag/AgCl	Density kgL ⁻¹	Al	Ca	Fe	K	Mg	P	Si
Feed Liquor					0	0	0	0	0	0	0
60		0.57		1.336	602	5260	649	343	495	1830	206
120		0.64		1.324	691	4935	778	432	522	1663	163
240		0.68		1.330	872	5097	1130	621	596	1627	170
360		0.72		1.326	966	4985	1351	732	638	1553	150
480		0.90		1.306	1127	5018	1788	905	708	1352	160
Final				1.381	1115	4931	1760	909	707	1599	183
METAL EXTRACTIONS											
Time mins	Extraction, %							Si**			
	Al	Ca	Fe	K	Mg	P					
60	10.9	95.6	3.3	4.1	15.2	96.0	0.7				
120	12.6	95.4	3.9	5.1	16.1	97.4	0.5				
240	15.7	96.0	5.6	7.4	18.2	97.7	0.5				
360	17.5	96.3	6.7	8.7	19.5	96.9	0.5				
480	20.2	96.2	8.9	10.8	21.6	96.3	0.5				
** May include some colloidal silica											
ACCOUNTABILITY											
Accountability, % (Out/In)											
Physical Mass	Al	Ca	Fe	K	Mg	P	Si				
96.9	105.0	100.1	97.2	96.2	100.1	104.2	100.7				
HEAD GRADE											
Analysis, %											
	Al	Ca	Fe	K	Mg	P	Si				
Calculated	3.86	3.52	14.1	5.86	2.28	1.12	22.2				
Actual	3.68	3.52	14.5	6.09	2.28	1.07	22.0				

CLIENT NAME :		Tracker Geoservices Pty Ltd		TEST CONDITIONS:							
JOB NUMBER:		G		Ore (g):	76.38	Sulfuric Acid Mass (g):	136.70				
SAMPLE:		Glaucinite Concentrate		Water (g):	0	H ₂ SO ₄ Conc. (% w/w):	98				
TEST NO. :		2		Solution (mL):	598						
DATE :		21-April-2015		Solution (g):	687.7		Temperature °C:	95			
				Solution Density (g/mL):	1.150						
				Pulp Density, % (w/w):	10.0						
SOLIDS											
Sample mins	Sample wt., g		Solid Analysis, %*								
	Slurry	Solid (dry)	Al	Ca	Fe	K	Mg	P	Si		
Feed Solid	764.1	76.4	3.68	3.52	14.5	6.09	2.28	1.07	22.0		
60	41.7	3.4	3.04	0.072	14.2	5.68	1.94	0.040	27.1		
120	39.8	3.0	2.68	0.067	12.7	4.99	1.72	0.019	29.4		
240	35.1	2.3	2.13	0.056	10.0	3.97	1.39	0.026	32.0		
360	38.1	2.5	1.70	0.073	7.9	3.11	1.09	0.033	34.2		
480	47.7	2.8	1.40	0.093	6.2	2.45	0.87	0.025	35.5		
Final	530.8	38.1	1.12	3.001	4.6	1.89	0.66	0.053	32.2		
LIQUORS											
Sample mins	Liquor				Liquor Analysis, mg L ⁻¹						
	FA gL ⁻¹	pH	Eh mV Ag/AgCl	Density kgL ⁻¹	Al	Ca	Fe	K	Mg	P	Si
Feed Liquor					0	0	0	0	0	0	0
60		-0.32		1.192	1439	278	3236	1606	830	1417	93
120		-0.05		1.178	2018	385	5748	2652	1186	1386	80
240		-0.07		1.184	2797	426	9436	4168	1663	1441	72
360		-0.07		1.190	3364	449	12117	5156	2045	1512	63
480		-0.07		1.195	3756	466	14178	5953	2293	1547	67
Final				1.193	3853	457	14895	6212	2374	1505	23
METAL EXTRACTIONS											
Time mins	Extraction, %										
	Al	Ca	Fe	K	Mg	P	Si**				
60	31.7	6.3	18.3	21.7	29.5	97.2	0.3				
120	44.5	8.7	32.6	36.2	42.4	98.8	0.3				
240	61.6	9.7	53.5	56.2	59.4	98.6	0.3				
360	70.6	10.1	65.0	66.8	69.4	98.2	0.2				
480	78.0	10.4	75.1	76.2	77.7	98.8	0.2				
** May include some colloidal silica											
ACCOUNTABILITY											
Accountability, % (Out/In)											
Physical Mass	Al	Ca	Fe	K	Mg	P	Si				
96.0	98.3	52.4	97.7	96.6	96.9	107.4	99.1				
HEAD GRADE											
Analysis, %											
	Al	Ca	Fe	K	Mg	P	Si				
Calculated	3.62	1.84	14.1	5.88	2.21	1.15	21.8				
Actual	3.68	3.52	14.5	6.09	2.28	1.07	22.0				

CLIENT NAME :		Tracker Geoservices Pty Ltd		TEST CONDITIONS:							
JOB NUMBER:		G		Ore (g):		76.44		Water (g):		0	
SAMPLE:		Glaucanite Concentrate		Solution (mL):		532		Solution (g):		691.1	
TEST NO. :		3		Temperature °C:		95		Solution Density (g/mL):		1.299	
DATE :		23-April-2015		Pulp Density, % (w/w):		10.0					
SOLIDS											
Sample mins	Sample wt., g		Solid Analysis, %*								
	Slurry	Solid (dry)	Al	Ca	Fe	K	Mg	P	Si		
Feed Solid	767.6	76.4	3.60	3.04	14.3	5.95	2.24	0.98	22.0		
60	38.0	2.7	3.01	0.151	13.5	4.98	1.86	0.066	26.5		
120	44.0	3.3	2.95	0.153	13.4	4.96	1.85	0.068	27.2		
240	43.7	3.3	2.86	0.136	12.9	4.79	1.78	0.096	27.3		
360	39.4	2.8	2.82	0.129	12.8	4.73	1.76	0.061	28.1		
480	56.9	4.2	2.71	0.121	12.2	4.54	1.69	0.071	28.0		
Final	518.4	42.9	2.68	0.133	12.2	4.57	1.69	0.062	28.0		
LIQUORS											
Sample mins	Liquor				Liquor Analysis, mg L ⁻¹						
	FA gL ⁻¹	pH	Eh mV Ag/AgCl	Density kgL ⁻¹	Al	Ca	Fe	K	Mg	P	Si
Feed Liquor					0	0	0	0	0	0	0
60		1.19		1.325	1501	3602	4013	2327	915	1308	133
120		1.16		1.327	1608	3680	4480	2479	988	1355	133
240		0.97		1.332	1811	3852	5264	2767	1109	1444	135
360		1.02		1.336	1953	3953	5850	2993	1181	1501	137
480		1.12		1.336	2192	4107	6774	3371	1325	1560	151
Final				1.328	2240	4102	6887	3420	1346	1594	194
METAL EXTRACTIONS											
Time mins	Extraction, %										
	Al	Ca	Fe	K	Mg	P	Si**				
60	33.0	95.9	22.7	31.6	32.7	95.1	0.5				
120	34.1	95.8	24.0	32.1	33.6	94.9	0.5				
240	36.8	96.3	27.3	34.7	36.5	93.2	0.5				
360	41.0	96.8	31.3	38.8	40.2	96.1	0.5				
480	43.3	97.0	34.4	41.2	42.5	95.4	0.5				
** May include some colloidal silica											
ACCOUNTABILITY											
Accountability, % (Out/In)											
Physical Mass	Al	Ca	Fe	K	Mg	P	Si				
96.5	96.5	92.3	97.3	96.8	97.6	110.7	98.4				
HEAD GRADE											
Analysis, %											
	Al	Ca	Fe	K	Mg	P	Si				
Calculated	3.53	2.80	13.9	5.75	2.18	1.09	21.7				
Actual	3.60	3.04	14.3	5.95	2.24	0.98	22.0				

CLIENT NAME :		Tracker Geoservices Pty Ltd		TEST CONDITIONS:											
JOB NUMBER:		G		Ore (g):		81.66									
SAMPLE:		Limed Roasted Glauconite Concentrate		Water (g):		585									
TEST NO. :		4		Solution (mL):		586		Solution (g):		585.0		Temperature °C:		95	
DATE :		24-April-2015		Solution Density (g/mL):		0.998									
				Pulp Density, % (w/w):		12.2									
SOLIDS															
Sample mins	Sample wt., g		Solid Analysis, %*												
	Slurry	Solid (dry)	Al	Ca	Fe	K	Mg	P	Si						
Feed Solid	666.7	76.4	3.37	11.65	14.3	5.74	2.52	0.78	21.2						
60	32.4	1.6	3.11	15.855	13.2	4.01	2.66	0.784	19.7						
120	29.9	1.3	3.04	16.789	12.9	3.56	2.67	0.803	19.2						
240	28.5	1.1	2.93	18.320	12.3	2.84	2.70	0.791	18.5						
360	34.4	2.5	3.12	15.061	13.3	4.26	2.60	0.788	19.7						
480	34.8	2.7	3.14	14.660	13.4	4.40	2.58	0.804	19.8						
Final	487.0	72.7	3.32	11.069	14.9	5.68	2.46	0.790	20.9						
LIQUORS															
Sample mins	Liquor				Liquor Analysis, mg L ⁻¹										
	FA gL ⁻¹	pH	Eh mV Ag/AgCl	Density kgL ⁻¹	Al	Ca	Fe	K	Mg	P	Si				
Feed Liquor					0	0	0	0	0	0	0				
60		4.35		1.001	2	560	4	16	6	2	23				
120		8.37		1.001	2	587	1	19	6	2	24				
240		9.96		1.001	2	452	9	16	7	2	26				
360		9.97		1.001	1	295	0	16	7	2	27				
480		10.89		1.001	0	329	0	15	7	2	26				
Final				0.999	1	530	0	14	9	2	31				
METAL EXTRACTIONS															
Time mins	Extraction, %														
	Al	Ca	Fe	K	Mg	P	Si**								
60	0.2	6.5	0.1	0.8	0.4	0.5	0.2								
120	0.1	7.3	0.0	1.2	0.5	0.4	0.3								
240	0.2	5.6	0.2	1.3	0.6	0.6	0.3								
360	0.1	2.5	0.0	0.5	0.3	0.4	0.2								
480	0.0	2.6	0.0	0.4	0.3	0.3	0.2								
** May include some colloidal silica															
ACCOUNTABILITY															
Accountability, % (Out/In)															
Physical Mass	Al	Ca	Fe	K	Mg	P	Si								
97.1	97.9	102.7	103.3	96.1	98.8	101.1	98.1								
HEAD GRADE															
Analysis, %															
	Al	Ca	Fe	K	Mg	P	Si								
Calculated	3.30	11.96	14.7	5.51	2.49	0.79	20.8								
Actual	3.37	11.65	14.3	5.74	2.52	0.78	21.2								

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