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CHARACTERISTICS AND UTILIZATION OF THE KAOLIN CLAYS IN HAT CREEK COAL

Fifth Report

Jan. 1, to August 31, 1978

sponsored by B.C. Hydro

DEPARTMENT OF METALLURGY

VANCOUVER, BRITISH COLUMBIA • CANADA

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"CHARACTERISTICS AND UTILIZATION OF THE KAOLIN CLAYS IN HAT CREEK COAL"

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(January 1, to August 31, 1978)

(Under the Sponsorship of B.C. Hydro and Power Authority)

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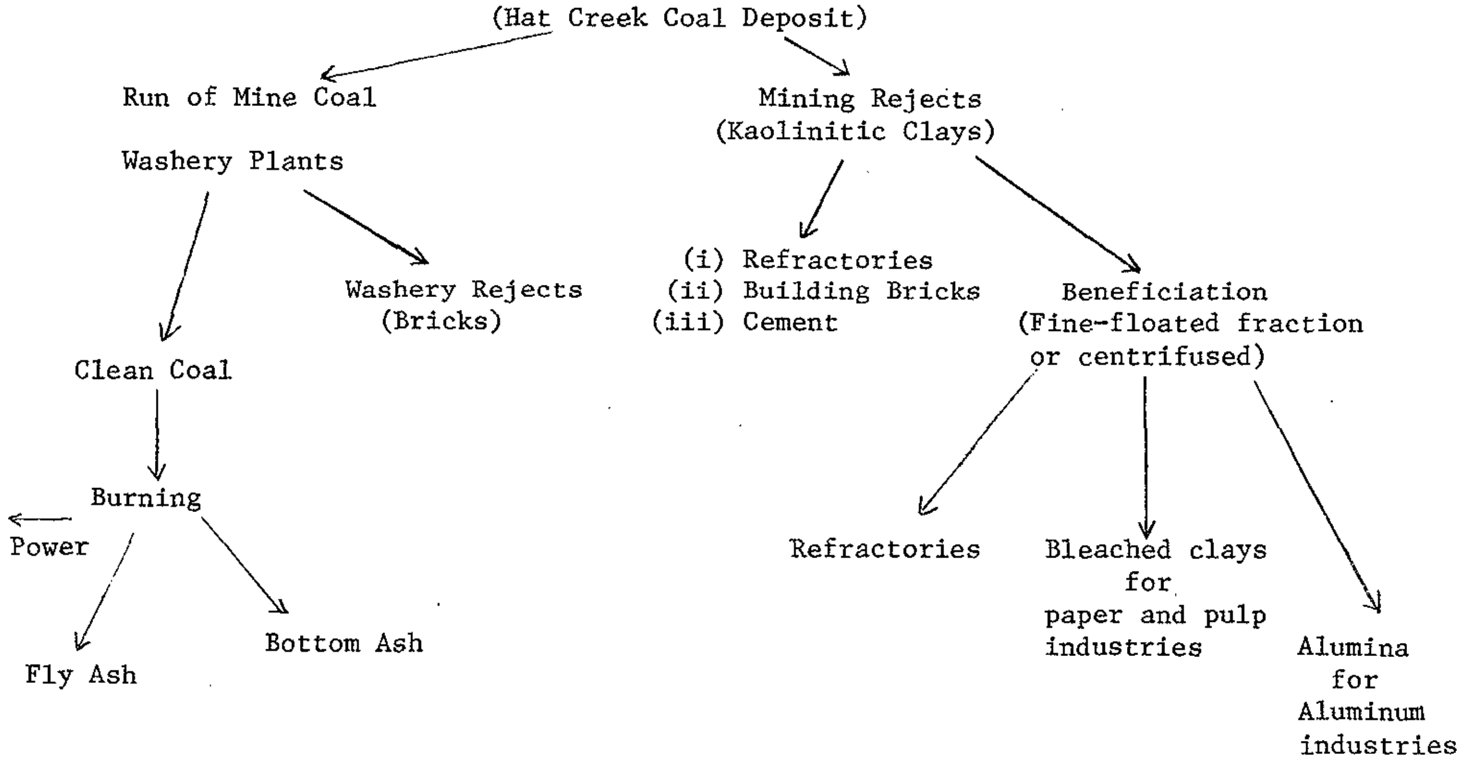
Abstract

In this investigation efforts were mainly concentrated on the possible utilization of materials generated when mining the Hat Creek coal deposit. Other materials, such as washery refuses generated from this coal after cleaning from a coal-washery plant, have also been investigated for their possible uses. No work has been done to-date on the ash materials (both bottom and fly ash) which would be produced in large quantities, if this coal is used for power generation.

The total utilization can be schematically illustrated by a flow sheet as shown below:

Possible Material Utilization



It has been shown that kaolinitic clay exists in large concentration in the Hat Creek coal deposit, particularly in the lower section of the deposit and in several foot thick bands. Bentonitic clay exists throughout the deposit, in the overburden, in the hanging walls and in larger concentrations in the upper part of the coal measures.

It is expected that the kaolinitic clays can be mined out separately without being mixed up with bentonitic clays. The technical possibility of utilizing mined clays (mostly kaolinitic) and washery refuse clays (mixture of kaolinitic and bentonitic clays) has been explored. Attempts were made to generate products of commercial and industrial interests from the kaolinitic clays of the Hat Creek deposit.

A. Kaolinitic clays - as received (raw materials)
   1. Refractory bricks (may also be used as building bricks) products
   2. Cement

B. Kaolinitic clays - after beneficiation (raw materials)
   1. Refractory bricks (high quality)
   2. Al_2O_3 extraction for Al- and refractory industries products
   3. Bleached clay for paper and pulp industries.

C. Clays from washery Plants (raw materials)
   1. Building bricks ... ... products

The aforementioned products have been successfully produced and it appears that there is no technical barrier to manufacture these products. No economic assessment of these processes has been made. As there will always be demands for high-grade kaolinitic clays, it can be assumed that this type of clay (kaolinitic) will always find a market for use in secondary industries.

The quality of bentonitic clays as received from the washery plant is limited to the use of making bricks for the building brick industries.

The attached figure (Figure 0A) shows the products that have been successfully generated from the mined clays (kaolinitic) and washery refuse (mixed clays) of the Hat Creek deposit.

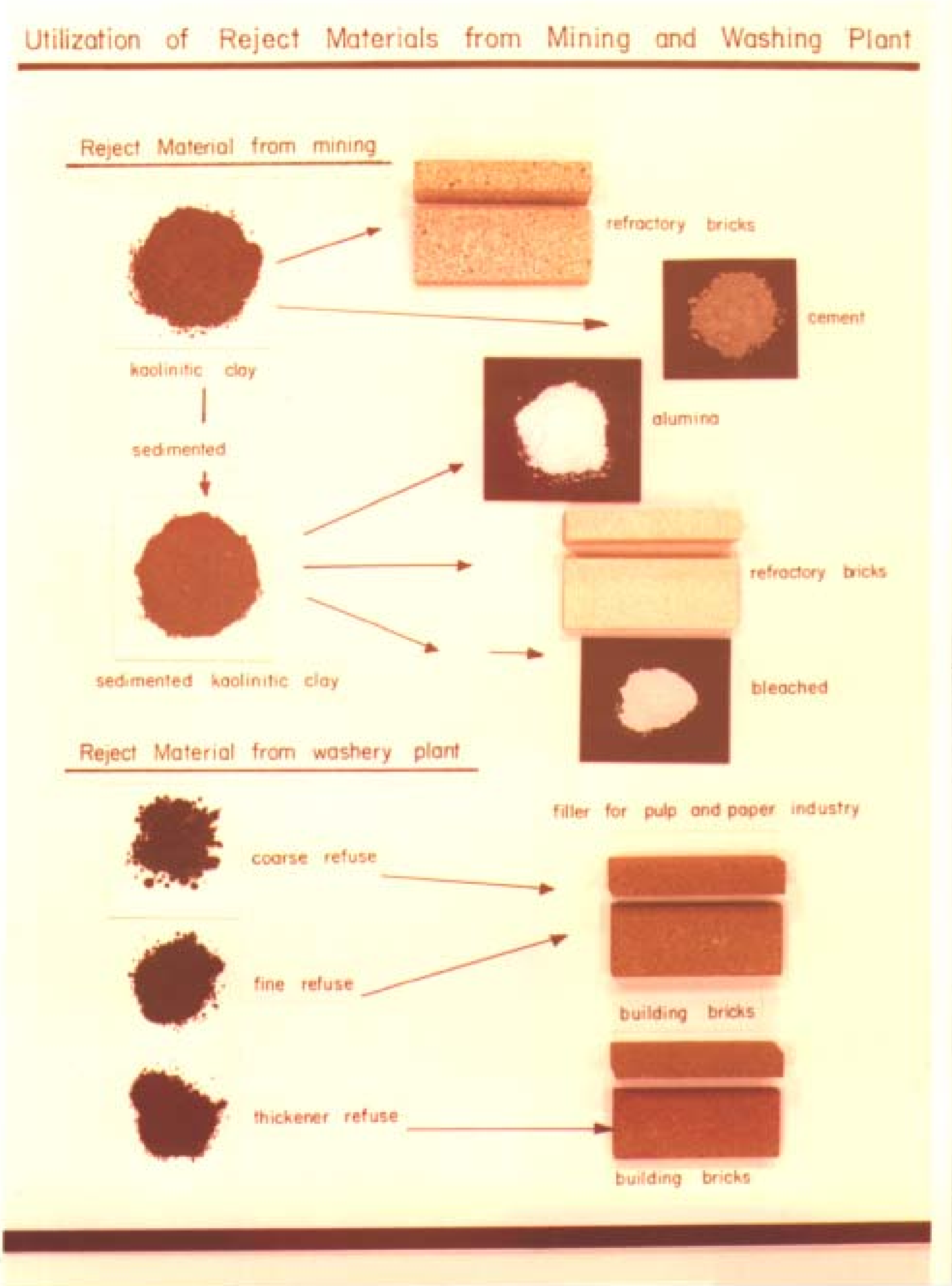

Utilization of Reject Materials from Mining and Washing Plant
Reject Material from mining
refractory bricks
cement
kaolinitic clay
sedimented
alumina
refractory bricks
bleached
sedimented kaolinitic clay
Reject Material from washery plant
filler for pulp and paper industry
coarse refuse
fine refuse
building bricks
thickener refuse
building bricks

Figure 0A

Table of Contents

Part II

Introduction

Previous Research Results

This being the fifth report of the Hat Creek coal research project carried out in the Department of Metallurgy, U.B.C., during the period of September, 1, 1976 to August, 31, 1978, it is intended to write a short note summarizing the results obtained to date on the overall investigation.

The work was originally started to investigate the mineral matter content and gross properties of Hat Creek coal. Using quantitative X-ray analyses on a large number of core samples from a number of diamond drill holes and at different depths, it has been established that Hat Creek coal contains a large array of inorganic minerals, essentially consisting of kaolinite, quartz, bentonite and siderite. Small quantities of other minerals, e.g., feldspar and pyrite were also found to be present. Highly concentrated zones of calcite, goyazite and ankerite were also encountered but they are all present in bands. Furthermore, it has been concluded from the analyses that the concentration of kaolinite increases as a function of stratigraphic depth, whereas the bentonite concentration decreases. Kaolinite also occurs in bands (i.e. in several feet thick seams). However, it appears that most of the kaolinitic clays are primarily concentrated in the lower part of the deposit.

The extent of the inorganic minerals content in the Hat Creek coal deposit was found to vary widely - from 6% to ~100% by weight. This means that about one-half of the coal deposit is mainly composed of clays, sand and other minerals. To burn this coal, as present in the deposit, entails a significant amount of energy loss to dehydroxylate the clay minerals [$Al_2Si_2O_s(OH)_2 \xrightarrow{\sim 600°C} Al_2Si_2O_7 + 2H_2O$ - endothermic reaction of ~40Kcal/mole] using up to 500 BTU/lb of clay or carbonates, and generating a huge quantity of ash in the process. Even a partial success in removing these minerals will increase the efficiency of power generation from this coal by two ways:

(i) less energy will be wasted to dry and dehydroxylate (or decarbonate) the minerals and subsequent fusion to produce clinkers and; (ii) increasing the heat-content per unit mass of coal burnt. Another aspect which should be considered is the large amount of minerals present if can be removed or separated out of the coal, may find useful markets for ceramic industries.

The success of inorganic minerals removal by washing depends very much on the degree of intergrowth of minerals in organic coal. It is well-known that the size of a coal generally influences its washability characteristics. Therefore, to choose the most suitable top size for washing, knowledge of the dispersion of the minerals and the thickness of the different coal macerals in Hat Creek coal would be useful. Some quantitative X-ray analyses performed on several samples of different size fractions indicate that these minerals are present in very finely powdered form.

It appears that the Hat Creek coal deposit can be classified into several groups of coal. So far six different groups of coal with ash content as low as 6% (db*) to as high as ~69% (db) have been encountered. It is surmised that the whole deposit, which consists of four zones - A, B, C and D, is mainly composed of admixtures of these coal groups in different proportions. However, the exact proportion of each of these coal groups in any particular zone has not been determined.

The washability characteristics of a coal is perhaps the most important tool available to determine the extent to which a coal may be cleaned. Examination of washability data for a particular coal or for a particular size of coal will reveal the quality of coal which may be obtained by mechanical cleaning as well as the quantity of coal of a particular quality.

First of all, water washing (along with stirring) alone of Hat Creek coal will reduce the inorganic mineral content (i.e. ash content) by ~10% by weight. For better cleaning, washing with specific gravity fluids (or equiv-

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*db - dry basis

alent) will be necessary.

From the washability curves generated in this research programme, it has been observed that the amount of recovery increases with decreasing sample top sizes, the amounts of recovery remain constant from 1.5 to 1.9 S.G.* fluids. The near gravity material is almost zero between 1.6 and 1.8 S.G. for all samples. This indicates that the coal can be cleaned by washing.

The important aspect of washability is the recoverable heat content. It is found that the total recoverable heat content per pound of washed coal is highest within 1.45 to 1.9 specific gravity range with only ~5% loss of the heat content at sample size ≲0.25".

In terms of mineral differentiation in washing it was found that both the weight percentages of kaolinite and bentonite in the sink fraction decreases with decreasing sample top size. But the concentration of bentonite with decrease of sample top size decreased at a faster rate than that of kaolinite. This means that sink fractions of sample top size ≲ 0.25" is more desirable to recover kaolinite by washing. The weight % distribution of the two major inorganic minerals - kaolinite and bentonite remains constant at 1.45 to 1.7 specific gravity fluid separation.

Current Research Objectives

With this background, it was proposed that characteristics of the kaolinitic clays in Hat Creek coal and its utilization to generate secondary industries in B.C. should be investigated. It has been planned also that attempts should be made to separate the kaolinitic clay component from other inorganic minerals and study its properties. Finally, development of numerous

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*S.G. - specific gravity

products would be tried to study the feasibility of utilization of this kaolinitic clay.

In this study it was also decided that a large batch of clay should be produced and supplied to the Clayburn Industries Limited (Abbotsford), B.C., for further testing.

It should not be out of place to mention here that kaolinitic and montmorillonitic clays are being used in a wide variety of products now-a-days. Conventionally, as everyone knows, clays are used in bricks, potteries, sanitary wares, pipes and vases.Better quality clays are used in refractories. In addition, clays are major constituents in cement industries (both Portland cement and high temperature réfractory cements). Very pure and white clays are used for paper coating (high quality papers contain a significant proportion of clay) and as fillers in paper and pulp. Clays are also being used as fillers in paints, varnishes and rubber. Very pure clay (kaolinitic) is also added in food and drugs. Montmorillonitic clays can be used as a bleaching agent, as normally they have high ion exchange capacity. Swelling type montmorillonite (bentonite) is being used as a fire-retardant. Clay-based granules are used as catalysts. Both clays can be very useful sources of Al_2O_3, which is the raw material for aluminium. Low grade clays are normally used for building bricks. From this it is apparent that clay is a very useful raw material for a large number of industries.

In view of the fact that clays are such a useful raw material, the investigation was primarily concentrated on the study of possible uses of clays from the Hat Creek coal deposit.

Raw Materials

In this research project two groups of raw materials were used:

1. clays from mining rejects, and
2. rejects from washery plant

#1 Clays from Mining Rejects

The reject material from mining was supplied in a big steel drum weighing -800 lbs. This material (Fig.1) came from the D zone of B trench of the Hat Creek deposit. This material was supplied for testing as large quantities of this material will be produced when mining the coal. Unless some ways of utilizing this material can be found, disposal of this material may eventually

Figure 1 - Mining Rejects

become a problem and mining cost of the gangue material may be reduced if this clay material can be sold.

#2 Rejects from the Washery Plant

Rejects are supplied from the washery plant (Fig. 2) at the Science, Mines & Resources of Canada in Alberta. In this laboratory a pilot plant cyclone is used to wash the Hat Creek coal on a large scale. The refuses, supplied for testing here, consist of a total of thirty one bags, but actually there were only fourteen samples, of which eight are coarse refuse, four are fine refuse and one thickener refuse. They are identified as follows:

Table I

Samples Received Number of Bags	Sample No.
2	HC TI CR
2	HC TII CR
1	HC TIII CR
2	HC TIV CR
5	HC TV CR
5	HC TVI CR
3	HC TVII CR
5	HC TVIII CR
1	HC TIII FR
1	HC TIV FR
1	HC TVIII FR
1	HC TVI Thickener II

Figure 2 - Rejects from the Washery Plant

coarse refuse

fine refuse

thickner refuse

Experimental Procedures

(i) As-Received Materials

i. Mining Rejects

The drum of clay supplied was well mixed using a splitter. One eighth of the drum was pulverized to -100 mesh and this constituted the as-received sample for testing.

The kaolinitic clay has chemical composition* of approximately 46% SiO_2, 25% Al_2O_3, 3→4% Fe_2O_3 and 1% TiO_2. Mineralogical analyses* by the X-ray diffraction technique have shown that this material contains about 70% kaolinite and 30% quartz. Concentration of kaolinite can be increased up to 80→90% by sedimentation methods. The alumina (Al_2O_3) content is about 29→30% at 80→90% kaolinite.

The high percentage of kaolinite in the mining reject material lends itself to the refractory, alumina, cement and paper industries. Two batches of sample were prepared for the investigation. These are, 1) as-received kaolinitic clay having the above mentioned composition and, 2) two-hours sedimented kaolinitic clay having 74% kaolinitic and 26% quartz and particular size of < 4.5 micron. Cement and good quality bricks have been produced with the as-received material. Bleached clay for paper filler, refractory bricks and alumina for the refractory industry have been produced with the two-hour sedimented clay sample.

The as-received sample was placed in water, approximately 1-part sample to 50 parts water and mixed. It was stirred mechanically for over 4 hours at 40RPM and then allowed to settle. The suspended portion after 2-hours sedimentation was siphoned off, dried and ground. This constituted the two-hours sedimentation sample. Duplicates were made. Particle size and mineral distributions were determined on these samples after sedimentation tests.

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*see Table

The results are shown in Tables II and III and also in Figure 3.

Table II (A)

Batch C: Particle Size and X-ray Analyses of Sedimented Clays

Sample Nos.	Diameter of particles $(cm)X10^{-3}$	Settling time (secs.)	Settling time (hrs.)	Quantitative X-ray analysis		Wt.%
CAA,C1,C3	6.15→3.15	0→180	0→.05	70K	30Q	3.74
C4,C5,C6,C7	2.88→1.82	260→600	.072→.17	68K	32Q	8.89
C8,C9,C10,C11	1.58→1.22	780→1200	.22→.33	68K	32Q	12.1
C12,C13,C14,C15	1.12→ .871	1380→2100	.38→.58	72K	28Q	15.3
C16→C20	.80→ .37	2400→9900	.67→2.75	73K	27Q	24.2
C21→25	.136→ .107	6.9→9.02(10^4)	19.2→ 25.1	82K	18Q	50.8
CT	<.107	<9.02(10^4)	>25.1	92K	8Q	79.5
CB	>6.15	<60	<.017	63K	37Q	-

Table II (B)

Batch D:

Sample Nos.	Diameter of particles $(cm)X10^{-3}$	Settling time (secs.)	Settling time (hrs.)	Quantitative X-ray analysis		Wt.%
DAA,D1,D3	6.15→3.15	0→180	0→.05	70K	30Q	1.98
D4,D5,D6,D7	2.88→1.82	260→600	.072→.17	71K	29Q	8.58
D8,D9,D10,D11	1.58→1.22	780→1200	.22→.33	71K	29Q	10.7
D12,D13,D14,D15	1.12→ .871	1380→2100	.38→.58	71K	29Q	15.2
D16→D20	.80→ .37	2400→9900	.67→2.75	74K	26Q	22.5
D21→D25	.136→.107	6.9→9.02(10^4)	19.2→25.1	80K	20Q	50.2
DT	<.107	>9.02(10^4)	>25.1	92K	8Q	78.1
DB	>6.15	<60	<.017	60K	40Q	-

Cumulative Weight % As Function of Log of diameter of particles

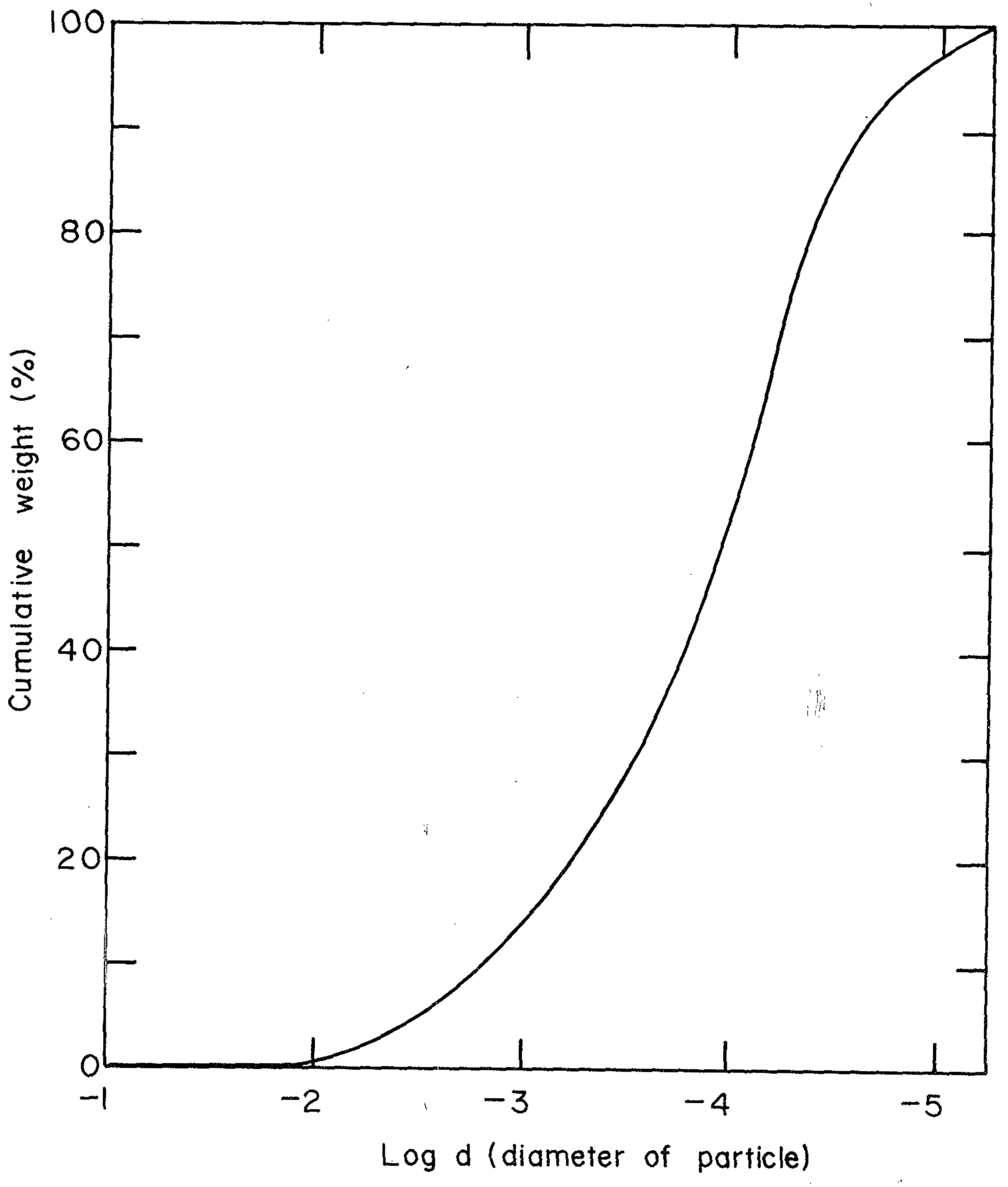

Table III

Chemical Analysis of Kaolinitic Clay+

	As-received Sample		2-Minutes Sedimented Sample		19 Hours Sedimented Sample	
	*	**	*	**	*	**
SiO_2	46.48	60.69	43.61	59.93	49.45	59.89
Al_2O_3	24.47	31.95	23.98	32.95	29.59	35.84
Fe_2O_3	3.83	5.00	3.66	5.03	1.93	2.34
K_2O	.21	.27	.22	.30	.24	.29
Na_2O	.12	.16	.08	.11	.12	.14
TiO_2	.98	1.28	.80	1.10	1.07	1.30
MgO	.26	.34	.22	.30	.06	.07
CaO	.24	.31	.20	.28	.11	.13
	76.59	100	72.77	100	82.57	100

* The balance is water for all three samples.

** On dry basis

\+ Chemical analysis by Cantest of Vancouver

(ii) Washery Refuses

Samples used for analyses are dried at 105°C and ground to -100 mesh. Analyses performed include mineral analysis by X-ray diffraction, proximate analysis by thermogravimetric technique (TGA), and elemental identification by scanning electronmicroscopy (SEM).

Mineral analyses have been performed on all of the samples. The mineral contents of the three types of refuses are very similar. The major minerals are kaolinite, quartz, and bentonite while the minor minerals are feldspar, siderite and gypsum. Siderite and gypsum occur only in some of the samples and only in traces. No attempt has been made to quantitatively determine these minerals.

Proximate analysis of the refuse shows that there are definite differences in the fixed carbon and ash contents between the coarse and fine refuses. The coarse refuse has volatile[b] content of 25→28% db, fixed carbon of 9→14% db, and ash content of 58→62% db. On the other hand, the fine refuse has volatile[b] content of 28→33% db, fixed carbon of 14→22% db, and ash content of 46→58% db. It seems then, the coarse refuse has slightly lower volatile, lower fixed carbon and higher ash contents than the fine refuse. The difference among samples of the coarse refuse or the fine refuse themselves is probably dependent on the history of the samples.

There is only one thickener sample, sample number HC TVII Thickener II. Proximate Analysis of this sample shows that it has 34% volatile[b], 12% fixed carbon and 54% ash (db).

Analyses of rejects from the washery plant are presented in Table IV below.

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[b] volatile and dehydration of clay.

Table IV

Sample No.	Proximate Analysis**		(db)	X-ray Analysis+	Elemental Analysis by SEM
	Volatile & Deh.*	Fixed Carbon	Ash		
HC T1 CR	-	-	-	K,Q,B,F,G(t)	Si,Al,Fe,Ca, K,Ti,S
HC T11 CR	27.8	13.9	58.3	K,Q,B,F,G(t)	" "
HC T111 CR	-	-	-	K,Q,B,F,G(t)	" "
HC T1V CR	-	-	-	K,Q,B,F,G,S(t)	" "
HC TV CR	-	-	-	K,Q,B,F,G(t)	" "
HC TV1 CR	28.6	8.8	62.6	K,Q,B,F,G,S(t)	" "
HC TV11 CR	25.4	12.4	62.3	K,Q,B,F,G	" "
HC TV111 CR	-	-	-	K,Q,B,F,G(t),S(t)	" "
HC T111 FR	31.4	16.4	52.3	K,Q,B,F,G(t),S(t)	" "
HC T1V FR	30.3	18.7	51.	K,Q,B,F,G(t)	" "
HC TV FR	-	-	-	K,Q,B,G,F,S(t)	" "
HC TV111 FR	32.6	21.5	45.9	K,Q,B,G,F	" "
HC TV11 Thickener II	34.	12.2	53.8	K,Q,B,F	" "

* Volatile & Dehydration of clay

** Sample dried at 105°C

\+ Listed in decreasing quantities; comment: X-ray diffraction peaks are weak.

K - kaolinite; Q - quartz; B - bentonite; F - feldspar;

G - gypsum; S - siderite (t) trace only

Part I - Utilization

A. As-Received Kaolinitic Clay Used in the Production of

1) refractory bricks
2) cement
3) mullite

1) Refractory Bricks:

Refractory clays are those clays with a high resistance to heat which enables them to be used at high temperatures, 1500°C→1600°C. These clays should also have resistance to molten metals and slags and the capability of withstanding high thermal or mechanical stresses.

In the refractory industry, conventional articles such as bricks, tiles, crucibles, stoneware vessels and furnace linings are manufactured from clays. In addition, increasing demands are being made by the users in the metallurgical, carbonising and other industries for materials capable of withstanding more severe conditions.

The refractories of alumino-silicates, such as kaolinite, are very largely dependent on the ratio of their alumina to silica content. In general, the higher the alumina content of the clay, the greater is the refractoriness. Certain oxides such as silica, lime, magnesia, alumina, zirconia are highly refractory but their behaviour depend chiefly on the amount of impurities present, as comparatively small proportions of these seriously reduce the refractoriness. The refractoriness of many fireclays can be implied from the ratio of their contents of alumina and silica.

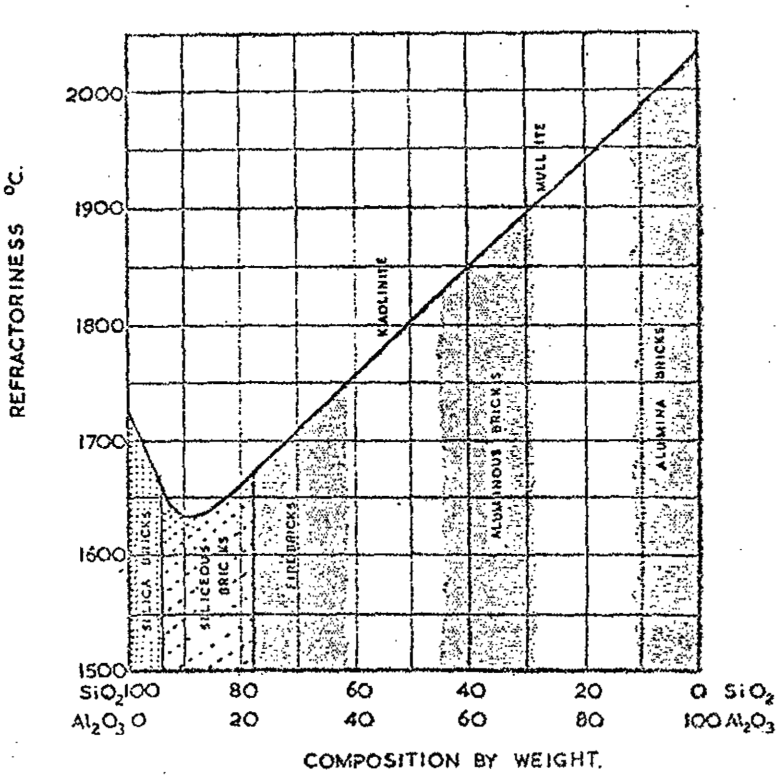

Figure 2: The Refractoriness of Commercial Alumino-Silicate Materials (after Mellor and Green)

As-received kaolinitic sample has approximately 70% kaolinite and 30% quartz. Therefore the alumina and silica contents are 28% and 60%* respectively. Bricks made from this material would fall into region of "firebricks", as can be seen from Figure 2.

*balance is water (kaolinite $Al_2O_3.2SiO_2.2H_2O$)

Experimental

A batch of 120g. of as-received kaolinitic clay is mixed thoroughly with ~13 ml water and .5 ml of kerosene. The sample should barely stick together when pressure is applied. 20 g each is poured into the die and pressed at 10,000 psi[d] pressure to form bricks. They are numbered and dried at 105°C. The dimensions of these bricks are recorded then fired at 1200°C for two hours. After firing colour changes are noted and dimensions are recorded. These specimens are crushed to -18 mesh and used as grog in the next section below.

Calcined clay[f] is then prepared by firing the as-received sample at 500°C until the samples are oxidized.

A 50-50 mix of 1200°C grog[f] and calcined clay, in addition, 10% bentonite and 10% of as-received kaolinitic clay are blended together thoroughly (Series B). About 10%→15% by weight of water is added gradually with splashes of kerosene. This should be a barely moist mixture. Approximately 50 g of the sample is poured into the die and pressed at 15,000 psi[e]. This is weighed and dried. The dimensions and weights of the dried bricks are recorded. A total of about 14→15 bricks are made. Then these are fired at 1200°C in a large furnace having firing characteristics as that of Clayburn kilns. The heating period takes about two days. The weight and dimensions of the bricks after firing are again recorded.

Two bricks numbered AV and AV1 are prepared slightly differently. A 50-50 mix of 1200°C grog. and calcined clay, 10% as-received kaolinitic clay and 10% ball clay[f] instead of 10% bentonite are blended thoroughly. The mixing, pressing, drying and heating procedures are exactly the same as mentioned above.

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[d] small die is used

[f] see appendix

[e] big die is used

Another two bricks numbered A111 and A1V are prepared differently. A 50-50 mix of 1200°C grog. and calcined clay, 10% as-received kaolinitic clay and 10% Hat Creek clay samples numbered 74-44-2120[g] and 74-29-625[h] are blended thoroughly. All other preparation procedures are exactly the same as the one mentioned.

Bricks numbered A1 and A11 are prepared by mixing 50-50 of 1200°C grog and calcined clay.

Results: The results of calcining clay at 1200°C with respect to these dimensional changes are used in Table IV.

Table IV

	Length (cm)			Width (cm)			Height (cm)			Volume				
Sample #	as-received	Dried at 105°C	Fired at 1400°C	as received	Dried at 105°C	Fired at 1400°C	as-received	Dried at 105°C	Fired at 1400°C	as-received	after drying	% reduction	after firing	% reduction
I	6.32	6.29	5.85	.952	.954	.90	1.646	1.625	1.65	9.903	9.751	1.53	8.687	10.9
II	6.354	6.304	5.70	.95	.952	.90	1.66	1.656	1.66	10.020	9.938	6.39	8.516	14.31
III	6.31	6.284	5.80	.95	.95	-	1.612	1.598	1.61	9.663	9.540	1.27	-	-
IV	6.308	6.28	5.85	.95	.95	.87	1.582	1.59	1.58	9.480	9.486	-	8.041	15.23
V	6.34	6.268	5.87	.952	.944	.87	1.652	1.64	1.65	9.971	9.704	2.68	8.426	13.17
VI	6.35	6.288	5.92	.962	.95	.91	1.626	1.634	1.63	9.933	9.761	1.73	8.781	10.04

[g] mineral analysis: bentonite, feldspar, quartz

[h] mineral analysis: bentonite, feldspar, kaolinite, quartz

Table V shows the dimensional change of some of the bricks prepared as outlined above.

Table V

	Weight of Sample (g)		Length (cm)		Width (cm)		Height (cm)		Volume (cm^3)			Bulk Density
Sample #	after drying	after firing	Dried at 105°C	Fired at 1200°C	Dried at 105°C	Fired at 1200°C	Dried at 105°C	Fired at 1200°C	after drying	after firing	% reduction	after firing (g/cm^3)
AV	49.2	47.3	7.708	7.526	1.320	1.286	3.176	3.12	32.314	30.197	6.6	1.56
AV1	49.	46.9	7.684	7.494	1.314	1.292	3.190	3.116	32.209	30.170	6.3	1.55
B1*	50.9	49.1	7.672	7.504	1.380	1.33	3.186	3.126	33.731	31.198	7.5	1.57
B11	50.9	49.1	7.702	7.536	1.376	1.33	3.188	3.120	33.786	31.271	7.4	1.57
B111	51.	49.1	7.678	7.516	1.422	1.340	3.188	3.118	34.807	31.403	9.8	1.56
B1V	51.	49.1	7.698	7.530	1.388	1.328	3.188	3.110	34.063	31.100	8.7	1.58
BV	51.	49.1	7.666	7.476	1.370	1.332	3.182	3.116	33.419	31.029	7.2	1.58
BV1	51.2	49.5	7.686	7.512	1.376	1.344	3.188	3.128	33.716	31.581	6.3	1.57
BV11	51.2	49.8	7.674	7.50	1.40	1.346	3.192	3.124	34.294	31.537	8.0	1.58
1BV	41.3	39.8	7.660	7.51	1.098	1.096	3.19	3.12	26.830	25.681	4.3	1.55
1BV1	41.8	39.9	7.690	7.526	1.120	1.094	3.176	3.098	27.354	25.507	6.8	1.56
1BV11	41.9	40.1	7.67	7.512	1.134	1.10	3.20	3.108	27.833	25.682	7.7	1.56
1BV111	41.7	40.	7.664	7.482	1.144	1.084	3.198	3.118	28.039	25.289	9.8	1.58
1B1X	41.9	40.1	7.67	7.50	1.112	1.104	3.186	3.106	27.174	25.718	5.4	1.56
1BX	42.2	40.6	7.698	7.496	1.126	1.110	3.174	3.10	27.512	25.794	6.2	1.57

Sample #	AV,AV1, B1 → BV11	starting sample weight ≈55g
	1BV → 1BX	starting sample weight ≈50g

*Series B

Discussion:

On the whole, the bricks produced from various mixtures are very similar in texture with slight difference in colours. The moisture loss from drying, volume shrinkage after firing, and bulk density are approximately 5%, 7.3% and 1.57 g/cm^3, respectively.

Shown below are bricks produced from 50-50 mix of 1200°C grog and calcined clay, 10% as-received kaolinitic clay and 10% Hat Creek clay samples numbered 74-44-2120' and 74-29-625'. The colour is yellowish with dark spots. The dark spots are due to the presence of iron oxide and fused materials.

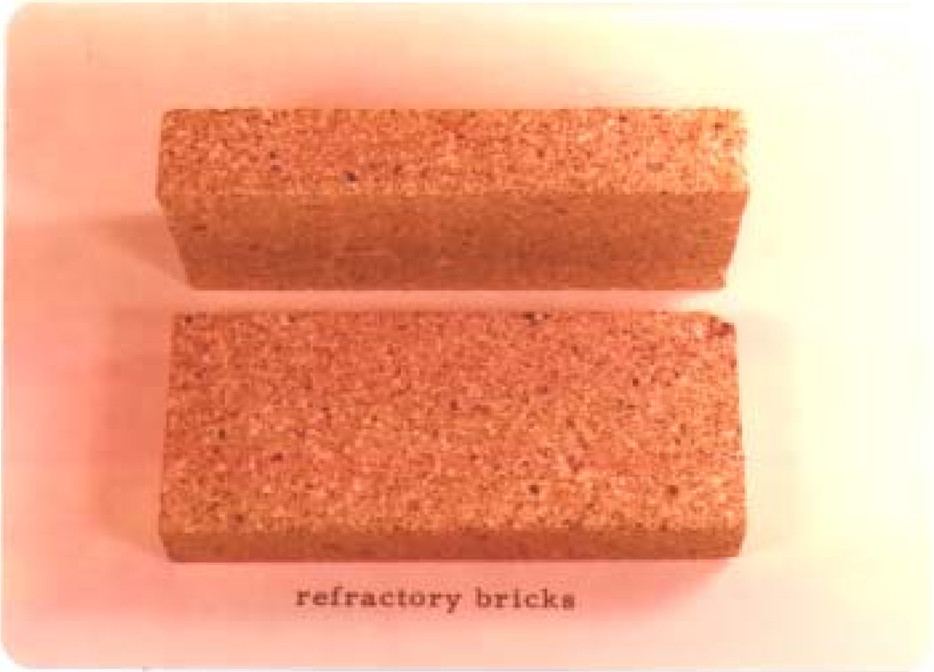

Figure 4

The colour of the bricks made from 50-50 mix of 1200°C grog and calcined clay, 10% as-received kaolinitic clay and 10% bentonite is the same as ones obtained above. The colour of the bricks made from 10% ball clay[f] instead of bentonite is lighter yellowish.

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[f] see appendix

2) Cement

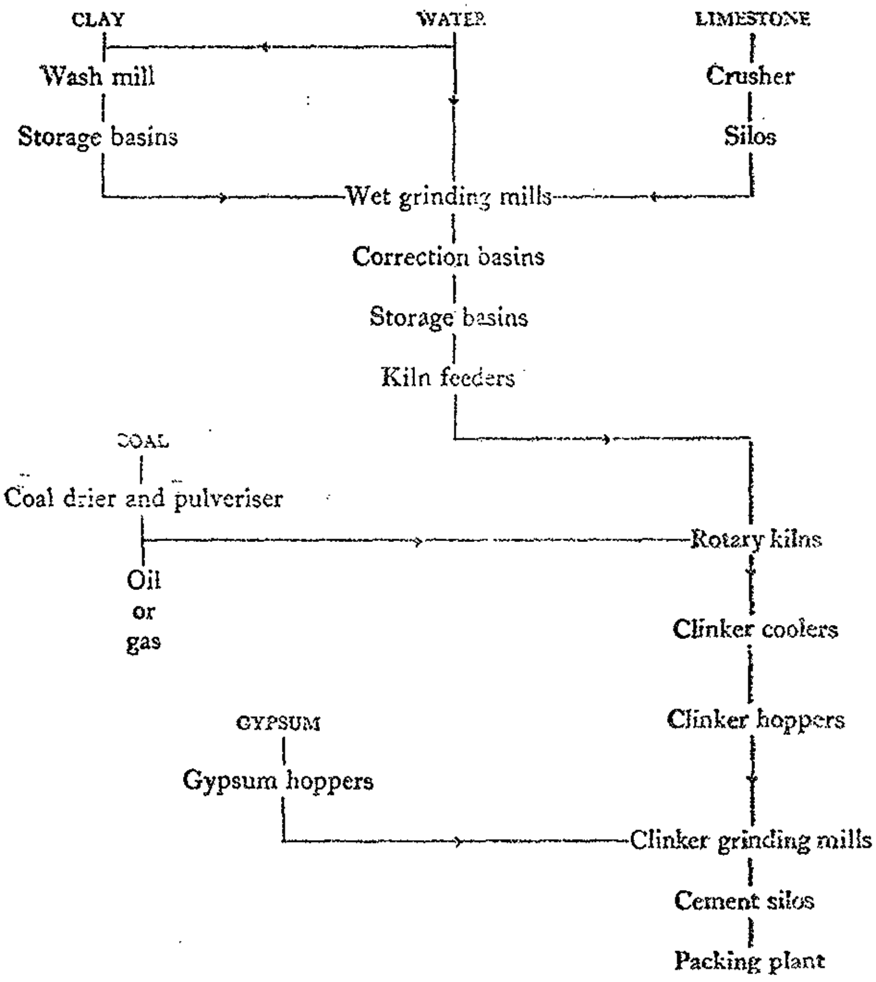
Portland cement is prepared by igniting a mixture of raw materials one of which is mainly composed of calcium carbonates and the other aluminum silicates. A variety of materials can be used as raw materials; these are chalk, clay, limestone, shale & marl. Blast furnace slag and alkali waste from chemical plants are also used in some cases.

Materials used in the manufacture of Portland cement must contain appropriate proportions of lime, silica, alumina, and iron components. The composition of the finished product should contain approximately 50% tricalcium silicates, 25% dicalcium silicates, 10% tricalcium aluminates, and 8% tetra-calcium aluminoferrite.

The process of manufacturing cement consists essentially of grinding the raw materials, mixing them in certain proportions and burning in a large rotary kiln at a temperature of approximately 1300° to 1400°C. The materials are sintered and fused into clinkers. The clinkers are cooled and ground to a fine powder, with some gypsum added, and the resulting product is the commercial Portland cement.

A flow sheet of cement manufacture process is shown in Figure 5.

Figure 5



In modern cement plants elaborate instrumentation is installed to control the burning process, combined sometimes with automatic control of the kiln. The raw materials in some plants are sampled automatically and the raw-mix composition required is calculated by a computer.

Only preliminary investigations are made to produce cement with the as-received kaolinitic clay. No attempt has been made to study the process in detail . According to a cement expert* who has talked to cement manufacturers regarding Hat Creek mining rejects, the kaolinitic clay seems to be suitable for making cement. But the recommendation is to send some samples to the companies for testing . This is because control of various parameters in the manufacturing process is critical in obtaining the required quality.

Typical raw materials for the cement industry are listed in Table VI. Reject material from mining is also shown for comparison. Comparison of Hat Creek rejects with shale is favourable.

Table VI - Analyses of typical raw materials

	Chalk	Clay	Lime-stone	Shale	Marl	Typical raw mix	Hat Creek Mining Rejects
SiO_2	1.14	60.48	2.16	55.67	16.86	14.30	60.69
$Al_2O_3^+$	0.28	17.79	1.09	21.50	3.38	3.03	31.95
Fe_2O_3	0.14	6.77	0.54	9.00	1.11	1.11	5.00
CaO	54.68	1.61	52.72	0.89	42.58	44.38	.27
MgO	0.48	3.10	0.68	2.81	0.62	0.59	.34
S	0.01	n.d.	0.03	0.30	nil	nil	-
SO_3	0.07	0.21	0.02	nil	0.08	0.07	-
Loss on ignition	43.04	6.65	42.39	4.65	34.66	35.86	-
K_2O	0.04	2.61	0.26	4.56	0.66	0.52	.27
Na_2O	0.09	0.74	0.11	0.82	0.12	0.13	.16
	99.97	99.96	100.00	100.20	100.07	99.99	1.28 TiO_2
$CaCO_3$	97.6		94.1		76.0	79.3	99.96**

$^+$Includes also P_2O_5, TiO_2 and Mn_2O_3

** on dry basis

* Civil Engineering Department

Experimental

Calculations[a] have shown that approximately three parts of calcium carbonate ($CaCO_3$) per one part kaolinitic clay are needed to prepare Portland cement. These are mixed well and fired at 1350°C in a platinum crucible for one hour. Then it is cooled, ground and analysed.

Results: Mineral analysis on the sintered samples are as follows:

Table VII

Minerals Identified

Sample #	
1	tricalcium silicate ($3CaO.SiO_2$), dicalcium silicate ($2CaO.SiO_2$), free lime (CaO), tricalcium aluminate ($3CaO.Al_2O_3$) trace, calcium silicate ($CaO.SiO_2$) trace
2	tricalcium silicate ($3CaO.SiO_2$), dicalcium silicate ($2CaO.SiO_2$), free lime (CaO)
3	tricalcium silicate ($3CaO.SiO_2$), free lime (CaO) dicalcium silicate ($2CaO.SiO_2$).

---

[a] calculation of raw materials for cement making. See appendix.

Figure 6

cement

Discussion:

Tricalcium silicate, dicalcium silicate, tricalcium aluminate which are the main constituents of Portland cement are all present in the sintered products.

As mentioned earlier in the introduction, the chemical composition of the kaolinitic clay is in accordance with shale used in the cement industry. There is every reason to believe that mining rejects* in Hat Creek are suitable for producing commercial quality cements. Samples should be sent to various cement manufacturers for evaluation and testings.

The price for this clay would not be expected to be high although the exact price cannot be determined at present.

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* kaolinitic clay supplied for this study.

The tonnages of clay that can be absorbed into the cement industry is not large, only around 30 tons/day so only part of the Hat Creek mining rejects can be utilized in the cement industry in conjunction with other industries.

3) Mullite

Preliminary investigation has shown that firing the kaolinitic clay at 1200°C produces minerals such as cristobalite, mullite and iron oxide and quartz (trace). The mullite content is only about 25+35% which is of no commercial significance. No further work has been done in this area. However, to produce mullite refractories, the kaolinite component has to be separated first and then enriched by the addition of Al_2O_3 (which can be generated from the clay itself) and then fired to produce larger concentrations of mullite ($3Al_2O_3\ 2SiO_2$).

Two-hour Float Fraction of Kaolinitic Clay

Figure 7

Products from Sedimented Kaolinitic Clay

1. refractory bricks
2. alumina production
3. bleached clay for the paper industry

1. Refractory bricks

Experimental

Following the same procedure, as described in the earlier section for producing bricks using the 'as-received' kaolinitic clays, the float fraction of kaolinitic clays (Fig. 7) were fired at 1200°C in the form of blocks to produce grog. The procedure of brick making was the same as described before. Initial attempts to produce bricks with a mixture of 50-50 grog and raw clay produced bricks which had minute cracks all over. In order to eliminate this problem a revised batch formulation is adopted as follows. In the revised mix, raw clay is calcined at 500°C and added to the mix. To obtain the green strength and pleasant colour in the brick 20% raw clays is also added. The final formulation is a 50-50 mix of 1200°C grog and calcined clay, and 10% two-hour sedimented clay and 10% Hat Creek clays 74-44-2167' and 74-29-625'. These are blended thoroughly. About 10→15% water is added gradually with splashes of kerosene. This should be a barely moist mixture. Approximately 20g of the sample is poured into the die and pressed at 10,000 psi[d]. This is weighed and dried. The dimensions and weights of the dried bricks are recorded. A total of about 14 to 15 bricks are made. Then these are fired at 1200°C in a large furnace having firing characteristics as that of Clayburn. The heating period takes about two days. The weights and dimensions of the bricks after firing are again recorded.

Two large bricks are also prepared as mentioned above. The pressure used is 15,000 psi. The results of the dimensional change are shown in Table VIII.

---

[d] small die is used

74-44-2167' - bentonite, quartz, feldspar, kaolinite
74-29-625' - bentonite, feldspar, kaolinite, quartz

Results:

Table V111

	Weight of Sample (g)		Length (cm)		Width (cm)		Height (cm)		Volume (cm^3)			Bulk Density
Sample #	after drying	after firing	Dried at 105°C	Fired at 1200°C	Dried at 105°C	Fired at 1200°C	Dried at 105°C	Fired at 1200°C	after drying	after firing	% reduction	after firing (g/cm^3)
1S111	47.8	46.2	7.70	7.436	1.316	1.27	3.188	3.06	32.305	28.898	10.5	1.60
1S1V	47.2	45.7	7.692	7.40	1.298	1.256	3.18	3.076	31.750	28.590	10.0	1.60
S1	17.	16.7	6.396	6.198	.95	.926	1.822	1.770	11.071	10.159	8.2	1.64
S11	17.1	16.8	6.41	6.206	.952	.928	1.884	1.832	11.497	10.551	8.2	1.59
S111	17.	16.7	6.386	6.206	.95	.934	1.852	1.80	11.236	10.434	7.1	1.60
S1V	17.1	16.8	6.392	6.206	.956	.928	1.856	1.80	11.342	10.367	8.6	1.62
SV	17.1	16.8	6.392	6.198	.964	.926	1.858	1.804	11.449	10.354	9.6	1.62
SV1	17.1	16.8	6.392	6.20	.956	.932	1.842	1.788	11.256	10.332	8.2	1.63
SV11	17.2	16.9	6.390	6.204	.964	.932	1.870	1.820	11.519	10.523	8.6	1.61
SV111	17.1	16.8	6.392	6.20	.958	.94	1.846	1.792	11.304	10.444	7.6	1.61
S1X	17.2	17.	6.388	6.20	.956	.936	1.868	1.832	11.530	10.631	7.8	1.60
SX	17.1	16.8	6.392	6.20	.956	.928	1.834	1.786	11.207	10.276	8.3	1.63
SX1	17.1	16.9	6.394	6.214	.956	.934	1.846	1.802	11.284	10.459	7.3	1.62
SX11	17.2	16.9	6.394	6.206	.962	.926	1.844	1.790	11.342	10.287	9.3	1.64
SX111	17.2	17.	6.398	6.20	.958	.928	1.884	1.824	11.548	10.495	9.1	1.62
SX1V	17.2	17.	6.398	6.204	.960	.932	1.864	1.800	11.449	10.408	9.1	1.68

1S111 → 1S1V starting weight ≈60 g

S1 → SX1V starting weight ≈20 g

Discussion:

The bricks produced from the float fraction of two-hours sedimented clay are light beige colour. The moisture loss after drying is ~5%, the shrinkage after firing is ~8.6%, and the bulk density after firing is ~1.62 g/cm^3.

Figure 8 shows bricks produced from a 50-50 mix of 1200°C grog and calcined clay, 10% two-hours sedimented clay, and 10% Hat Creek clays 74-44-2167' and 74-29-625'.

Figure 8

Photograph of bricks produced from the float fraction of 2 hour sedimented clay.

2. Alumina (Al_2O_3) Production

Alumina is produced as a raw material for two main industries, 1) aluminium industry, and 2) refractory industry. The aluminium industry in particular is dependent on foreign imports of raw material which is bauxite. Since 1960, processes for treating low-grade aluminium containing material resources such as clay or anorthite are developed. These processes include acid processes and alkali processes. Of these processes, lime-soda sinter process, lime sinter process and Pechiney H^+ process are studied most widely.

Both the Department of Energy, Mines and Resources of Canada and U.S. Bureau of Mines have investigated the sinter processes in detail and have found that the percentage of alumina extraction is as high as 85% to 95% and 79% respectively. The sinter processes are also very versatile as they are capable of extracting alumina from almost all aluminosiliceous materials.

The Pechiney H^+ process is currently studied in pilot plant scale in France financed jointly by Alcan Ltd. and Pechiney Company of France. The Department of Energy, Mines and Resources of Canada have also done some work on this process. The alumina produced is said to be very pure compared to that produced by other processes. One disadvantage of this process is that it cannot extract alumina from fly ash because alumina is present as mullite ($3Al_2O_3$ $2SiO_2$) which is a very stable compound.

The alumina content of the two-hours sedimented kaolinitic clay is approximately 28%. The extraction of the alumina from the clay can be produced by various processes. All three processes have been carried out to investigate the possibility of extracting Al_2O_3 from the clays of the Hat Creek coal deposit.

The lime-soda sinter process and the lime sinter process are very similar. The only difference is that sodium carbonate (soda) is added in the sintering stage for the first case and soda is added in the leaching stage in the second case (i.e lime sinter process).

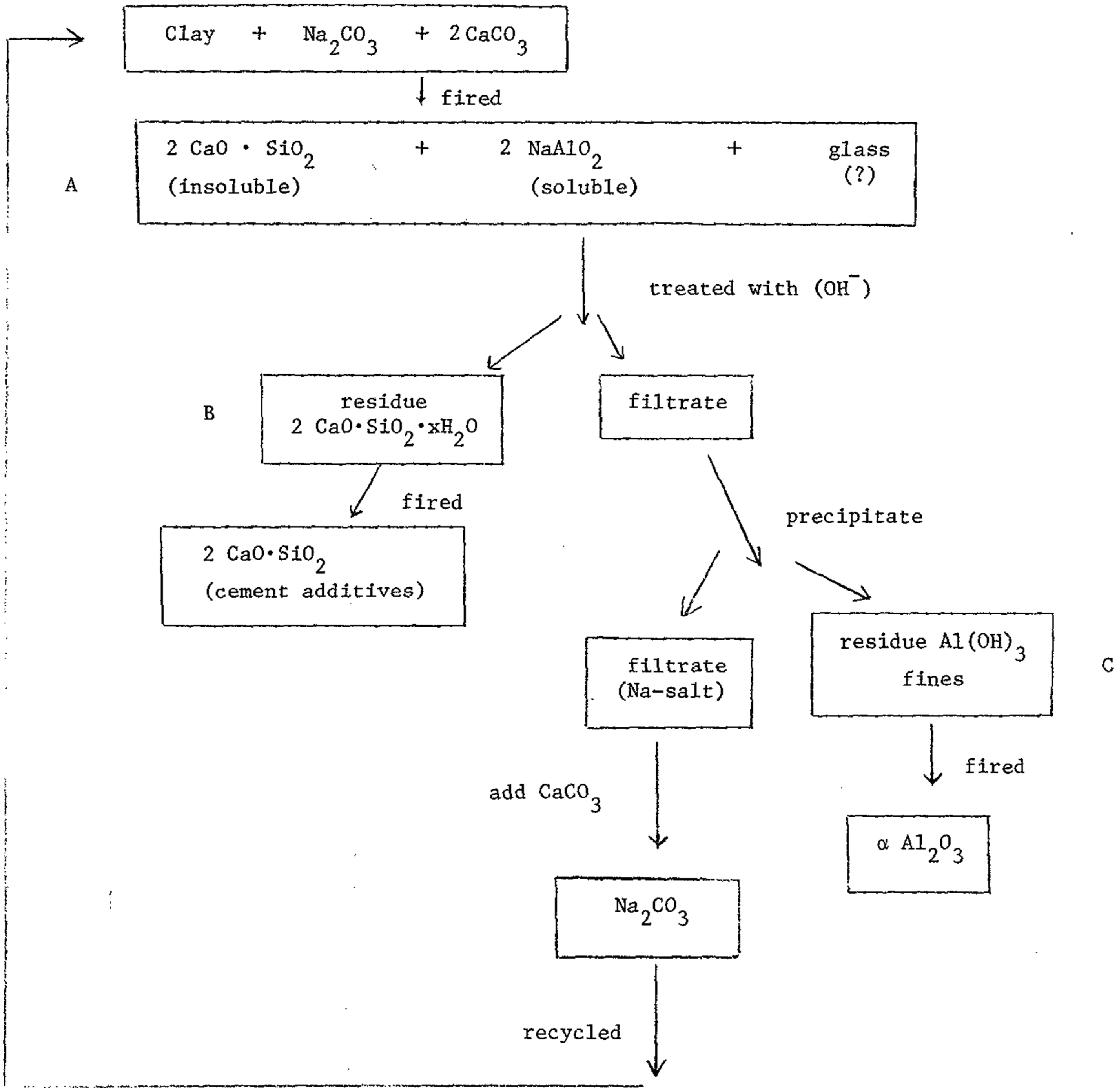
There are three stages to the lime-soda sinter process; these are sintering, leaching and precipitation. In the sintering stage, kaolinitic clay, limestone and soda ash are reacted at high temperature (1280°C to 1300°C) for 20 to 25 minutes to give a mixture of sodium aluminate and dicalcium silicate. The solid-state reactions that occur during sintering are as follows.

$$Al_2O_3.2SiO_2.2H_2O + SiO_2 + Na_2CO_3 + 6\ CaCO_3 \rightarrow Na_2Al_2O_4 + 3(2CaO.SiO_2) + 8\ CO_2 \uparrow + 2H_2O \uparrow$$

The sodium aluminate is readily soluble in dilute sodium hydroxide solution and can be removed from the sinter by leaching. Finely ground sintered material is added gradually to hot sodium hydroxide solution at 85°C for approximately four hours. The residue is filtered and it is hydrated dicalcium silicates. The filtrate is cooled and bubbled with CO_2 for rapid precipitation of aluminium hydroxide. The precipitated aluminium hydroxide is filtered and calcined at 1100°C to produce alpha alumina.

Flow sheet of the lime-soda sinter process is presented below.

Figure 9



There are also three stages to the lime sinter process: sintering, leaching and precipitation. In the sintering stage, only kaolinitic clay and limestone are reacted at high temperature (1280 to 1300°C) for 20 to 25 minutes to give a mixture of calcium aluminate and dicalcium silicate. The sintered material is then ground to -100 mesh and leached in sodium carbonate or sodium hydroxide solution to convert calcium aluminate to soluble sodium aluminate. Studies by the U.S. Bureau of Mines[i] have shown that recovery of alumina is higher when leached with sodium carbonate solution. But the soda recovery is higher when leached with sodium hydroxide solution. The solution is filtered with dicalcium silicate as the residue. The filtrate is bubbled with CO_2 for rapid precipitation of $Al(OH)_3$ when cooled.

The Pechiney H^+ process is an acid leaching process. Kaolinitic clay is leached with 65% sulfuric acid at 140°C for one to four hours. Then the solution is washed in three counter current washes. Filtrate from the second wash contains much of the iron and potassium. This wash is concentrated to precipitate the sulphates which are removed by filtering. The mother liquor is diluted to approximately $40gAl_2O_3/\ell$ and cooled to 40°C. Additional cooling is required while saturating the solution with HCl gas to precipitate aluminum trichloride hexahydrate. The precipitate is filtered, washed with HCl, heated and dissolved in dilute acid, filtered again to remove any insolubles, cooled and recipitated again with HCl gas. The purified aluminum trichloride is heated to 1100°C to produce α-alumina and hydrochloric acid. The resultant alumina is somewhat finer and purer than that obtained by the Bayer process.

The detailed flow-sheet of the Pechiney process in Figure 10.

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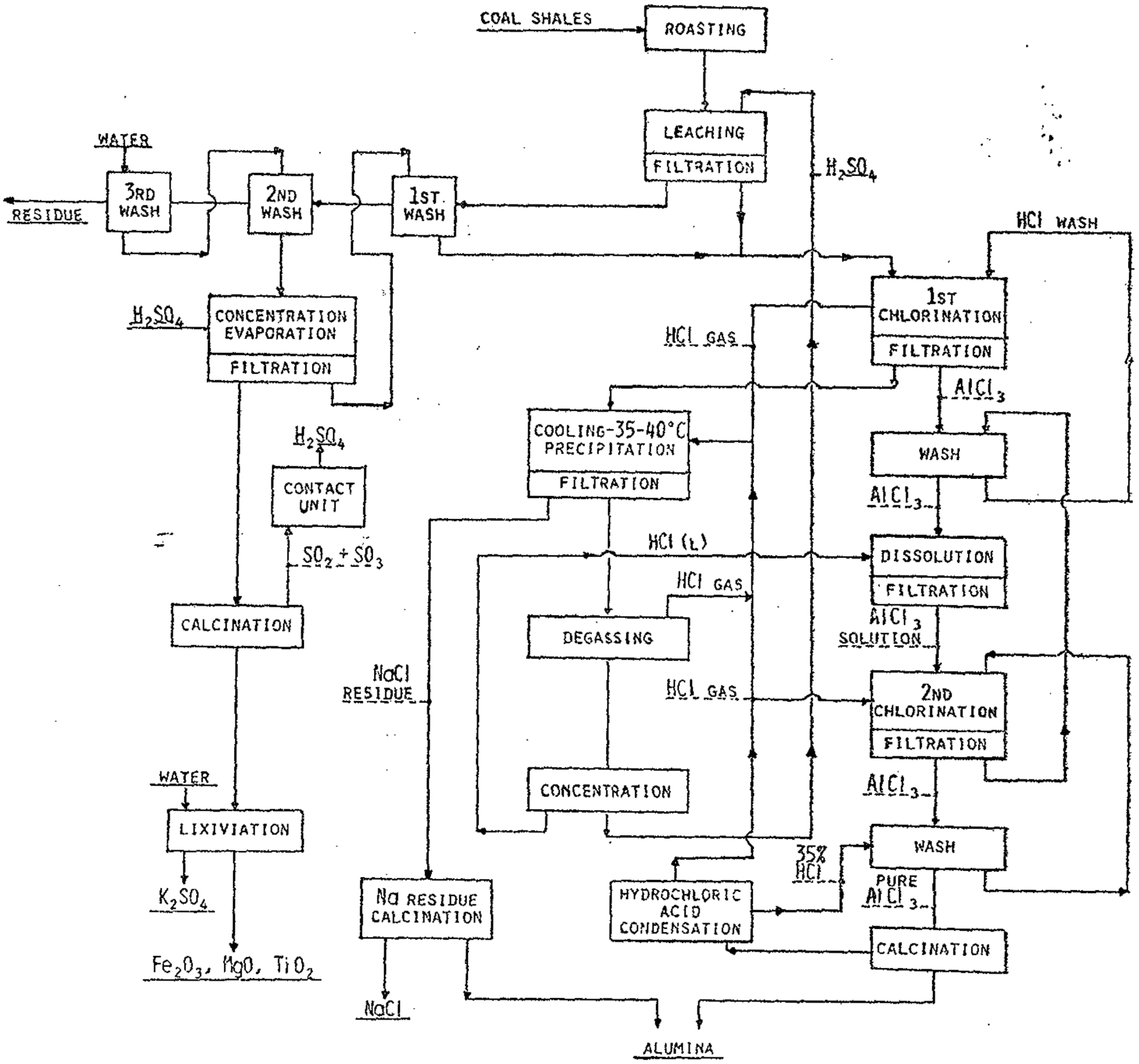
[i] U.S. Bureau of Mines, RI 7434

Figure 10: Pechiney H Plus process



Experimental

(i) Soda-lime sinter process

Mixtures of $CaCO_3$, Na_2CO_3 and the float fraction of two-hour sedimented sample are weighed and blended thoroughly. A list of weights for sintering, sintering temperature, soaking time, weight of NaOH for leaching, leaching time and leaching temperature are presented in Table IX.

The mixture is sintered and quenched. Then it is ground to -100 mesh and added gradually to hot NaOH solution. The system is stirred vigorously for four to five hours and then filtered. The residue is dried and analysed. The filtrate is cooled and bubbled with CO_2 to precipitate aluminium hydroxide [$Al(OH)_3$]. The aluminium hydroxide is then filtered and calcined at 1100°C. The amount of alumina is determined by weighing and then is analysed.

Table IX

Weights for Sintering (g)			Mole Ratio						
Na_2CO_3	$CaCO_3$	Kaolinitic Clay	Na_2O/Al_2O_3	CaO/SiO_2	Sintering Temp. (°C)	Sintering Time (mins.)	Weight of NaOH for Leaching(g)	Leaching time(hrs.)	Leaching Temp. (°C)
14.	18.	23.	2.1	.8	1300°C	90	.66	5	90
24.	30.	37.	2.2	.8	1300	40	.21	5	90
19.	24.	30.	3.7	.8	1300	35	1.45	5	90
19.	24.	30.	3.7	.8	1300	15	1.07	5	90
4.0	20.	9.	1.5	2.1	1280	20	.39	5	85
4.0	20.	9.	1.5	2.1	1280	25	.30	5	85

(ii) Lime-sinter process

Mixtures of $CaCO_3$ and the float fraction of two-hours sediment sample are weighed and blended thoroughly. The experimental parameters are listed in Table X.

Table X

Weight for sintering(g)		Mole Ratio	Sintering Temp.	Sintering Time
$CaCO_3$	Kaolinitic Clay	CaO/Al_2O_3	(°C)	(min.)
26.0	24.5	3.9	1280	75
26.0	36.6	2.6	1280	45
13.0	11.1	4.3	1280	30

The mixture is cooled to 900°C and quenched.

(iii) Pechiney H^+ process

30 g of 2-hrs. (calcined at ~680°C) kaolinitic sample (float fraction) is added to 65% H_2SO_4 solution, stirred and heated at 140°C for four to five hours. The solution is then filtered and the mother liquor is diluted to 40 g Al_2O_3/ℓ and cooled to 40°C.

The solution is saturated with HCl gas to precipitate aluminium trichloride hexahydrate. In this experiment HCl gas is produced by adding HCl to H_2SO_4 and HCl gas is piped to the solution. No purification steps are done.

The aluminium trichloride hexahydrate is heated to 1100°C to produce α-Al_2O_3 and HCl.

Results and Discussion:

(i) Soda-lime sinter process

Alumina has been produced from the soda-lime sinter process. It is estimated that approximately 60% of $CaCO_3$, 12% of Na_2CO_3 and 27% of two-hours sedimented kaolinitic clay by weight are required to produce maximum yield of alumina. The mole ratios of Na_2O/Al_2O_3 and CaO/SiO_2 are 1.5 and 2.1 respectively. Approximately 10 to 12 tonnes of waste will be produced per ton of alumina by this process.

The concentration of sodium hydroxide solution for leaching seems to affect the purity of the alumina produced. Analyses of the alumina produced from different runs are shown on Figure 11 (a→e). The amount of NaOH necessary is about 1.5 g per 100 g sinter material for higher purity of alumina.

No attempt has been made to study the effects of other parameters. The percentage of recovery obtained so far is ~60%. The percentage of recovery should increase to 80 to 90% as obtained by Energy, Mines & Resources of Canada and U.S. Bureau of Mines. But further investigation for optimum conditions are needed to obtain higher yields of alumina.

The advantage of the soda-lime sinter process is its versatility. It can extract alumina from any alumino-siliceous materials. The main disadvantage of this process is the high sintering temperature ~1300°C. But if the plant is located near Hat Creek where coal is readily available the energy cost will probably be very low.

It is estimated that approximately 10 to 12 tonnes of dicalcium silicates will be produced per ton of alumina. The ideal situation would be the consumption of dicalcium silicates in the cement industry. Otherwise, dicalcium silicates is not a very useful material.

(ii) Lime-sinter process

The whole process has not been carried through to produce alumina. This is because disintegration of the sintered materials has not been observed. Apparently the control of the disintegration stage is the essential element in the success of the process.

(iii) Pechinery H^+ process

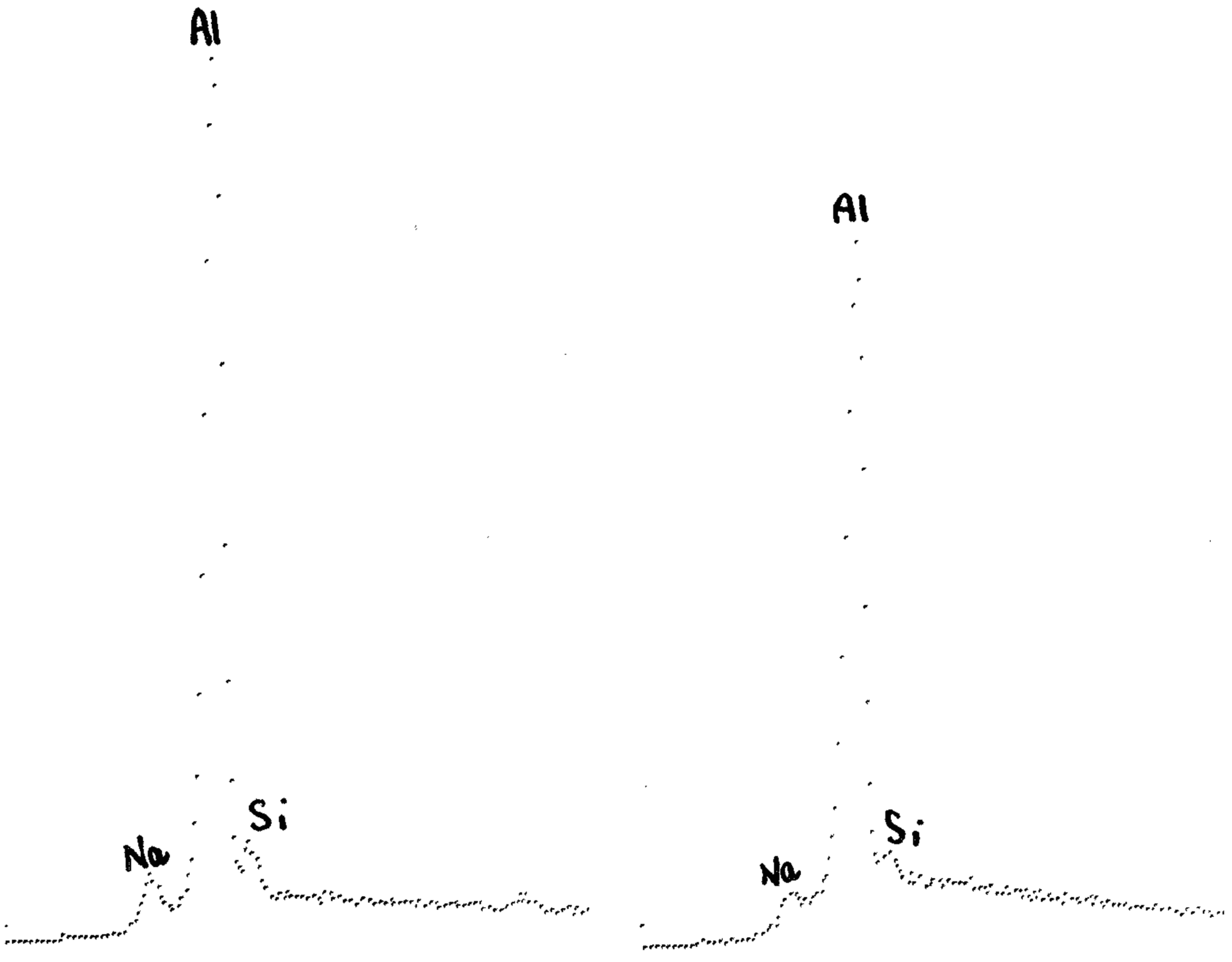
Only preliminary run of the process is performed as limited time is available. Alumina is produced by this process but the percentage of recovery is low. More investigations are definitely required to increase recovery of alumina.

According to publication on this process, the extractability of alumina from clays depends on parameters such as the time and temperature of calcining to dehydroxylate the clay, the acid quantity and concentration, and the time and temperature of leaching. However, the precentage of recovery of alumina by this process has never been mentioned in literature. Other processes by sulfuric acid leaching give 80 to 90% extraction of alumina.

One disadvantage of the Pechiney H^+ process as compared to the sinter processes is its incapability to extract alumina from fly ash. The alumina produced is somewhat finer and purer than that by the sinter processes. This is probably one of the reasons which stimulated research and participation of Aluminium Co. of Canada in the development of this process.

Figure 11

Elemental Analysis of the Alumina Produced
by Lime-soda Sinter Process (Five Runs)



Run # 1

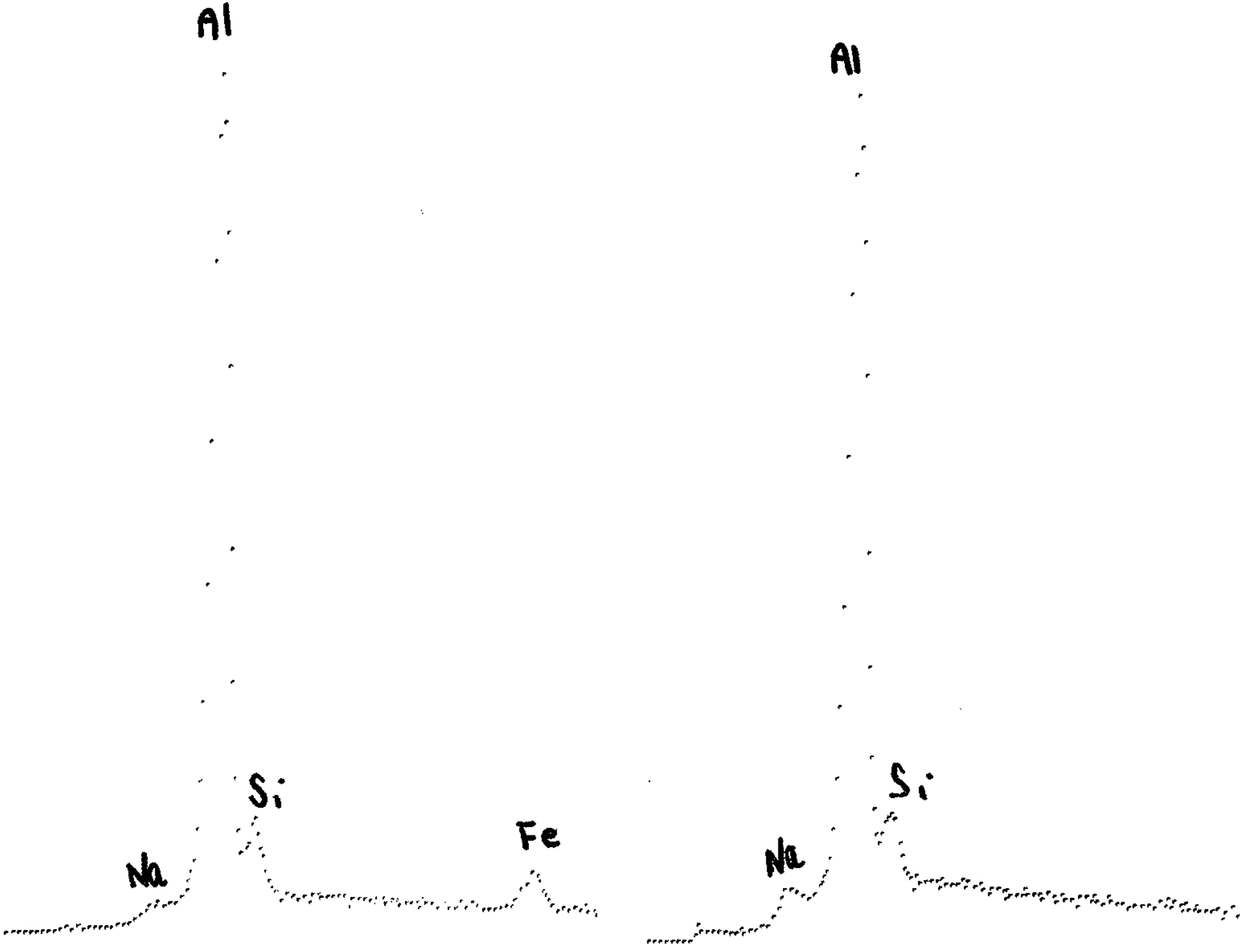
(a)

Run # 2

(b)

Figure 11 (cont'd)

Elemental Analysis of the Alumina Produced
by Lime-soda Sinter Process (Five Runs)



Run # 3

(c)

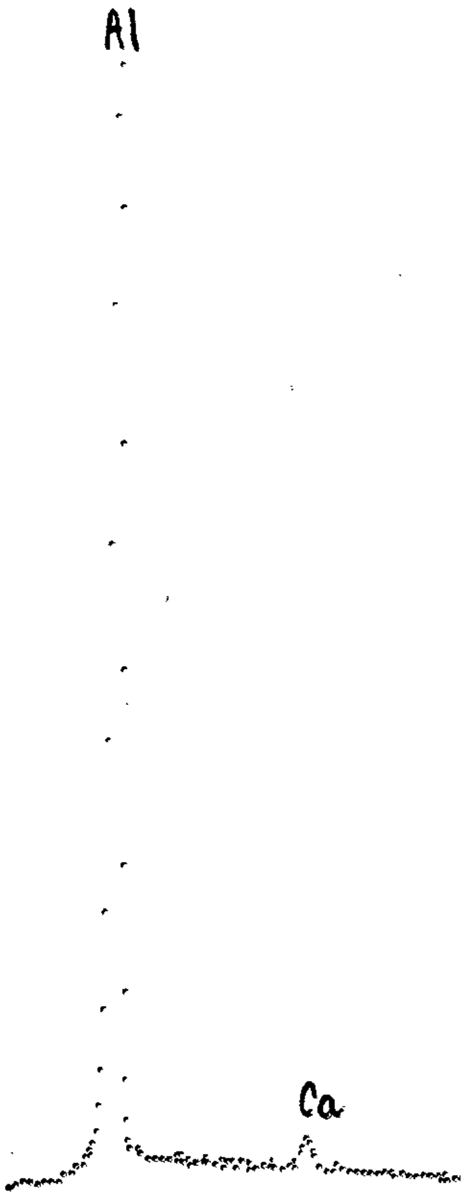
Run # 4

(d)

Figure 11 (cont'd)

Elemental Analysis of the Alumina Produced

by Lime-soda Sinter Process (Five Runs)



Run # 5

(e)

Figure 12

Alumina product from Hat Creek clays by the soda-lime sinter process.

The market situation of the alumina is favourable in the refractory industry but not in the aluminium industry. The Aluminum Co. of Canada at present is jointly financing the Pechiney H^+ process pilot plant in France. Also the tonnages that the aluminium company required greatly exceed the amount of alumina that is required by the refractory industries in Canada.

One company in the refractory industry, Clayburn of Abbotsford, has expressed interest in purchasing alumina if the price is competitive to those imported. The tonnages required for this industry are quite small, -2500 tonnes per year.

The purity of alumina used in the refractory industry is less stringent than in the aluminum industry. The requirement is -98% Al_2O_3 in the refractory industry. This is an advantage as every percent of increase in Al_2O_3 content would mean higher production cost.

The economic evaluation of various processes have been studied and published by U.S. Bureau of Mines, updated in 1973. But inflation cost of raw materials, location of plant, energy cost, etc., all have to be taken into consideration before economic feasibility of producing alumina can be done.

3. Bleaching of clay

Kaolinite ($Al_2O_3.2SiO_2.2H_2O$) is used extensively in the paper and paint industries. It is used as paper filler and coater in the paper industry and as pigment in the paint industry. It is amongst the less expensive for these purposes. Vast deposits of kaolinite can be found in Devon and Cornwall in England and in Georgia, Florida, Carolina and Idaho in the United States. The supply of kaolinite used in British Columbia is from the United States.

The current prices of kaolinite for use as paper coateris approximately $100/ton and of Georgia kaolinite as paper filler is $50/ton. The commercial value of this clay mineral depends very much on its whiteness. The whiteness of clay has to be comparable to magnesium oxide (MgO) to be used as a coater. The clay used for filler can be less white. The reflectance characteristics and the particle size are also critical factors for use in the paper and pulp industries.

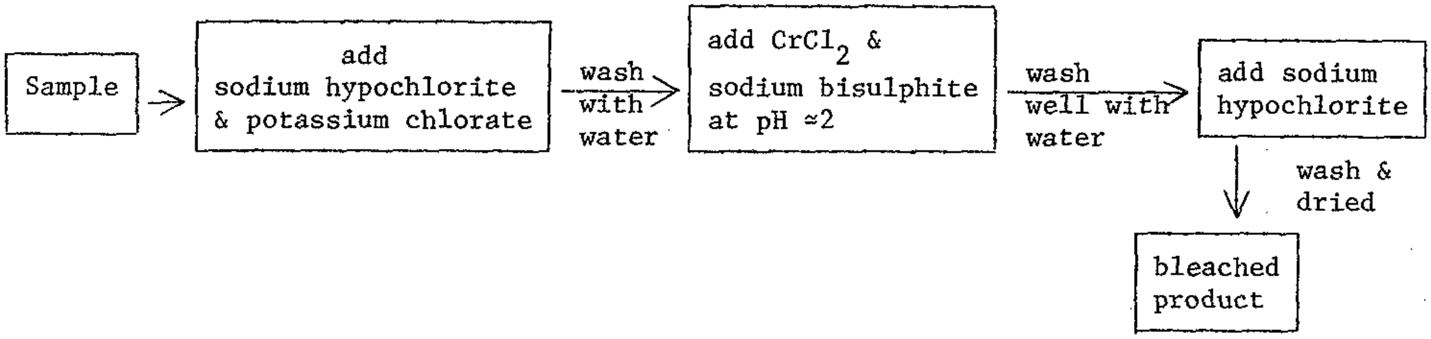
The two-hours sedimented kaolinitic clay from Trench B zone D of the Hay Creek deposit is dark grey as shown on Figure 7. The dark colour of the clay is caused by many factors, titaniferrous minerals and grey silica can contribute to its dark colour. Analyses have shown that the float fraction of the two-hour sedimented sample contains approximately 2% carbonaceous material, 2% iron oxide (Fe_2O_3), 1% titanium oxide (TiO_2), and 30% quartz.

Chemical treatment and heat treatment are the approaches used to bleach the clay. Various chemicals and chemical procedures have been tried. The result is chemical treatment involving an oxidizing agent and a reducing agent. The flow-sheet of the procedure is shown in Figure 13. Various temperature and heating environments have been explored using the gradient furnace. It was found that heating at 450 to 500°C in an oxidizing atmosphere whitens the clay considerably.

Three batches of samples are produced. One is chemically treated, one is heat treated and the other is first chemically treated then heat treated. These samples have been sent to Dr. John Howard of B.C. Research to investigate the properties and utilization of the bleached clay in the paper and paint industries.

Figure 13.

Flow sheet of chemical treatment.



Experimental

Chemical treatment

Preliminary tests using various chemicals, e.g., water, acid, akaline, oxidizing agent and reducing agents are carried out individually to observe any changes in colour. Variation of pH of the sample in water is also done using HCl and NaOH. The results are recorded. Combinations of chemicals and procedures of using them are then studied and the results are noted. Summarized below are the results of the investigation. (Table X1).

Table XI

	Solvents	Reagents	Results
1.	water	-	useless
2.	acid	dilute HCl	useless
3.	acid	50% warm HCl	useless
4.	acid + oxidizing agent	$Br_2/HNO_3/KClO_3$	good-white product with greyish tint
5.	acid + oxidizing agent + removal of Fe	$Br_2/HNO_3/KClO_3$, add sodium dithionite, add H_3PO_4 before filtering	good-white product with greyish tint
6.	alkaline	dilute hot NaOH	useless
7.	alkaline	dilute NH OH	useless
8.	oxidizing agent	bleach + $KClO_3$	fair-light yellow product
9.	oxidizing agent + heating at 600°C	bleach & heating at 600°C	good-white product with greyish tint
10.	oxidizing agent + removal of Fe	bleach + $KClO_3$, $pH \approx 2$, add sodium dithionite	good-white product with greyish tint
11.	oxidizing agent + removal, of Fe heating at 600°C	bleach + $KClO_3$, $pH \approx 2$, add sodium dithionite, heat at 600°C	good-white product with greyish tint
12.	heating at 850°C	-	white product with reddish tint, Kaolinite transformed
13.	heating at 500°C	-	yellowish-metakaolinitic

Heat treatment

Approximately 200g of the float fraction of the two-hour sedimented sample is mixed with ~25ml of water to form a paste. The paste is poured into a plaster of Paris mold to form bars. These bars are dried in the drying oven overnight. One bar is placed in a gradient furnace having temperature gradient of room temperature to 800°C in an oxidizing atmosphere. The heating time is three hours. The colour on the gradient bar is observed and recorded. Another bar is placed in the gradient furnace in a reducing atmosphere. The colour on the bar is again observed and recorded.

Qualitative analyses of the two-hour sedimented sample, Georgia kaolinite, heat treated samples are carried out for comparison. Analyses include mineral analysis by X-ray diffraction and elemental analysis by scanning electron-microscopy (SEM).

Result

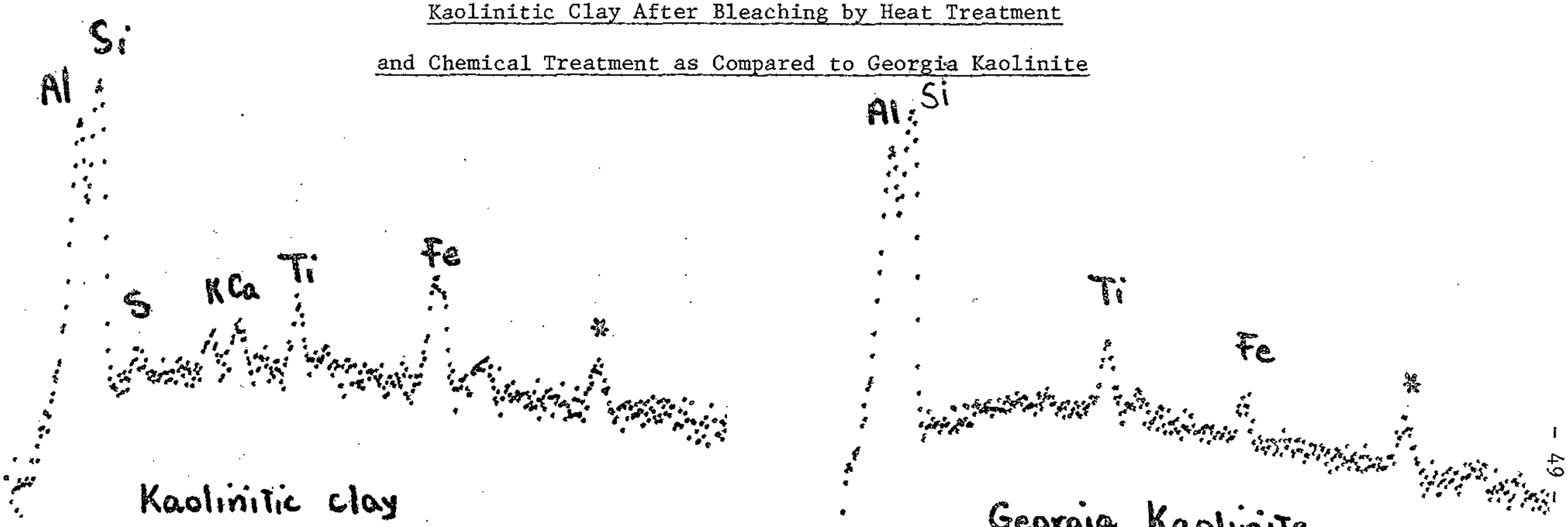
Three batches of bleached clay are produced. One is chemically treated, one is heat treated and the other is chemically treated and then heat treated.

Qualitative elemental analyses have been performed on the product by SEM. The results are shown on Figure 14. The elements present in the kaolinitic clay are silicon, aluminum, iron, titanium, calcium, potassium and sulfur. The Georgia kaolinite which is presently used as filler and coater in the pulp and paper industry consists of silicon, aluminum, titanium and traces of iron. Kaolinitic clay after heat treatment consists of essentially all of elements except sulfur. Sulfur has combined with oxygen to form sulfur dioxide (SO_2) and escaped during heat treatment. The chemically treated kaolinitic clay shows the presence of silicon and aluminum, much lower contents of iron and titanium, and virtually the disappearance of calcium and potassium. These elements, calcium and potassium, have reacted to form soluble compounds during chemical treatment.

Both the heat treated and chemically treated kaolinitic clay are not as white as MgO which is the colour standard for paper coater. Therefore, these products can only be used as filler in the pulp and paper industry.

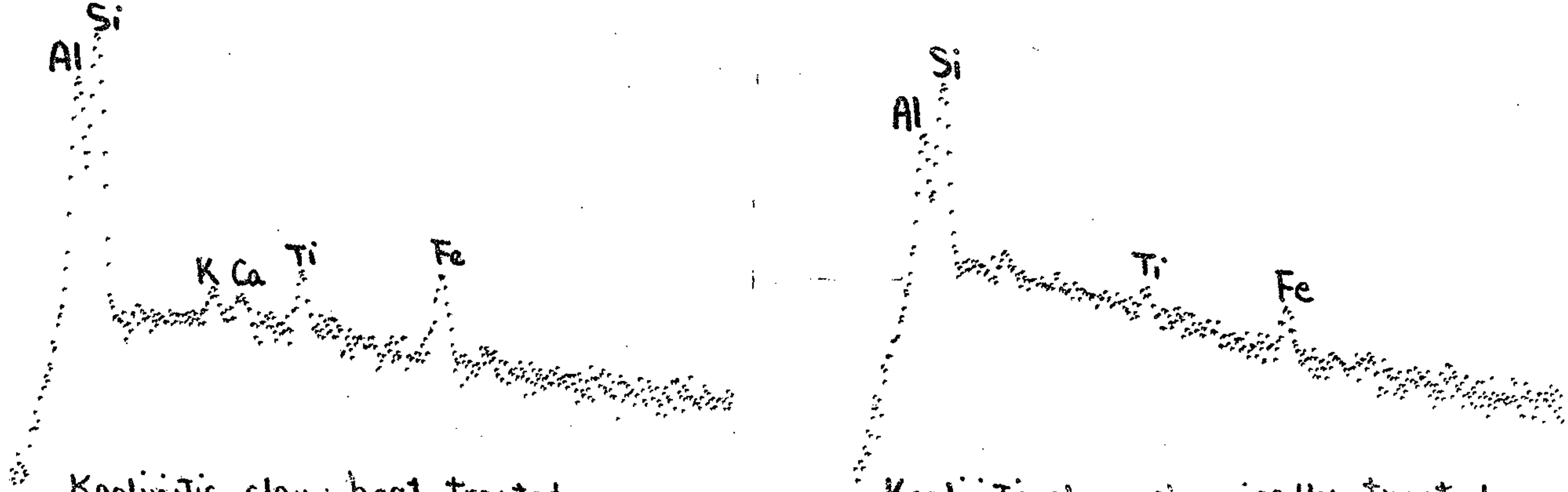
Figure 14

Elemental Analyses of Hat Creek Kaolinitic Clay, Kaolinitic Clay After Bleaching by Heat Treatment and Chemical Treatment as Compared to Georgia Kaolinite



Kaolinitic clay

Georgia Kaolinite

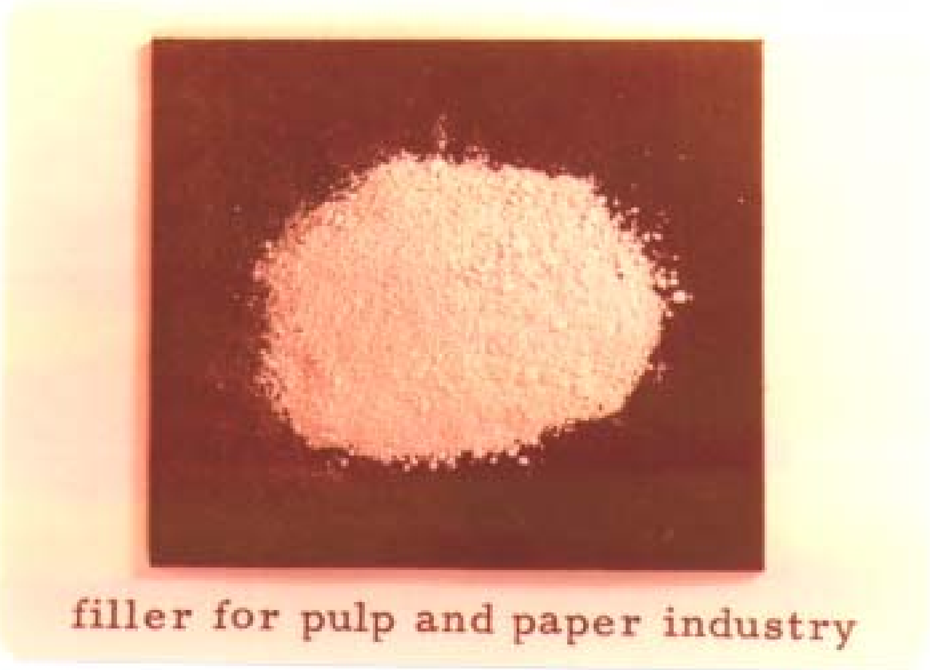


Kaolinitic clay : heat treated

Kaolinitic clay : chemically treated

The photograph of a lump of bleached Hat Creek (Kaolinite) clay is shown in Figure 15.

Figure 15



As far as producing the bleached clay is concerned, the heat treatment method is much simpler as compared to the chemical treatment method. The cost of producing bleached clay by the heat treatment method should also be much lower.

Part II

Utilization of Refuse from Washery Plant

1. Building Bricks

Preliminary investigation has shown that rejects from the washery plant have low fusion temperature ~1300°C. Therefore, these bricks are not very satisfactory for refractory industries. But this material should be very suitable for building bricks.

Building bricks do not require refractory oxides but because of the high content of fluxes in raw materials, they can be fired at a lower temperature. Normally their fusion point is in the range 1250 → 1350°C and the bricks bloat if fired above these temperatures. Colour also is an important factor in the quality of the building bricks. Reddish, reddish-brown and yellowish colours are very common for building purposes.

SEM studies on elemental contents of these samples indicate (Figure 16(a)to(d)) that they contain a large amount of Fe and K. This suggests that only red bricks can be made from these samples.

Experimental

A. Investigation on Grog-making

Approximately 100 g of sample is mixed thoroughly with ~10 ml water and .5 ml of kerosene. The sample should barely stick together when pressure is applied. ~20 g each is poured into a small die and pressed at 10,000 psi[d] pressure to form bricks. They are numbered and dried at 105°C. The dimensions of these bricks are recorded and then fired at 1400°C, 1300°C and 1200°C for two hours. The colour changes are observed and dimensions after firing are recorded. The samples used for this investigation are HC T11 CR, HC TV11 CR, HC TV111 CR, HC TV CR, HC TV1 CR, HC TV FR, and HC TV11 Thickener II. These are crushed to -18 mesh and used as grog for subsequent steps in brick making.

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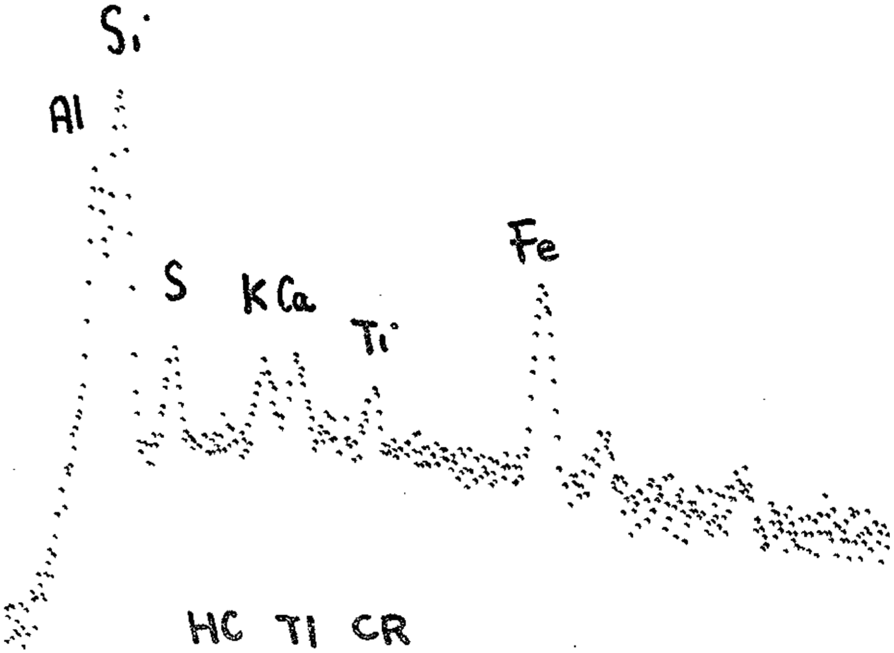
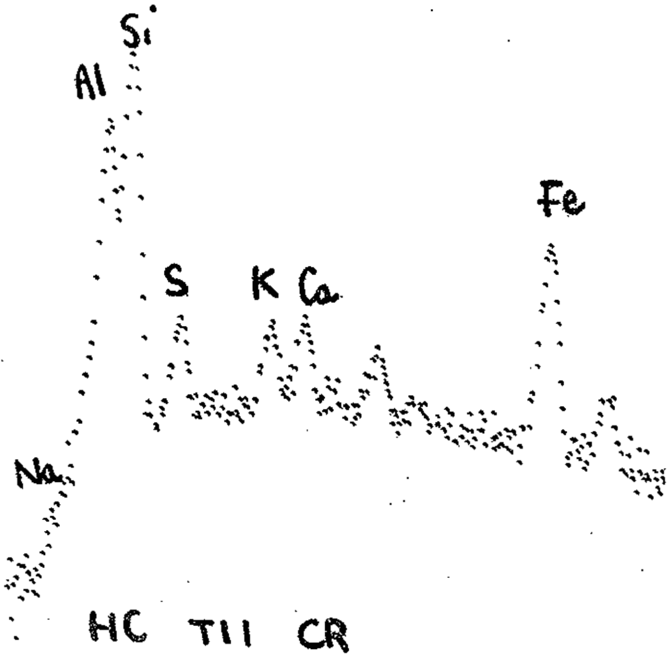
[d] small die is used

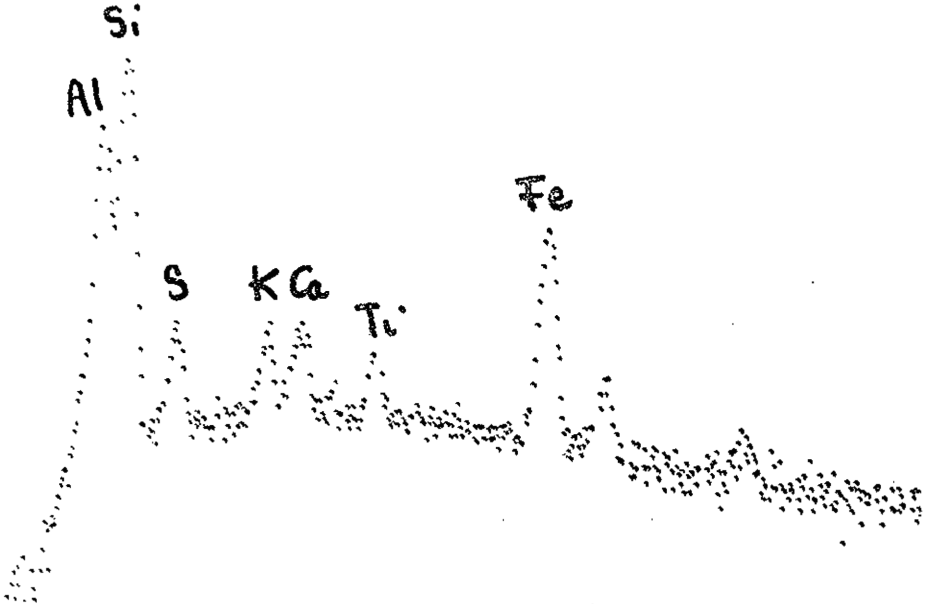
Elemental Analysis of Refuse Samples



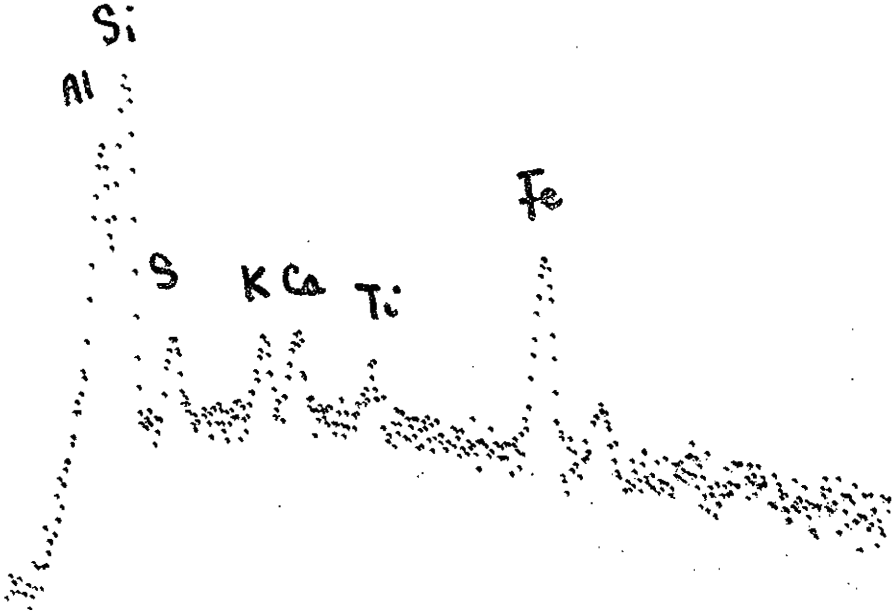
HC TI CR



HC TII CR



HC TIII CR



HC TIV CR

Figure 16(a)

Elemental Analysis of Refuse Samples

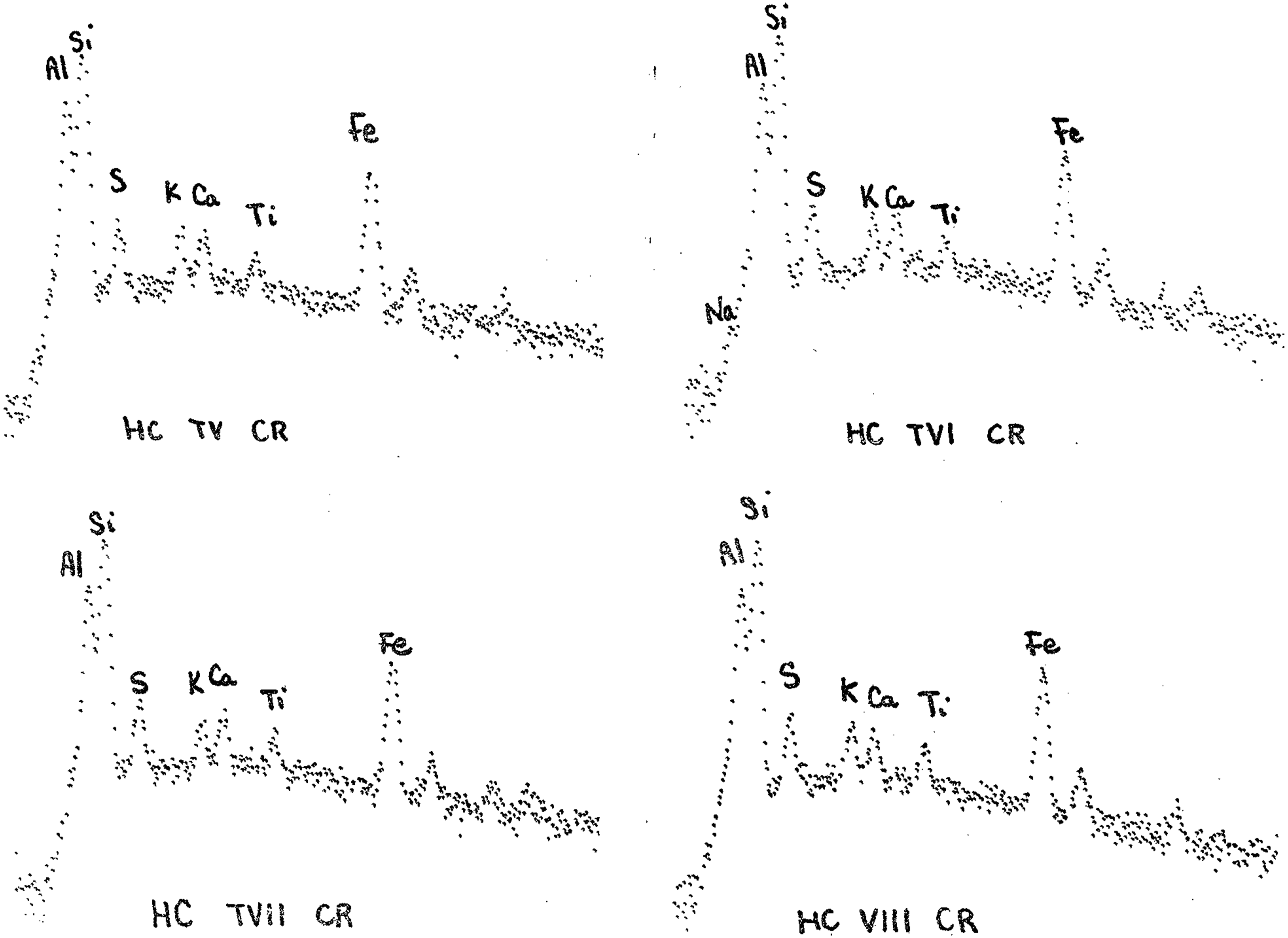
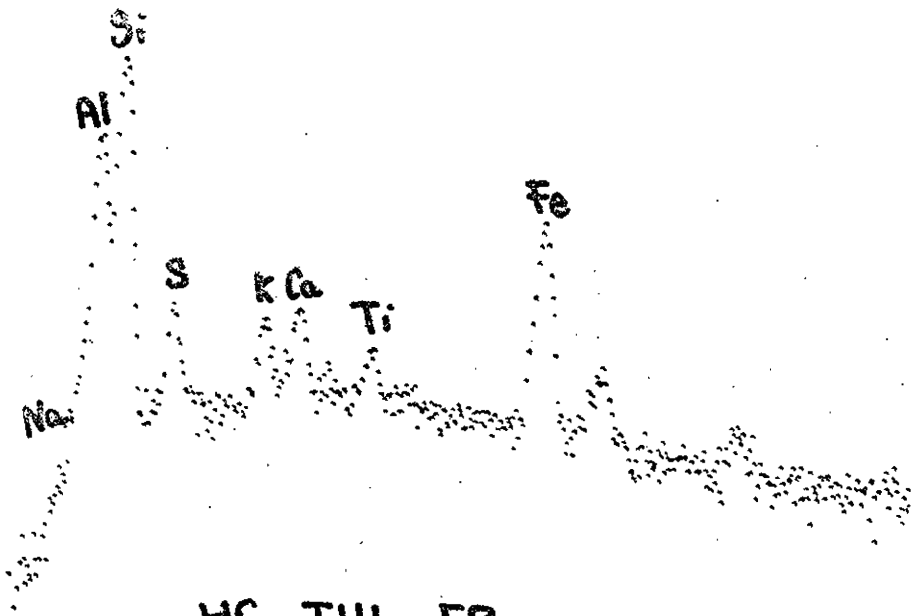
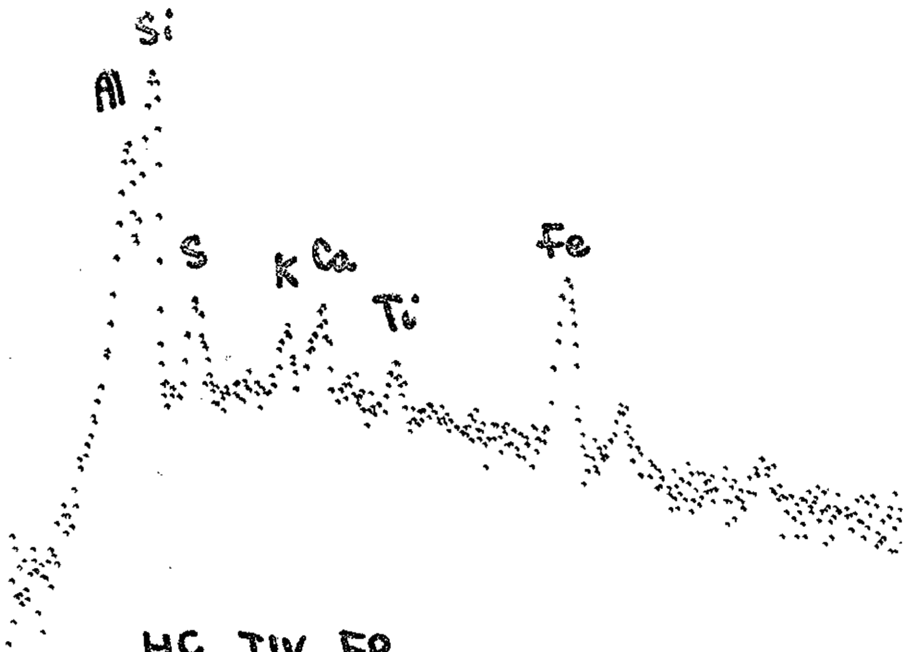


Figure 16(b)

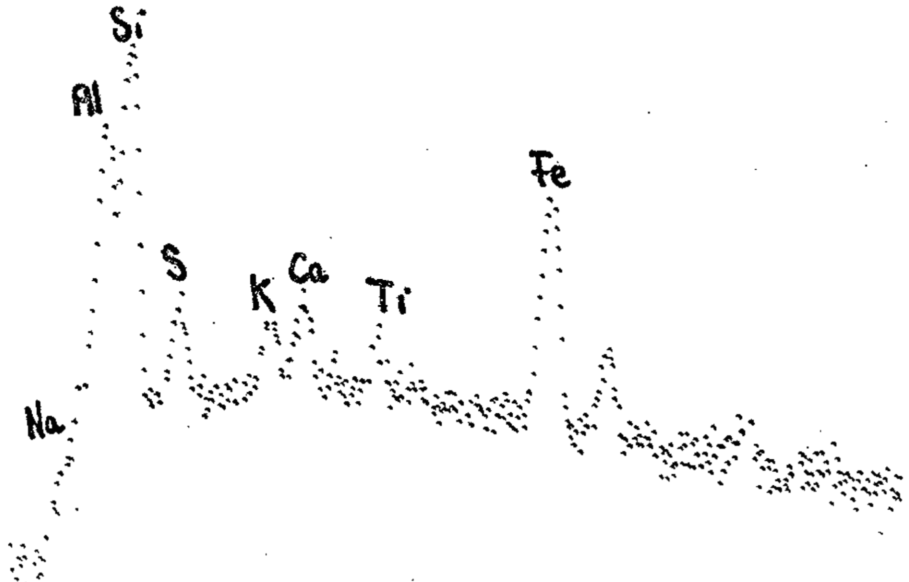
Elemental Analysis of Refuse Samples



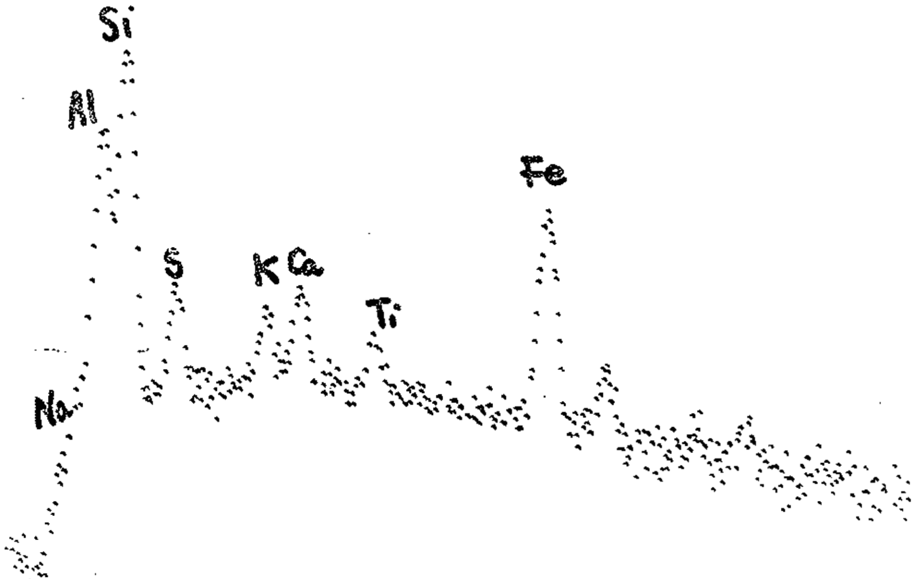
HC TIII FR



HC TIV FR



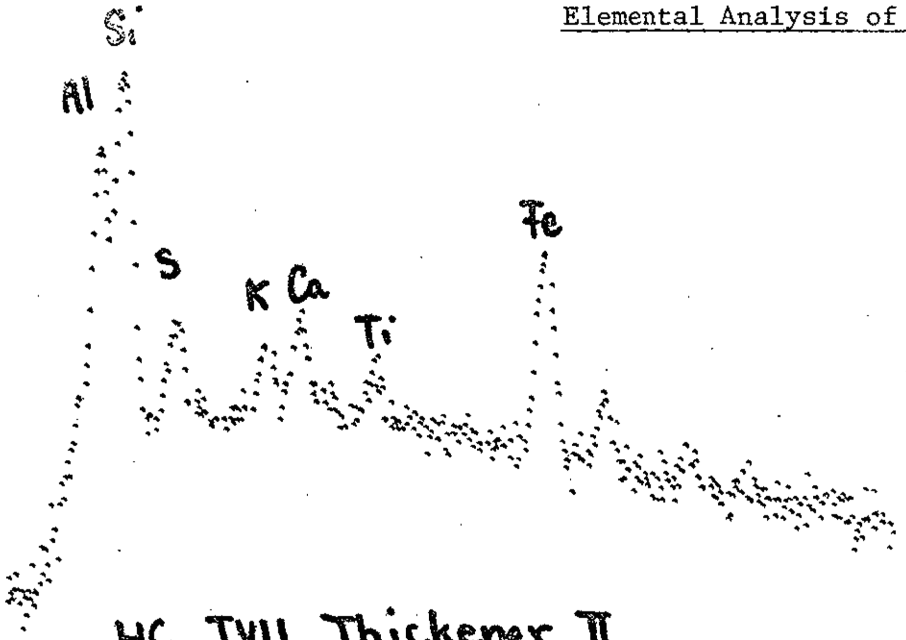
HC TV FR



HC TVIII FR

Figure 16(c)

Elemental Analysis of Refuse Samples



HC TVII Thickener II

Figure 16(d)

Results: Mineralogical and proximate analysis as carried out by X-ray and TGA techniques are shown below:

a) HC T11 CR - Mineral content: kaolinite, quartz, bentonite, feldspar and gypsum. Proximate analysis (db) shows 27.9% volatile[f], 13.9% fixed carbon and 51% ash.

b) HC TV11 CR - Mineral content: kaolinite, quartz, bentonite, feldspar and gypsum. Proximate analysis (db) shows 25.4% volatile[f], 12.4% fixed carbon, 62.3% ash.

c) HC TV111 CR - Mineral content: kaolinite quartz, bentonite, feldspar, gypsum (trace) and siderite.

d) HC TV FR - Mineral content: kaolinite, quartz, bentonite, gypsum, feldspar and siderite (trace).

e) HC TV11 Thickener II - Mineral content: kaolinite, quartz, bentonite and feldspar. Proximate analysis (db), 34% volatile[f], 12.1% fixed carbon and 53.8% ash. All the above specimens (#(a) to #(e)) are fired at 1400°C. The dimensional changes which occurred after firing are shown in Table XII.

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[f] volatile & dehydration of clay

Table XII (Grog)[f]

		Length (cm)			Width (cm)			Height (cm)			Volume			
Refuse #	Sample #	As-received	Dried at 105°C	Fired at 1400°C	As-received	Dried at 105°C	Fired at 1400°C	As-received	Dried at 105°C	Fired at 1400°C	As-received	After drying	% reduction	After firing
HC T11 CR	Z1	6.40	6.278	*	.964	.944	*	2.014	1.982	*	12.426	11.746	5.5	-
	Z11	6.408	6.30	*	.964	.944	*	2.064	2.036	*	12.750	12.108	5.0	-
HC TV11 CR	1A	6.40	6.292	*	.964	.940	*	1.96	1.926	*	12.092	11.391	5.8	-
	11A	6.40	6.30	*	.958	.938	*	1.982	1.962	*	12.152	11.594	4.6	-
HC TV11 CR	A1	6.414	6.322	*	.96	.944	*	1.992	1.966	*	12.266	11.733	4.3	-
	A11	6.392	6.258	*	.96	.936	*	2.004	1.97	*	12.297	11.539	6.2	-
HC TV FR	A	6.39	6.264	*	.96	.938	*	2.056	2.008	*	12.612	11.798	6.5	-
	B	6.338	6.27	*	.958	.936	*	2.038	2.0	*	12.472	11.737	5.9	-
HC TV11	01	6.40	6.28	*	.968	.94	*	2.118	2.08	*	13.121	12.279	6.4	-
Thickener	011	6.408	6.266	*	.964	.938	*	2.126	2.084	*	13.133	12.249	6.7	-
	0111	6.41	6.298	*	.964	.946	*	2.156	2.122	*	13.322	12.643	5.1	-

[f] see appendix

* no measurements are taken because of excessive bloating after firing at 1400°C

f) <u>HC TV1 CR</u> - One specimen made from HC TV1 CR is fired at 1200°C The mineralogical and proximate analyses are shown below. Mineral content: kaolinite, bentonite, quartz, feldspar, gypsum and siderite (trace). Proximate analysis (db), 28.6% volatile[f], 8.8% fired carbon and 62.6% ash. The dimensional changes on firing are shown in Table XIII.

<u>Table XIII</u>

	Length (cm)			Width (cm)			Height (cm)			Volume				
Sample #	As-received	Dried at 105°C	Fired at 1200°C	As-received	Dried at 105°C	Fired at 1200°C	As-received	Dried at 105°C	Fired at 1200°C	As-received	After Drying	% Reduction	After Firing	% Reduction
1.	6.374	6.262	5.758	1.466	1.436	1.34	.954	.932	.866	8.914	8.381	6.0	6.682	25.0
2.	6.38	6.252	5.758	1.414	1.386	1.296	.96	.923	.886	8.660	8.00	7.6	6.612	23.6

B) <u>Brick making</u>

<u>Thickener Samples</u> (HC TV111 ThickenerII)

Bricks are made from grog prepared from HC TV11 Thickener II and calcined clay of the same.

Calcined clay is prepared by firing these samples at 500°C until the samples are oxidized.

In a 50-50 mix of 1200°C grog and calcined clay, 10% bentonite, and 10% of thickener sample are added and blended together thoroughly. About 10 to 15% water is added gradually with splashes of kerosene. This should be a barely moist mixture. Approximately 50 g of the sample is poured into the die and pressed at 15,000 psi[e]. This is weighed and dried. The dimensions and weights of the dried bricks are recorded. A total of about 14 to 15 bricks are made. Then these are fired at 1200°C in a large furnace having the same firing characteristics as that of Clayburn. The heating period takes about two days. The weight and dimensions of the bricks after firing are again recorded.

Results: The dimensional changes of the bricks are recorded in Table XIV.

Table XIV

	Weight of Sample (g)		Length (cm)		Height (cm)		Width (cm)		Volume (cm^3)			Bulk Density
Sample #	after drying	after firing	Dried at 105°C	Fired at 1200°C	Dried at 105°C	Fired at 1200°C	Dried at 105°C	Fired at 1200°C	after drying	after firing	% reduction	after firing g/cm^3
T11	41.3	38.8	7.668	7.398	3.184	3.088	1.172	1.022	28.614	23.348	18.4	1.66
T111	41.	38.	7.658	7.380	3.200	3.082	1.152	1.104	28.230	25.111	11.0	1.51
TIV	40.5	37.8	7.654	7.376	3.216	3.10	1.136	1.090	27.963	24.926	10.9	1.52
TV	40.2	37.7	7.700	7.404	3.180	3.058	1.128	1.080	27.620	24.453	11.5	1.54
TV1	40.5	37.7	7.658	7.374	3.208	3.096	1.138	1.096	27.957	25.022	10.5	1.5
TV11	39.9	37.1	7.662	7.364	3.20	3.07	1.14	1.096	27.951	24.778	11.4	1.50
TV111	39.9	37.1	7.694	7.40	3.176	3.056	1.056	1.10	25.805	24.876	3.6	1.40
T1X	40.	37.2	7.668	7.376	3.194	3.088	1.178	1.104	28.851	25.146	12.8	1.48
TX	40.4	37.8	7.664	7.386	3.200	3.088	1.130	1.084	27.713	24.724	10.8	1.53
TX1	41.0	37.2	7.690	7.372	3.210	3.064	1.286	1.190	31.745	26.879	15.3	1.38
TX11	41.	37.2	7.700	7.376	3.194	3.038	1.266	1.170	30.988	26.218	15.4	1.42
TX111	40.9	37.2	7.682	7.356	3.196	3.056	1.268	1.18	31.132	26.526	14.8	1.40
TX1V	41.6	37.9	7.686	7.350	3.210	3.062	1.260	1.20	31.087	27.007	13.1	1.40
TXV	44.2	40.3	7.676	7.342	3.22	3.068	1.342	1.28	33.170	28.832	13.1	1.40

II. Refuse Samples

For these bricks two of the samples are used. They are HC T1V FR and HC T11 FR, as the quantity of the sample HC T1V FR is not adequate to make all brick specimens.

Both HC T1V FR and HC T111 FR are fabricated into brick shapes and fired to produce grog. These grogs are then used following the procedure described in the Thickener section to produce final bricks. Brick numbers R111 → RX made from HC T1V FR grog and HC T111 FR from calcined clay. Brick numbers RX1 → RXV made from HC T111 FR grog and calcined clay. The results of the dimensional clays on firing are shown in Table XV.

Table XV

	Weight of sample (g)		Length (cm)		Height (cm)		Width (cm)		Volume (cm^3)			Bulk Density
Sample #	after drying	after firing	Dried at 105°C	Fired at 1200°C	Dried at 105°C	Fired at 1200°C	Dried at 105°C	Fired at 1200°C	after drying	after firing	% reduction	after firing g/cm^3
R111	41.7	38.1	7.690	7.40	3.184	3.066	1.272	1.240	31.145	28.134	10.0	1.35
RIV	43.	39.6	7.688	7.40	3.180	3.066	1.340	1.298	32.760	29.450	10.1	1.34
RV	41.7	38.2	7.680	7.386	3.196	3.08	1.286	1.23	31.565	27.981	11.4	1.37
RV1	41.4	38.1	7.680	7.388	3.204	3.08	1.278	1.218	31.447	27.716	11.9	1.37
RV11	41.8	38.2	7.708	7.396	3.182	3.056	1.294	1.228	31.738	27.755	12.5	1.38
RV111	41.3	38.	7.690	7.386	3.194	3.06	1.310	1.240	32.176	28.025	12.9	1.36
R1X	41.3	38.	7.692	7.404	3.192	3.07	1.278	1.216	31.379	27.640	11.9	1.37
RX	41.4	38.1	7.680	7.40	3.174	3.066	1.280	1.224	31.202	27.771	11.0	1.37
RX1	42.1	37.9	7.688	7.290	3.20	3.04	1.34	1.266	32.966	28.057	14.9	1.35
RX11	42.1	38.	7.704	7.324	3.190	3.048	1.336	1.266	32.833	28.262	13.9	1.35
RX111	42.1	38.	7.70	7.33	3.20	3.022	1.334	1.276	32.870	28.265	14.0	1.34
RX1V	42.1	37.9	7.692	7.314	3.198	3.042	1.332	1.244	32.766	27.678	15.5	1.37
RXV	33.9	30.5	7.712	7.328	3.186	3.03	1.086	1.00	26.683	22.204	16.8	1.37
RXV1	31.	27.9	7.670	7.312	3.20	3.05	1.016	.970	24.937	21.633	13.2	1.29

Discussion:

Refuse and Thickener Bricks

Bricks produced from Hat Creek refuses are very similar. The colour and texture of these bricks made from refuse (fine and coarse refuse) and thickener refuse can be noted from Figures 17 and 18.

Figure 17

Fine and Coarse Refuse Bricks

Figure 18

Thickener Refuse Bricks.

The moisture loss after drying for refuse bricks are -5%. The weight loss and volume shrinkage after firing and the bulk density after firing for the refuse (fine and coarse) bricks are -8.6%, -12.8% and 1.4 g/cm^3. While the weight loss and volume shrinkage after firing and the bulk density after firing for the thickener refuse are -7.8%, -12.3% and 1.5 g/cm^3.

Because of the similarity in colour and fired density between the refuse from coarse and fine refuse and Thickener, refuses can be mixed together for making building bricks, without having any significant effect on the final properties.

Summary and Conclusions:

I. Reject Material from Mining - Kaolinitic Clays

As noted in the Introduction section, rich kaolinitic clay deposits exist in the Hat Creek coal deposit. This kaolinitic clay appears to be present in the lower part of the deposit, especially in B and D zones. However, bands of pure kaolinitic clay (along with quartz) have been encountered in other zones also. For example, samples from diamond drill hole DDH 76-164 in the A zones at a depth of 253 to 273 feet mainly consist of kaolinitic (88%) and bentonite (12%), and DDH 76-126 at a depth of 853 to 870 feet (A zone) contains 64% kaolinitic and 25% quartz (with siderite and pyrite minor constituents). Similar bands of kaolinite have also been found in the 'C' zones at depths of ~200 feet (DDH 76-180), and 254 feet (DDH 76-181). In general the concentration of kaolinite increases in depth, whereas bentonite decreases. Some of the kaolinitic clays can even be found as protrusions near the overburden of the deposit.

If selective mining is feasible, uses can be found for much of the kaolinitic clay. Pure white kaolinitic clay is used in refractory, paper and pulp, paints and varnishes and pharmaceutical industries. The kaolinitic clay of the Hat Creek coal deposit contains silica as quartz and a small concentration of siderite. By sedimentation and washing the siderite compounds can be eliminated and the concentration of quartz can be reduced significantly. Depending upon the sedimentation time, it is possible to obtain a size fraction containing ~90% of kaolinitic and 10% of quartz (after a sedimentation period of 20 to 25 hours). In industrial practice, however, this type of separation would be carried out in a centrifuse shortening the period to a few minutes.

The kaolinitic clay as exists in the deposit is dark grey in colour. After separation by flotation (i.e. sedimentation) this becomes slightly lighter but not good enough for paper-pulp or paint-varnish industries. So attempts were made to bleach this clay (after sedimentation) by heating and/or chemical treatments, so that the grey colouration could be removed and make this clay suitable for use as paper filler and in paint-varnish industries.

The following attempts were made to generate products of commercial and industrial interests from the kaolinitic clay of the Hat Creek deposit.

A. From "Kaolinitic Clays - As-Received"
   1. Refractory bricks
   2. Cement
B. From "Float Fraction of Sedimented Kaolinitic Clays"
   1. Refractory bricks
   2. Aluminum oxide extraction for aluminum and refractory industries
   3. Bleached clay for paper-pulp industries

Refractory Bricks

Medium duty refractory bricks can be easily made from the enriched kaolinitic clay (float fraction) - see Figure 4. The bricks produced from the clay as received have black spots (Figure 2) indicative of the presence of iron-bearing compounds such as siderite and pyrite. The bricks of the unwashed clay can either be used as a low heat duty refractory brick or as building bricks, (because of the pleasing colour and texture).

Cement

The alumina content of the kaolinitic clay is higher than the necessary requirements for Portland Cement. However, preliminary assessment of cement manufacturing potentiality shows that this clay may be too good to be used for cement. From the chemistry point of view, there is no doubt that this clay can be used for manufacturing cements. With some enrichment of Al_2O_3 this clay is suitable for producing refractory cements. Table VI shows the chemical analyses of several clays used in producing Portland cement, this kaolinitic clay is qualitatively much superior than that of clays listed in the table.

Attempts to manufacture cement as detailed previously showed that the major constituents necessary for cementation (i.e. hydraulic-sensitive components) are present as shown in Table VII. It should be pointed out that no exhaustive studies are made on this aspect and further work is necessary to draw any final conclusion in this respect.

Aluminum Oxide Extraction

Attempts were made to extract Al_2O_3 from the float fraction of the kaolinitic clay by three methods; (i) soda-lime sinter; (ii) lime sinter, and; (iii) the Pechiney H^+ process. Only few attempts were made in this regard to explore the potentiality of the materials as a source for alumina. No quantitative assessment is made about pros and cons of different processes available. There is no obstacle in extraction Al_2O_3 from this clay. Although the experiments to date show only a modest recovery, ~60% of the Al_2O_3 present in the clay, an extensive experimental programme can optimize the processing variables for extraction of most of the alumina present in the material. The general behaviour of this clay with respect to extraction of alumina is very similar to other clays reported previously by the workers.[a]

The experimental programme carried out in this investigation shows that both lime-soda sinter and the Pechiney H^+ process can be easily used to obtain Al_2O_3 from this clay.

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[a] Reference number 7,8,9.

Bleached Clay

The clay contains significant concentrations of iron, titanium and organic impurities. The colours originating from these impurities were bleached by the following methods:

1. Chemical treatment
2. Heat treatment, and
3. Combination of chemical and heat treatments.

Both chemical and heat treatments bleached the grey colouration of the clay. But because of the high iron content completely white clay cannot be produced from this material. The bleached clay has a very light yellowish stain (Figure 10) which would prevent it from being used as a paper coater. However, there is every reason to believe that the bleached clay may be suitable as a paper-filler and also may be useful in paint and varnish industries.

To be suitable for use in the paper or paint industries, certain other characteristics such as grit size, grain size and reflectance properties have to be met by any clay. For these tests a large batch of bleached clay (by heat treatment) has been supplied to Dr. John Howard, B.C. Research, for further tests.

The bleaching operation by heat treatment was carried in batches in a gas fired kiln. This resulted in agglomeration of the clay particles, which have to be ground subsequently for use as a paper filler. In industrial practice the clay can be heated in a fluidized bed which would eliminate the batch operation and the subsequent step of grinding (which may be an expensive operation).

C) Rejects from Washing Plants

Elemental analyses by SEM (Figures 16A to D) showed that these materials contain Fe, Ti, Ca and alkaline, and similarly proximate analysis showed that these materials also have 12-13% of fixed carbon. Presence of large concentrations of Fe_2O_3 (>3%), TiO_2, CaO, Na_2O and K_2O in these materials precludes their use as refractory materials. The only use we can consider is in the building brick and cement industries.

Beautiful red, brown or yellow coloured bricks can be produced from these materials without any difficulty as discussed previously. See for example Figures 17 and 18.

It should be pointed out that all the efforts in this programme were devoted to the technical aspects of utilization of mine wastes and refuses from washing plants, which would be generated from the Hat Creek coal deposit. No attempt has been made to analyse the economic aspects of any of the uses, developed in this investigation and reported herein.

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Appendix

Calculation of calcium carbonate and shale for making cement.

Portland cement consists of ~50% $3\ CaO.SiO_2$, ~25% $2\ CaO.SiO_2$, and ~10% $3\ CaO.Al_2O_3$

To make 1g of Portland cement, the amounts of CaO, SiO_2, and Al_2O_3 required are as follows:-

$$\text{Weight of CaO} = .5g\,\frac{3(56.1)}{228.4} + .25\,\frac{2(56.1)}{172.3} + .10\,\frac{3(56.1)}{270.3} = .368g + .163g + .068g$$

$$= .593g$$

$$\text{Weight of } SiO_2 = .5g\,\frac{60.1}{228.4} + .25\,\frac{60.1}{172.3} = .132g + .087g$$

$$= .219g$$

$$\text{Weight of } Al_2O_3 = .10\,\frac{102}{172.3}$$

$$= .059g$$

$$.593g \text{ of CaO} \rightarrow 1.057g\ CaCO_3$$

$$\therefore \text{Weights required } 1.057g\ CaCO_3 \rightarrow .219g\ SiO_2$$

As-received kaolinitic sample consists of ~63% SiO_2

$$\text{Wt. of kaolinitic sample required} = \frac{100}{63} \times .219g\ SiO_2 = .35g$$

Therefore, 1.057g $CaCO_3$, and .35g kaolinitic sample are required to make 1g of Portland cement.

(Approximately 3 parts of $CaCO_3$ to 1 part of kaolinitic clay).

APPENDIX

Bricks are made from two components: clay and grog. Clay is the raw material.

Grog:	Grog is clay fired at high temperatures 1200 → 1400°C. Grog is much harder than clay and it forms the skeleton of the bricks.
Calcined Clay:	In this case, calcined clay is used instead of raw clay to get higher density bricks. Calcined clay is fired at 500°C.
Ball Clay:	The mineralogical composition of ball clay consists mainly of three components: kaolinite, hydrous mica and quartz with some primary mica and titania, but no feldspar. The chemical analyses of ball clays usually fall within these limits; silica 45 → 60%, alumina 25 → 35%, loss of ignition 7 → 15%, iron oxide <2%, lime and magnesia <1% and potash and soda <3%. Ball clay consists of fine particle sizes, and has excellent plasticity and dry strength.

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TITLE: CLAY RESOURCE
HAT CREEK COAL DEPOSIT

FILE F.10.2

PROJECT No. 524.78

AUTHOR: D. Albon

DATE September 12, 1978

COPY TO: J. L. Williams

INTRODUCTION

Samples of partially calcined clay were collected at the Hat Creek coal deposit and returned to the Abbotsford laboratory for evaluation. A sample of beneficiated crude clay, prepared by Dr. Chaklader at U.B.C., was also forwarded to Abbotsford for pyrometric cone equivalent determination.

CONCLUSIONS

1) The calcined material satisfied the A.S.T.M. specification for a Low Duty refractory type material.

2) The material will require further treatment to minimize the shrinkage (approximately 8.5%) prior to admixture in any structural clay body - this will also serve to eliminate the problems likely to be associated with the 12.5% loss on ignition.

3) The Cone 30 value of the beneficiated sample satisfied the A.S.T.M. specifications for a Medium Duty refractory material.

4) The alumina content 28.01% (on a partially calcined basis) is high for this type of material and reflects in the P.C.E. values. This in spite of the high iron (6.52%)and alkalies (NaK_2O) 2.36%.

D. Albon
Director of Research

EXPERIMENTAL

SAMPLE LOCATION

Sample 1 - South side of exploratory cut east end.

Sample 2 - South side of exploratory cut west end.

Sample 3 - North side of exploratory cut east end.

Sample 4 - North side of exploratory cut west end.

LOSS ON IGNITION (1830°F for 3 Hours)

Sample	L.O.I.	
1	8.47%	
2	15.42%	
3	10.13%	
4	15.93%	Average 12.49%
Control Sample (Clayburn Calcines)	0.20%	

THERMAL GRADIENT TESTS

The individual samples were ground minus 14 mesh, bonded with 5% M&D ball clay, dry pressed into thermal gradient bars and fired to 2300°F in 20 hours and held for one hour. After cooling the specimens were checked for linear shrinkage.

% LINEAR SHRINKAGE

Temperature °F	Sample #1	Sample #2	Sample #3	Sample #4	Control Sample Clayburn Calcines
1400	0.3	1.5	0.1	2.3	Nil
1500	0.4	2.0	0.2	3.1	Nil
1600	0.5	2.7	0.4	4.0	Nil
1700	0.5	3.3	1.1	4.9	Nil
1800	1.1	4.1	2.2	6.0	Nil
1900	4.1	5.5	3.4	7.1	0.1
2000	6.1	6.6	4.5	8.3	0.6
2100	7.4	6.9	5.7	9.0	1.2
2200	8.3	7.5	6.8	9.6	1.6
2300	8.3	8.1	7.7	9.5	2.0

PYROMETRIC CONE EQUIVALENT DETERMINATIONS

Composite of Samples #1, #2, #3 and #4 -	Cone 19 (2806°F)
Beneficiated Sample	Cone 30 (3029°F)