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AMDL Report 259
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ALUMINIUM SULPHATE FROM ALUNITE

by

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to

SOUTH AUSTRALIAN GOVERNMENT
DEPARTMENT OF MINES

Investigated by: Industrial Chemistry Section

Officer in Charge: F.R. Hartley

THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES
Adelaide South Australia

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RESEARCH FOR INDUSTRY

THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

CONYNGHAM STREET · PARKSIDE · SOUTH AUSTRALIA
TELEPHONE 79 1662 · TELEGRAMS 'AMDEL' ADELAIDE

Please quote this reference in your reply:

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21st June, 1963

The Director,
Department of Mines,
Rundle Street,
ADELAIDE.

Dear Sir,

We are transmitting to you ten copies of AMDL Report 259 entitled "Aluminium Sulphate from Alunite", dated June, 1963.

Both aluminium sulphate and potassium sulphate could be recovered from alunite but unless large deposits of high-grade, easily workable alunite were available, the operation could be of doubtful economic value.

We consider that aluminium sulphate could be produced more readily and more cheaply from some of the white clay deposits in South Australia. Some preliminary work has been done under your sponsorship on samples of clay from Williamstown and Birdwood. The results so far have been encouraging.

We should be pleased to receive your comments on this Report.

Yours faithfully,

L. Wallace Coffer

L. Wallace Coffer
Director.

1. INTRODUCTION

It was proposed that the recovery of aluminium sulphate from South Australian alunite should be investigated. The only known deposit of any significance is in the Hundred of Ramsay, Yorke Peninsula, near Port Vincent. Material from this locality and also from Carrickalinga, about 30 miles south of Adelaide, has been examined previously,[1] but the emphasis was on the recovery of potash, the recovery of alumina being only a secondary consideration.

A major use for aluminium sulphate is in the paper-making industry. There is believed to be a fairly large demand for a product of the following specification[2]:

	%
Al_2O_3	16.0
Fe_2O_3	0.20 Maximum
Insolubles	0.50 "

The market could probably be widened if the Fe_2O_3 content were reduced to less than 0.03 per cent.

Various ways of treating the alunite to recover aluminium sulphate and other products were to be investigated. The possibility of further work would depend on the outcome of the initial investigation and on the quality of the aluminium sulphate which could be produced.

The following ways of recovering aluminium sulphate were considered:

1. Heating mixtures of alunite and limestone followed by leaching and other treatments - details of this procedure are given in a report by M.J. O'Connor.[1]
2. Heating alunite alone followed by leaching with water and/or sulphuric acid.
3. Direct treatment with sulphuric acid.
4. Direct treatment with potassium hydroxide.

Two samples from the Yorke Peninsula deposit were available, as well as one sample of fairly pure alunite from Carrickalinga. All three samples had been used for previous work and had been analysed chemically for major constituents.

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1. O'Connor, M.J., "Recovery of Potash and Alumina from Alunite Part 1. Dept. of Mines, South Australia, Research and Development Branch. Report RD101.

2. Letter from Wallaroo-Mount Lyell Fertilizers Limited dated 7th January, 1963.

2. SUMMARY

Alunite samples from the Hundred of Ramsay on Yorke Peninsula and from Carrickalinga Head to the south of Adelaide were treated in various ways to recover aluminium sulphate and by-products. Four procedures were investigated for decomposing the alunite:

1. Mixtures of alunite and limestone were heated at 500°C then leached with water to remove potassium sulphate and gypsum. The alumina in the residue was dissolved by sulphuric acid treatment.
2. The alunite was heated for 4 hours either at 550 or 600°C. In one series, the dehydrated alunite was leached first with water, then with sulphuric acid and, in another, it was treated directly with sulphuric acid.
3. An amount of sulphuric acid required to react with the aluminium hydroxide in the alunite was added to the dry material and the mixture was heated for 4 hours at 300°C. The sulphated material was leached with water.
4. Potassium hydroxide was added as an aqueous solution, the mixture was evaporated to dryness and then heated for 4 hours at 400°C. The fused mass was leached with water and the residue was treated with sulphuric acid to dissolve alumina.

The simplest and most effective procedure was to heat the alunite at 600°C and then treat it with sulphuric acid to dissolve the alumina. By this treatment, up to 90 per cent of the potash and alumina was dissolved. None of the other procedures gave as good recoveries and they were all more complicated and probably more expensive.

Two methods of recovering the components from liquor prepared by the preferred method were investigated.

1. Direct evaporation gave fairly sharp separation into potassium alum and aluminium sulphate. About 75 per cent of the aluminium could thus be recovered as the sulphate in saleable form.
2. Aluminium hydroxide was precipitated by aqueous ammonia and separated by filtration. The filtrate yielded a mixture of ammonium and potassium sulphates when evaporated. The aluminium hydroxide was dissolved in sulphuric acid and the solution was evaporated to produce aluminium sulphate. Virtually all the alumina could be recovered by returning the mother liquor to an earlier stage of the process.

The use of either of these procedures could result in production of saleable aluminium sulphate. Probably recrystallization or perhaps more complicated treatment would be required to produce sulphate of higher quality (less than 0.03 per cent Fe_2O_3). The procedure based on direct evaporation of liquor would probably be the simpler and more economical, particularly if there were a market for the alum produced in the first stages of evaporation.

3. MATERIAL EXAMINED

Hundred of Ramsay:

Sample AL2	From the cliffs near Port Vincent
Sample AL4	A representative sample from the whole deposit.

Carrickalinga:

Sample AL3	From a large nodule in the clay at Carrickalinga Head, Hundred of Myponga.

All samples were ground to 60 per cent minus 200-mesh (Tyler). Table 1 shows the chemical analysis of the samples.

TABLE 1: CHEMICAL ANALYSIS OF ALUNITE SAMPLES

Sample No.	K_2O %	Na_2O %	Al_2O_3 %	Fe_2O_3 %	SiO_2 %	Cl %	SO_3 %	H_2O below 100°C	H_2O above 100°C
AL2	7.21	3.04	34.88	trace	11.84	0.20	29.0	1.12	14.02
AL3	10.1	2.68	34.58	0.48	0.14	1.64	36.3	0.74	17.31
AL4	5.95	0.83	24.60	1.92	35.40	0.67	19.1	0.92	11.0
Pure alunite(a)	11.3	nil	37.0	nil	nil	nil	38.5	nil	13.2

(a) Theoretical composition.

4. ANCILLARY MATERIALS

Limestone. High grade marble from Angaston was ground to 60 per cent minus 200-mesh. The sample contained about 98 per cent $CaCO_3$.

Chemicals and Reagents. "Analar" or "chemically pure" materials were used.

5. DECOMPOSITION OF ALUNITE

Conventional laboratory equipment was used for heating, leaching, filtering,etc. Either a controlled temperature furnace or a drying oven was used for heating at specific temperatures. The leaching temperature was controlled by a constant temperature water bath at 50°. Filtrates were made up to known volumes and assayed for K_2O or Al_2O_3 as required.

5.1 Alunite-Limestone Reaction

The alunite was mixed with sufficient limestone to react with the sulphate combined with aluminium oxide and the mixture was heated at 500°C for 4 hours. The product was leached with water to remove soluble potassium sulphate and then leached with 0.6N sodium chloride (equivalent to sea water) to remove the gypsum formed in the initial reaction. The residue, which should then have consisted of alumina and original impurities, was dried and weighed. The dried material was mixed with sufficient sulphuric acid to convert all the alumina to aluminium sulphate, allowed to stand on a boiling water bath until reaction had ceased, then leached with water. The results are given in Tables 2 and 3.

5.2 Thermal Decomposition of Alunite

The alunite was heated at the required temperature for 4 hours, then cooled and weighed. The heated material was treated by several different procedures.

5.2.1 Water Leaching and Acid Leaching

The calcined material was leached for 1 hour at 50°C to remove potassium sulphate, then filtered, and the residue dried and weighed. The dried material was mixed with sufficient sulphuric acid to convert the alumina to sulphate. After leaching and filtering, the residue was dried and weighed. The results are given in Tables 4 and 5.

5.2.2 Acid Leaching

Soluble potassium sulphate was not first removed, but the calcined material was mixed with the requisite amount of the sulphuric acid and leached with water after reaction had ceased. The results are given in Table 6.

TABLE 2: WATER LEACHING OF ALUNITE-LIMESTONE HEATED AT 500°C

Sample Number	Wt Alunite	Wt $CaCO_3$ (a)	Loss at 500°C (b)		K_2O Leached (c)
			Actual	Theoretical	
	g	g	g	g	%
AL2	25	6.4	4.5	6.6	70
AL3	25	8.5	6.5	8.2	100
AL4	25	4.3	3.9	4.9	72

(a) Limestone. (b) Moisture, combined water, CO_2. (c) Leaching efficiencies are calculated with respect to the total amount present in each sample.

TABLE 3: H_2SO_4 TREATMENT OF GYPSUM-FREE RESIDUES

Sample	Initial Wt	Final Wt	H_2SO_4	Leach Liquor (250 ml)			
				K_2O		Al_2O_3	
No.	g	g	g	g/l	LE(a) %	g/l	LE %
AL2	18.7	5.2	28	0.78	11	23.6	70
AL3	14.8	2.5	28	0.06	-	23.3	70
AL4	18.8	10.0	19	0.59	10	16.4	70

(a) Leaching efficiency.

TABLE 4: WATER LEACHING OF HEATED ALUNITE

Time of heating: 4 hours

Sample	Wt Alunite	Temp	Loss[a]		Leach Liquor (250 ml)			
					K_2O		Al_2O_3	
No.	g	°C	g		g/l	LE[b] %	g/l	LE %
AL 2	10	550	1.7	(1.5)	1.81	62		
AL 3	10	"	1.8	(1.8)	2.51	62	Not determined	
AL 4	10	"	1.3	(1.2)	1.26	63		
AL 2	25	600	4.2	(3.8)	3.35	45	2.8	8
AL 4	25	"	3.6	(3.0)	3.05	50	1.7	7

(a) Figures in parenthesis represent the weight of moisture and combined water in the alunite.

(b) LE - Leaching efficiency.

TABLE 5: H_2SO_4 TREATMENT OF WATER-LEACHED ALUNITE

Time of heating: 4 hours

Sample	Initial Wt	Final Wt	Temp	H_2SO_4	Leach Liquor (250 ml)			
					K_2O		Al_2O_3	
No.	g	g	°C	g	g/l	LE[a] %	g/l	LE %
AL 2	7.6	1.5	550	7.5	1.22	43	10.6	76
AL 3	6.4	0.5	"	7.5	1.37	34	11.4	81
AL 4	8.1	4.1	"	5.0	0.83	35	7.7	77
AL 2	18.9	5.5	600	18.0	4.3	60	24.8	71
AL 4	19.1	11.4	"	13.0	2.05	35	14.9	60

(a) LE - Leaching efficiency.

TABLE 6: H_2SO_4 TREATMENT OF HEATED ALUNITE
Time of heating: 4 hours

Sample	Wt Alunite	Temp	Loss	H_2SO_4	Leach Liquor (250 ml)			
					K_2O		Al_2O_3	
No.	g	^0C	g	g	g/l	LE[(a)] %	g/l	LE %
AL 2	10	550	1.7	6.0	3.21	100	12.9	92
AL 3	10	"	1.8	7.5	3.65	90	12.8	92
AL 4	10	"	1.3	5.0	2.07	87	8.5	84
AL 2	25	600	4.2	18.0	7.8	100	31.6	91
AL 4	25	"	3.6	13.0	5.2	85	18.0	73

(a) LE - Leaching efficiency.

5.3 Reaction of Raw Alunite with Sulphuric Acid

Sufficient sulphuric acid was added to react with alumina according to the equation:

$$K_2SO_4 . Al_2(SO_4)_3 . 4Al(OH)_3 + 6 H_2SO_4 \longrightarrow K_2SO_4 + 3 Al_2(SO_4)_3 + 12 H_2O$$

The H_2SO_4 should react with the $Al(OH)_3$ component of the alunite, that is with 2/3 of the total Al_2O_3, as follow:

$$4Al(OH)_3 + 6 H_2SO_4 \longrightarrow 3 Al_2(SO_4)_3 + 12 H_2O$$

or

$$Al_2O_3 + 3 H_2SO_4 \longrightarrow Al_2(SO_4)_3 + 3 H_2O$$

From these equations, approximately 3 g H_2SO_4 is required per gram Al_2O_3. The acid was added as an aqueous solution containing 1 g H_2SO_4 per ml. The mixture was dried at 100°C, heated for 2 hours at 200°C and finally for 4 hours at 300°C. The sulphated cake was broken up and leached with water. Results are given in Table 7.

TABLE 7: TREATMENT OF ALUNITE WITH H_2SO_4

Sample	Weight Alunite	H_2SO_4	Leach Liquor (330 ml)	
			Al_2O_3	
No.	g	g	g/l	LE[a] %
AL2	25	20	17.7	68
AL3	25	20	17.6	68
AL4	25	14	13.6	74

(a) LE - Leaching efficiency.

5.4 Reaction of Raw Alunite with Potassium Hydroxide

Sufficient potassium hydroxide was added to react with the alumina according to the equation:

$$K_2SO_4 . Al_2(SO_4)_3 . 4 Al(OH)_3 + 6 KOH \longrightarrow 4 K_2SO_4 + 6 Al(OH)_3$$

The potassium hydroxide was dissolved in the minimum amount of water and the solution was mixed with the alunite. After drying at 100°C, the mixture was heated for 4 hours at 400°C, i.e., just above the melting point of potassium hydroxide. The cake was broken up and leached with water. The dried residue was treated with sufficient sulphuric acid to react with the alumina and leached again. Results of acid treatment of the residue are given in Table 8.

TABLE 8: H_2SO_4 TREATMENT OF RESIDUES FROM KOH TREATMENT

Sample No.	Alunite Wt g	KOH Residue Wt g	H_2SO_4 g	H_2SO_4 Residue Wt g	Liquor[(a)] (250 ml) K_2O g/l	Al_2O_3 g/l	Al_2O_3 LE[(b)] %
AL 2	25	13.9	28	4.2	2.1	22.7	65
AL 3	25	11.5	28	1.2	0.2	22.4	65
AL 4	25	17.4	19	10.8	2.1	15.2	62

(a) Liquor from H_2SO_4 treatment
(b) LE - Leaching efficiency.

5.5 Discussion of Decomposition Procedures

5.5.1 Alunite-Limestone Reaction

Weight losses of the mixtures heated at 500°C were less than theoretical and, in fact, all the heated mixtures contained unreacted calcium carbonate. Nevertheless complete recovery of potash was achieved from the Carrickalinga alunite but only 70 per cent from the Yorke Peninsula samples. Only 70 per cent of the alumina was recovered by acid leaching the residues from all samples. Probably more of the potash could be recovered from the Yorke Peninsula alunite by heating the mixtures at a higher temperature (600°C) but the recovery of alumina would not be much improved.

This treatment is not considered to be as effective or as simple as some of the other methods, but it might be of value if the potash had to be removed before recovering the alumina.

5.5.2 Thermal Decomposition of Alunite

The recovery of potash by water leaching of alunite heated at 550 to 600°C was poor for all samples, but slightly better at the lower temperature. The proportion of alumina recovered by acid treatment of the leached material was also lower than expected. Slightly lower recoveries were achieved at the higher temperature, indicating that insoluble compounds were being formed by reaction with gangue material. Because of the relatively large amounts of potash remaining after water leaching, the sulphuric acid solutions contained more potash than was originally expected. Consequently no advantage is seen in the double treatment as opposed to direct treatment of the ignited alunite with sulphuric acid, because the potash would have to be removed in either case.

Direct treatment of the heated alunite with sulphuric acid was more effective than water leaching followed by acid treatment (Table 6). Approximately 90 per cent of both the potash and the alumina were recovered by this treatment, but again there was a slight reduction in efficiency at the higher temperature. This procedure is considered to be the most effective of those investigated. The liquors obtained by sulphuric acid leaching contained Al_2O_3 and K_2O in the approximate proportion by weight of 4 Al_2O_3: 1 K_2O which agrees with the proportion shown in the analysis of Sample AL4.

5.5.3 Reaction of Raw Alunite with Sulphuric Acid

This method of treatment was not as satisfactory as treating the heated alunite with sulphuric acid and was more difficult to apply.

5.5.4 Reaction of Raw Alunite with Potassium Hydroxide

This method could be of interest only if supplies of potassium hydroxide were available at low cost. The low recovery of alumina from the water-leached residue could be partly due to loss of aluminium as aluminate in the alkaline leach liquor. Better separation of potash and alumina could be achieved by controlling the pH of the aqueous liquor to prevent the formation of aluminate. The final acid liquor would still be likely to contain some potassium sulphate which would have to be removed before aluminium sulphate could be recovered.

5.5.5 Selection of Decomposition Procedure

None of the procedures described in Section 5 achieved complete separation of potash and alumina from each other. Hence to produce pure aluminium sulphate further separation would be required, regardless of the procedure adopted. The most effective procedure was that involving prior heating of alunite followed by acid treatment and leaching. By this means, approximately 90 per cent of the potash and of the alumina could be obtained in a solution from which the potassium and aluminium sulphates could be recovered by subsequent treatment.

6. RECOVERY OF POTASSIUM AND ALUMINIUM SULPHATES FROM LIQUOR

In order to examine methods of recovering the potash and the alumina, samples of liquor were prepared by the preferred method of initial decomposition.

6.1 Heat Treatment and Leaching

Portions of alunite AL4, each weighing 200 g, were heated at 550°C for 4 hours, then "sulphated" with sulphuric acid, 100 g being required to convert the Al_2O_3 to $Al_2(SO_4)_3$.

In two separate tests, the acid was added as a 92 per cent w/w solution and as a 50 per cent w/v solution respectively. The 92 per cent acid reacted rapidly with the calcined alunite and the mixture set hard before proper mixing was achieved. With the less concentrated acid, the reaction was slower, hence more effective mixing was possible.

After sulphation, the solids were leached with 500 ml water on a boiling water bath until softened, then stirred at 50°C for 1 hour. The slurry was filtered and washed with water. Samples were taken from the filtrates which were then combined to provide liquor for recovery tests. Results are shown in Table 9.

TABLE 9: HEAT TREATMENT AND LEACHING
Alunite heated at 550°C
Time of heating: 4 hours

Sample	Alunite Weight	Loss on Heating	Leached Residue	Liquor (1600 ml)			
				K_2O		Al_2O_3	
No.	g	g	g	g/l	LE[a] %	g/l	LE %
AL 4	200	26	91	5.9	80	25.1	81
AL 4	200	26	84	6.4	86	26.0	85

(a) LE - Leaching efficiency.

6.2 Treatment of Liquor

Two methods were considered for recovering the potash and the alumina viz: -

a. Direct evaporation in stages, recovering products which crystallised after each stage.

b. Neutralization of the liquor to precipitate aluminium hydroxide leaving the potassium sulphate in the liquor.

6.2.1 Direct Evaporation of Liquor

One litre of the combined liquor was evaporated in stages and allowed to stand at ambient temperature overnight between stages. Any crystals which deposited were filtered on dry paper on a Buchner filter and sucked dry. The volume of the filtrate was recorded at each stage. Each batch of crystals was given a rapid wash with water which was then added to the filtrate before continuing the evaporation. The crystals were dried at 60°C, weighed and assayed for K_2O and Al_2O_3. Results are given in Table 10.

TABLE 10: RECOVERY OF SALTS BY EVAPORATION OF LIQUOR

Initial liquor: Volume 1000 ml
K_2O 6.15 g/l
Al_2O_3 25.6 g/l

Crystalline Products						Liquor in Equilibrium with Salt				
Weight	K_2O		Al_2O_3		Al_2O_3/K_2O [b]	Volume	K_2O [a]		Al_2O_3 [a]	
	Weight	Recovered	Weight	Recovered			g/l	Remainder	g/l	Remainder
g	%	%	%	%		ml		%		%
10	13.5	22	14.4	6	1.07	750	6.4	78	32.3	94
16	14.6	38	15.7	10	1.08	560	4.4	40	38.7	84
15	12.9	31	14.3	8	1.11	170	3.1	9	115.3	76
41 (c)	0.67	5	15.3	60	-	75	3.5	4	57.3	16

(a) By difference.
(b) Al_2O_3/K_2O in potassium alum = 1.07.
(c) Fe_2O_3 0.13%

6.2.2 Precipitation of Alumina

Two procedures were considered:

a. Neutralising with calcium hydroxide ($Ca(OH)_2$)
b. Neutralising with ammonium hydroxide (NH_4OH)

Neutralising with Calcium Hydroxide. A portion of the combined liquor was treated with a water slurry of commercial hydrated lime, "Limil", to raise the pH to 5.0. All the aluminium was thus precipitated together with gypsum. Mixed crystals of potassium and calcium sulphates were obtained from the filtrate by evaporation.

The aluminium hydroxide containing gypsum was dissolved in sufficient sulphuric acid to reduce the pH to 2.5. There was a pronounced tendency for reprecipitation of gypsum to occur in this solution even after filtering. Further consideration was deferred in favour of the procedure using ammonium hydroxide.

Neutralising with Ammonium Hydroxide. Aluminium was precipitated as hydroxide from 1 litre of the liquor by adding aqueous ammonia until the pH was 7.0. The precipitate was filtered under suction and washed by displacement with water. By evaporating the filtrate to dryness a mixture of ammonium and potassium sulphates was obtained. This product contained approximately 10 per cent K_2SO_4. The aluminium hydroxide was dissolved by adding H_2SO_4 until the pH remained steady at 3.3. The resulting solution was evaporated to low volume to allow aluminium sulphate to crystallize. Although the aluminium hydroxide dissolved completely, the amount of H_2SO_4 added was insufficient to form $Al_2(SO_4)_3$, consequently some "basic" sulphate was present in the product. The crystals were filtered under suction without washing, dried at 110°C and weighed. A partial analysis of the dried sulphate is given below:

Weight of product dried at 110°C : 75 g

Component	%	
Insoluble	0.12	
Fe_2O_3	0.17	
Al_2O_3	24.7	SO_3/Al_2O_3: 2.28
SO_3	44.2	
H_2O above 100°C	30.0	

6.3 Discussion of Recovery Procedures

By direct evaporation of the sulphate liquor, a fairly sharp separation was obtained. The first products consisted of potassium alum (Al_2O_3/K_2O = 1.07) but 60 per cent of the aluminium was recovered as fairly pure aluminium sulphate containing only 0.67 per cent K_2O. Doubtless the proportion of aluminium recovered as sulphate could be increased by returning the residual mother liquor to the leaching circuit. Approximately 25 per cent of the aluminium was combined in the potassium alum.

Two products were obtained also by precipitating the aluminium as hydroxide with aqueous ammonia and then redissolving the precipitate in sulphuric acid. The product obtained by evaporating the filtrate to dryness consisted mainly of ammonium sulphate containing approximately 10 per cent potassium sulphate. The partly "basic" sulphate recovered by evaporating the redissolved hydroxide contained approximately 75 per cent of the aluminium in the liquor, but this proportion also could be increased by recycling the mother liquor.

Probably at least 75 per cent of the aluminium in the liquor could be recovered as sulphate by either procedure. The impurity levels in products should come within the limits quoted for ordinary grade aluminium sulphate, but improvement could possibly be effected by recrystallization. The choice of procedure would depend on the nature of products required. By direct evaporation, potassium alum and aluminium sulphate could be recovered in fairly pure form while, by precipitating the aluminium as hydroxide, mixed ammonium-potassium sulphates and aluminium sulphate would result. Unless the potassium alum could be sold as such, it would have to be treated to separate the potassium and aluminium. In this event, the ammonium hydroxide precipitation route would appear to be more attractive but, again, this would depend on the probable demand for mixed ammonium-potassium sulphates to be used as a fertilizer.

7. CONCLUSION AND RECOMMENDATIONS

Although the alunite from Yorke Peninsula is of low grade, about 80-90 per cent of the potassium and aluminium could be recovered. The most favoured procedure involves heating at 550°C followed by leaching with sulphuric acid to effect solution of aluminium and potassium. Subsequent treatment of the liquor would depend on the products required, e.g.,

a. Direct evaporation to produce two main products:

   i. potassium alum
   ii. aluminium sulphate

   The alum could be treated by procedure (b) if necessary.

b. Precipitation of aluminium as hydroxide with aqueous ammonia and separation by filtration or a similar technique. The products would be:

   i. ammonium sulphate containing about 10 per cent potassium sulphate

   ii. aluminium sulphate

No attempt has been made to determine the cost of producing aluminium sulphate and possible by-products. Much would depend on the quantity and grade of the alunite available, and the cost of mining and handling. However, if further consideration is to be given to the possibility of producing aluminium sulphate and other products from alunite, the following course of action is recommended:

1. The extent of the deposit in the Hundred of Ramsay (or of any other deposits which may be considered to have potential value) should be determined. The survey should be sufficiently comprehensive to indicate the approximate quantity and grade of the alunite and the approximate cost of mining and handling.

2. If sufficient alunite is available and readily accessible, the deposit (or deposits) should be sampled to provide material for further development. Probably up to 20 tons of alunite would be required.

3. Subject to the preceding stages being satisfactorily accomplished, a pilot-scale evaluation should be made of the recommended procedure referred to above. The estimated cost of this evaluation is £5,000.