OPEN FILE

937001

DOCUMENTATION ON BROWN PLAINS CLAY DEPOSIT

Compiled by

C.H.C. SHANNON

(July 1989)

EL 27/90

MICROFILMED
FICHE No. 012901 - 02

CORINNA CLAYS PARTNERSHIP

(South Raeburn Pty Ltd & C.H.C. Shannon)

319 Brisbane Street West Launceston 7250

9[illegible]-3542

937

937002

DOCUMENTATION ON BROWN PLAINS CLAY DEPOSIT

Compiled by

C.H.C. SHANNON

(July 1989)

CONTENTS

94-3542

CORINNA CLAYS PARTNERSHIP

(South Raeburn Pty Ltd & C.H.C. Shannon)

319 Brisbane Street West Launceston 7250

937003

CLAY SAMPLE LEDGER

SAMPLE NUMBER	LOCATION (grid ref)	DESCRIPTION
		Samples GS 30-34 comprise a series of partially overlapping 25kg samples from the main clay exposure. The aim of this sampling was to collect material of a particular colour and/or grain size which would be likely to be reproducable under full scale quarrying conditions.
GS 30	482917	1.5m, chocolate brown clay.
GS 31	"	1m, as above.
GS 32	"	1.2m, as above.
GS 33	"	1m, as above.
GS 34	"	1.2m, off white clay slightly sandy.
GS 35	471912	Roadside cutting, 1.5m section of chocolate brown clay, 25kg sample.
CR 1	449911	Light brown plastic clay from gravel pit south of road c.f. GS 3.
CR 2	435899	1.5m section of dark brown, well bedded clay. Base not exposed these but 15m away allowing thickness estimate of 2 - 3m. Road cutting exposure.
CR 3	452911	Brown silty clay from grader scrape next to road.

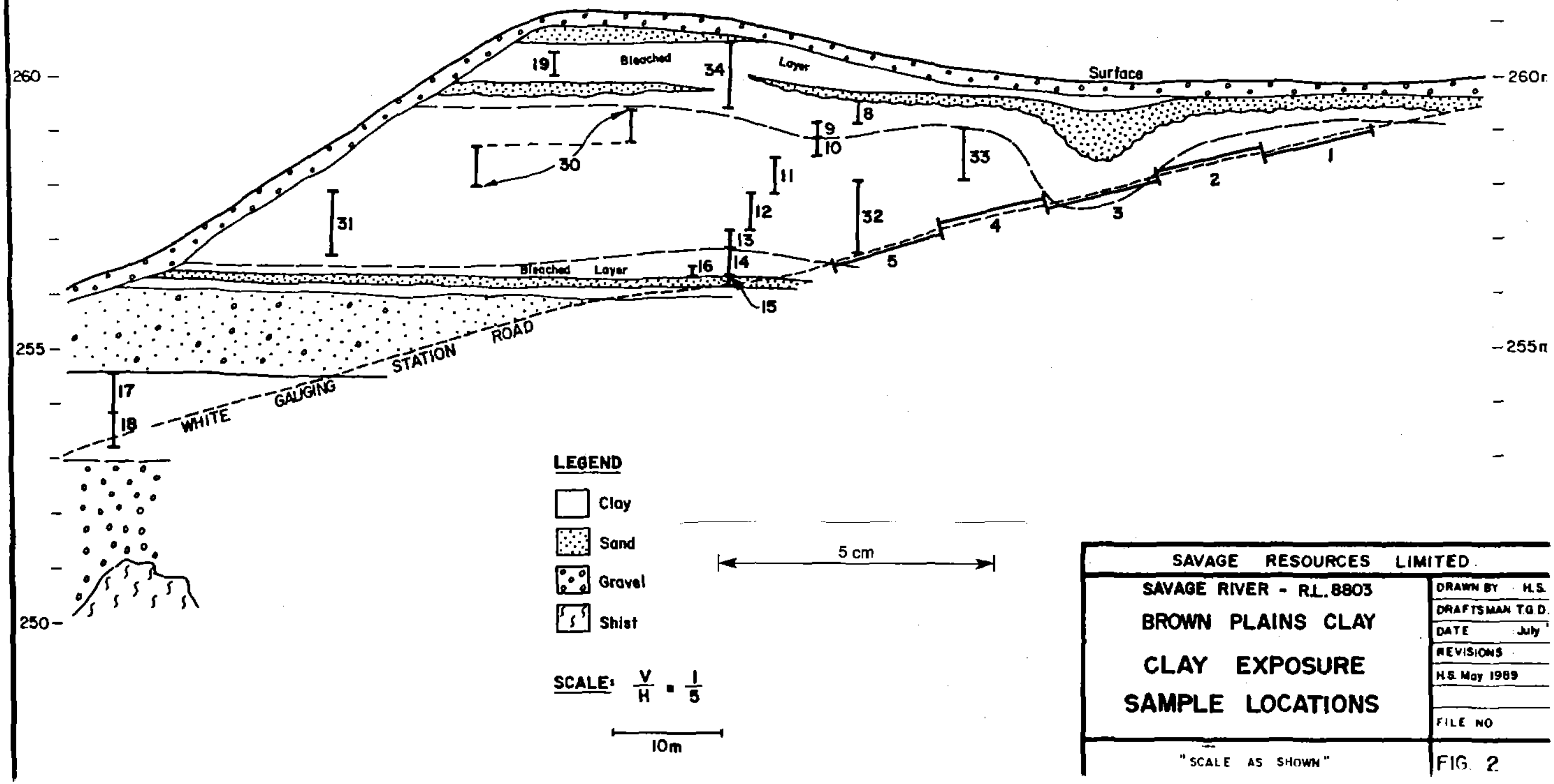
CLAY SAMPLE LEDGER

SAMPLE NUMBER	LOCATION (grid ref)	DESCRIPTION
GS 16	482917	2m south from GS 14, blister of yellow clay occupying 20cm of the interval sampled near base of GS 14.
GS 17	"	70cm leached white clay, silty in part from upper portion of clay bed below 1.5 - 2.0m of sand between this sample and GS 15.
GS 18	"	60cm yellow-orange-pink leached clay, lower portion of bed sampled by GS 17. Rests on basal gravel bed of variable thickness, which overlies weathered Timbs Formation.
GS 19	"	c. 30cm, white sandy clay from above 1.2m sand bed overlying GS 8.
		Samples GS 20 to GS 24 comprise a spot sampled column over 2.8m of exposure in an erosion gully in a gravel pit. The material is mostly indurated owing to weathering processes acting adjacent to transported gravel cover. The top is exposed but not the base and it is considered very likely that this is the same clay bed sampled by GS 1-5 and 8-15.
GS 20	480919	top, pink and brown clay, some silty.
GS 21	"	brown indurated clay and stiff clay.
GS 22	"	as above.
GS 23	"	as above.
GS 24	"	bottom of exposure, as above but with minor coarse sand indicating approach to true bottom of bed.
GS 25	480915	50cm hand auger sample, pink clay over orange sandy clay.
		Samples GS 26-28 constitute a continuous section taken with a hand auger, the top is truncated. At 471912 this locality is over 1km from the main sample area. It may represent the bed of samples GS 17-18 free of illuvial contamination.
GS 26	471912	top, 40cm, chocolate brown and some pink clay.
GS 27	"	55cm, pink clay.
GS 28	"	75cm, off white clay silty near base.
GS 29	476918	80cm, indurated, chocolate brown silty clay grading to clayey sand.

CLAY SAMPLE LEDGER

SAMPLE NUMBER	LOCATION (grid ref)	DESCRIPTION
GS 1	482917	From road gutter, dark brown clay with macerated plant fossil material, some humic acid material and sand in joints. Series of spot samples over 10m.
GS 2	"	From next 10m of road gutter downhill from GS 1, dark brown clay, minor contamination of sample from sand in joints.
GS 3	"	From next 10m of road gutter downhill from GS 2, light brown clay, more plastic than dark variety and apparently derived from it by a near surface wet weathering process.
GS 4	"	From next 10m of road gutter downhill from GS 3, dark brown clay c.f. GS 2.
GS 5	"	From next 10m of road gutter downhill from GS 4, dark brown clay c.f. GS 2. end of continuous section.
GS 6	482916	Fines component of gravel associated with the clay.
GS 7	479917	From the gravel pit area 300m W. of GS 1-5 suite, 1.5m stratigraphic section of dark brown clay.
		The aim is to get a precise sample of the column previously sampled by GS 1-5. Samples GS 8-15 constitute a complete column through the deposit taken with a hand auger in a series of auger holes. The staircase of holes is adjacent to old sample GS 5 in the new exposure.
GS 8	482917	Top of section, 45cm of pink plastic clay, with minor sand 2-3cm at c. 20cm.
GS 9	"	30cm pink plastic clay.
GS 10	"	35cm dark brown stiff clay.
GS 11	"	65cm as above.
GS 12	"	65cm as above.
GS 13	"	30cm as above.
GS 14	"	45cm pink clay with sand at base.
GS 15	"	clayey sand, mostly light grey, minor orange. end of continuous section.

937006



SAVAGE RESOURCES LIMITED.

SAVAGE RIVER - R.L. 8803

BROWN PLAINS CLAY

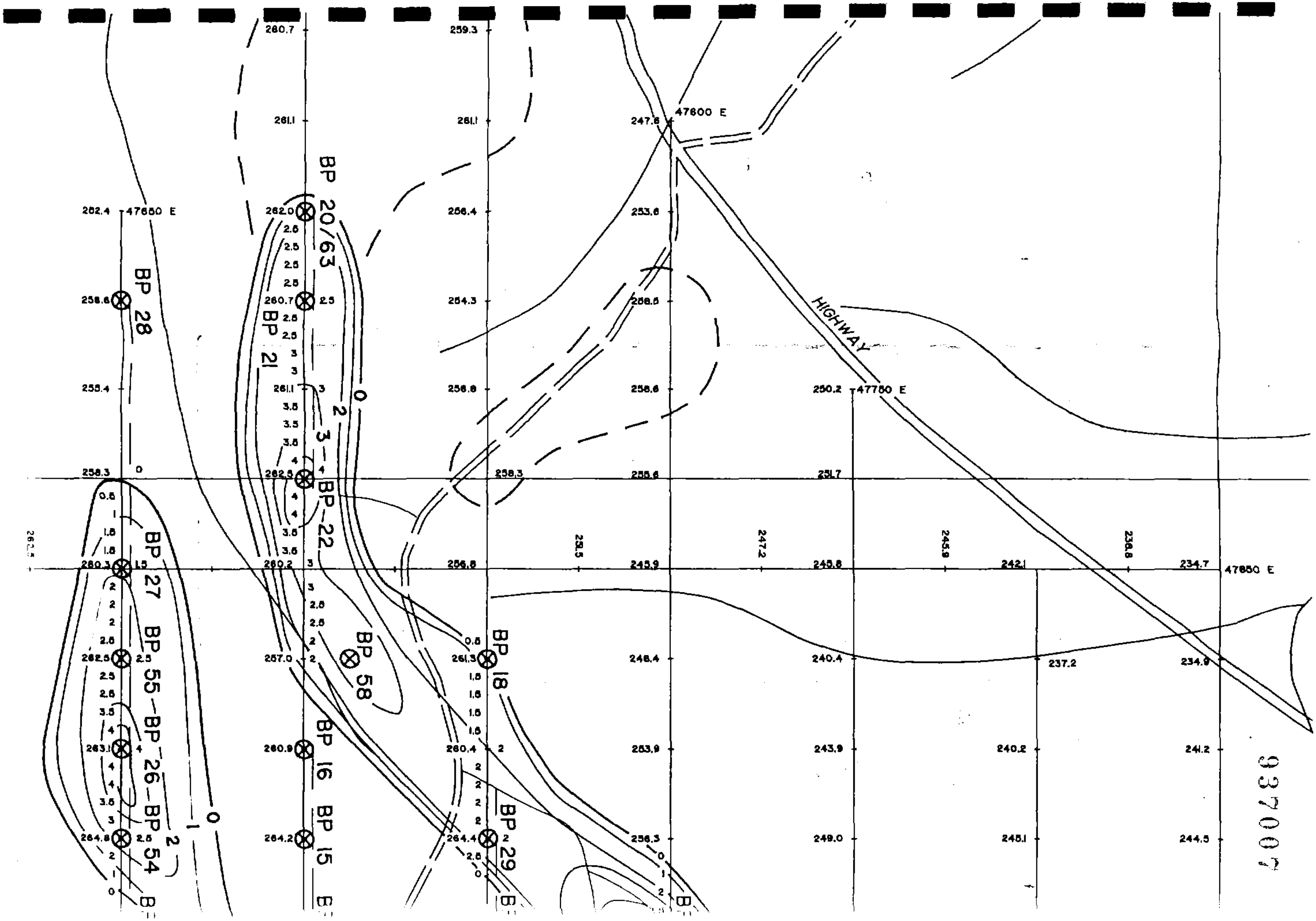
CLAY EXPOSURE

SAMPLE LOCATIONS

DRAWN BY H.S.
DRAFTSMAN T.G.D.
DATE July
REVISIONS
H.S. May 1989
FILE NO

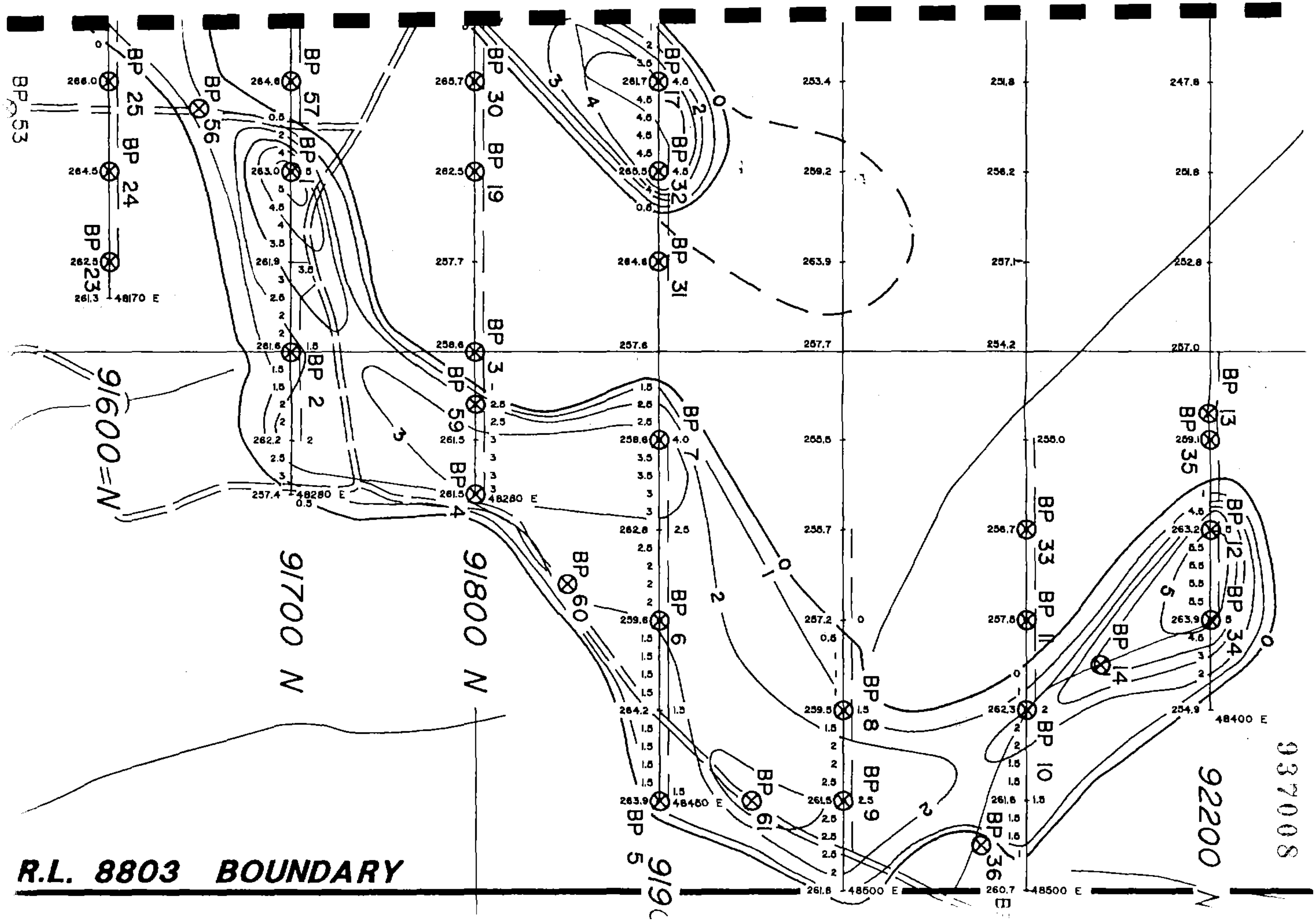
"SCALE AS SHOWN"

FIG. 2

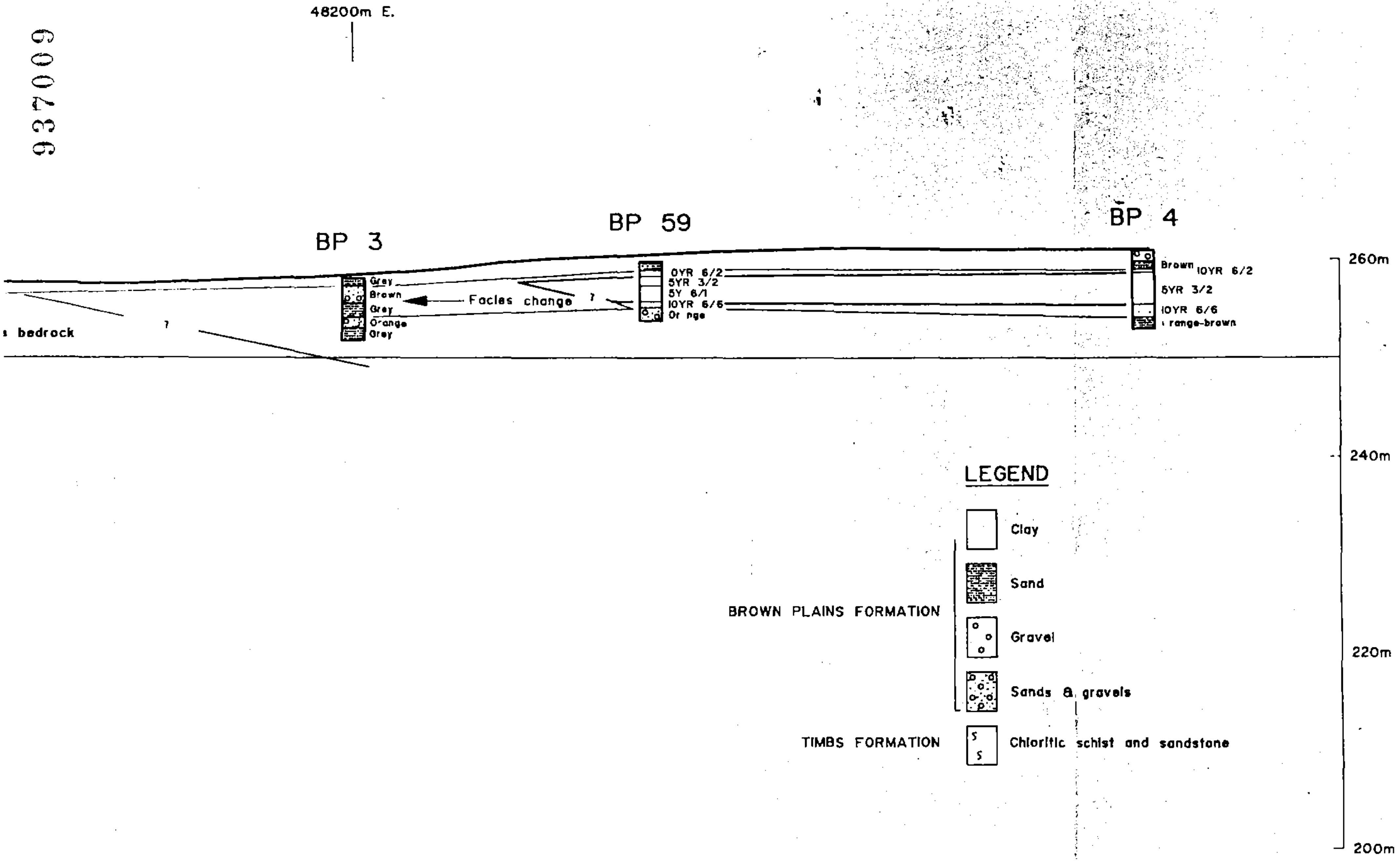


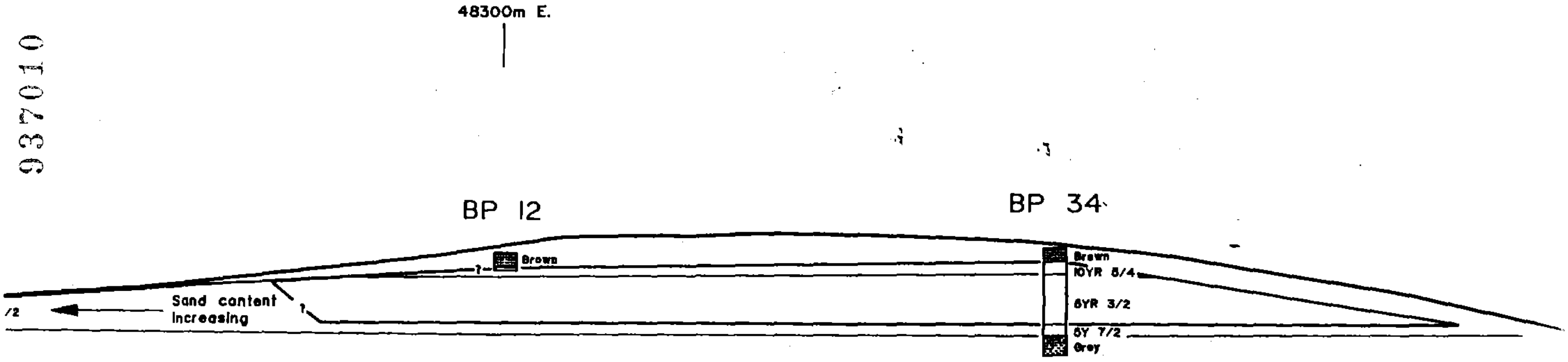
47600 E
47650 E
47700 E
47750 E
47800 E
47850 E
HIGHWAY
BP 20/63
BP 21
BP 22
BP 28
BP 27
BP 55
BP 26
BP 54
BP 58
BP 16
BP 15
BP 18
BP 29
260.7
259.3
261.1
261.1
247.8
262.4
262.0
256.4
253.6
258.6
260.7
254.3
256.5
255.4
261.1
256.8
256.6
250.2
258.3
262.5
258.3
255.6
251.7
260.3
260.2
256.8
245.9
245.8
242.1
234.7
255.5
247.2
245.9
236.8
262.5
257.0
261.3
246.4
240.4
237.2
234.9
263.1
260.9
260.4
253.9
243.9
240.2
241.2
264.8
264.2
264.4
256.3
249.0
245.1
244.5
0
1
2
3

937007


R.L. 8803 BOUNDARY
91600=N
91700 N
91800 N
9190
92200 N
48170 E
48260 E
48280 E
48400 E
48460 E
48500 E
BP 53
BP 25
BP 24
BP 23
BP 56
BP 57
BP 1
BP 2
BP 30
BP 19
BP 3
BP 59
BP 4
BP 60
BP 17
BP 32
BP 31
BP 7
BP 6
BP 5
BP 61
BP 8
BP 9
BP 36
BP 33
BP 11
BP 10
BP 13
BP 35
BP 12
BP 34
BP 14
266.0
264.5
262.5
261.3
264.6
263.0
261.9
261.6
262.2
257.4
265.7
262.5
257.7
258.6
261.5
261.5
261.7
266.5
264.6
257.6
258.6
262.8
259.6
264.2
263.9
253.4
259.2
263.9
257.7
255.5
258.7
257.2
259.5
261.5
261.6
251.8
256.2
257.1
254.2
256.0
256.7
257.8
262.3
261.6
260.7
247.8
251.6
252.8
257.0
259.1
263.2
263.9
254.9
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
937008

937009


48200m E.
BP 3
BP 59
BP 4
Grey
Brown
Grey
Orange
Grey
Facies change
?
0YR 6/2
5YR 3/2
5Y 6/1
10YR 6/6
Or nge
Brown 10YR 6/2
5YR 3/2
10YR 6/6
range-brown
s bedrock
?
260m
240m
220m
200m
LEGEND
Clay
Sand
Gravel
Sands & gravels
BROWN PLAINS FORMATION
TIMBS FORMATION
Chloritic schist and sandstone


48300m E.
BP 12
BP 34
Brown
?
Brown
10YR 5/4
5YR 3/2
5Y 7/2
Grey
/2
Sand content increasing
?

937011

MARAFIELD PTY LTD

THE RESULTS OF A PRELIMINARY INVESTIGATION OF TEN SAMPLES OF TASMANIAN CLAY SUPPLIED THROUGH "STECK RESOURCES PTY LTD"

John A. Hosking
22 February 1987

301 Lydiard St Nth, Ballarat, VIC 3350.

PREAMBLE

Ten clay samples were supplied by Steck Resources Pty Ltd with instructions for a "quick and cheap appraisal", this we have endevoured to do within the limitations and dictates of the material itself.

The material is very unusual in that much of it has a very high organic content and it was evident that there was significant sandy contamination, (it is not certain how much of this is inherent, and how much is due to near surface sampling.) Because of this high and variable contamination, it was felt that to achieve some sort of meaningful comparison, the samples should be examined only after some level of standard refining. The aspirations of the client, to satisfy a ceramic market, to some extent dictated the procedure, and it was decided to screen the fully dispersed samples though 150# prior to any physical or chemical examination.

THE PROCEDURE

Each clay was dispersed at 33% solids using a low speed mixer and a polyacrylate dispersant at an initial dose level of 0.4 %. In most cases this dose was found to be inadequate and undispersed residue was further treated in a high speed mixer with additional dispersant.

The clay slurry was diluted to about 15% solids and screened though a 150# screen. The >150# residue was dried and weighed. The screened slurry was topped up to 6 litres with water and thoroughly mixed before taking a 1 litre aliquot. The 1 litre sample was sedimented at 12 secs per millimeter depth to remove all +10u material and the residue rediluted and sedimented a second time. The <10u fraction of three clays was retained for further examination. The >10u residue was dried and weighed.

The remaining screened slurry was floculated by adding hydrochloric acid and allowed to settle for 24 hours. After this period, the supernatent liquid was decanted and a sample of clay filtered on a Buckner vacuum funnel.

The filter cake was cut into 100mm strips and dried. After drying the strips were measured to ascertain drying shrinkage and weighed prior to firing.

Each clay was fired at 1000 C and 1180 C and the resultant strips measured and weighed to determine loss on ignition and firing shrinkage.

The fired strips were then boiled in water for one hour, cooled, dried, and weighed, to determine absorption.

A subjective assessment of colour was also made.

Five selected samples were also sent for full chemical analysis.

THE RESULTS

The results of the physical examination of the samples are recorded in Table 1 and the chemical analysis of the five selected samples is recorded in Table 2.

Below are recorded a number of observations made during the process of examination.

General Comments

The majority of the samples have a very high organic content, this is distributed thoughout the size range. Some of the dispersed slurries showed evidence of an oily film on the surface, and in one case the >150µ fraction was actually smouldering after drying at 200 C !

Most of the clays are not very strong or plastic, but this is almost certainly a function of the high level of fine sand present, as evidenced by high >10u contents. The finer fractions increased dramatically in strength and plasticity.

As we were dealing with an unknown quantity, some procedures were modified as the investigation proceded, and, although we have no control, some logical deductions can be made from the varying results. Some of the GS clays in particular contained some very tough particles which resisted dispersion and, as we proceded we tried a number of methods to effect better dispersion. These methods varied from rubbing these particles out manually to redispersing them once or even twice in a high speed macerator. It may be significant that the sample subjected to the most violent dispersion also gave the highest <10u result.

TABLE 1

MPLE NO.	APPEARANCE	DISPERSANT DEMAND	% +150M	% +10u	% -10u	DRYING SHRINKAGE	LOSS ON IGNITION	FIRING 1000 C	SHRINKAGE 1180 C	ABSORPTION 1000 C	ABSORPTION 1180 C	FIRED COLOUR 1000 C	FIRED COLOUR 1180 C
GS1	Dark brown with large amount of humus	0.65	31.40	24.10	45.50	6.00	13.46	1.00	11.50	50.90	22.70	White	White
GS2	Dark brown clay with some humus	0.42	11.90	40.40	47.70	6.00	18.95	1.50	6.00	28.60	17.60	White	White
GS2 A	<10u fraction of GS2	-	-	-	100.00	9.00	-	1.00	3.00	31.90	-	White	-
GS3	Light brown clay	0.66	11.10	28.30	60.60	7.00	16.47	1.00	19.00	54.20	23.80	White	Off white
GS4	Dark brown clay with some humus	0.53	22.00	28.80	49.20	6.00	19.40	0.00	15.00	65.40	22.20	White	Pale cream
GS5	As above	0.74	34.20	32.60	33.20	7.00	16.51		8.00	61.50	34.80	White	Pale cream
GS6	Fine silica sand												
GS7	Dark brown clay	0.60	5.60	53.00	41.40	4.00	4.90	1.00	4.00	33.40	22.90	White	Cream
CR1	Off white clay	0.60	0.90	66.30	32.80	7.00	5.71	0.00	10.00	24.00	5.30	Pale cream	Buff
CR2	Dark brown with large amount of humus	0.60	21.80	22.60	45.60	6.50	10.14	0.00	11.50	43.80	15.20	Orange	Orange
CR3	Brown silt	0.60	43.90	26.20	29.90	9.00	6.03	1.00	3.00	24.80	19.90	Off white	Pale cream

937017

TABLE 2

SAMPLE NO.	DESCRIPTION	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	MnO	TiO2	L.O.I.
GS1	-150# fraction	61.60	19.20	0.84	<.01	0.56	0.05	2.80	0.01	0.75	14.20
GS1A	As above, fired to 1000 C	70.90	22.70	0.96	<.01	0.67	0.06	3.40	0.01	0.90	0.42
GS2	-150# fraction	58.40	16.90	0.98	<.01	0.61	0.12	2.70	0.01	1.10	19.90
GS2A	-10u fraction	55.70	27.10	0.97	<.01	0.68	0.07	3.50	0.01	1.00	10.92
CR1	-150# fraction	64.00	21.10	1.46	<.01	1.00	0.11	4.40	0.01	1.70	6.25

DISCUSSION

We will divide this discussion into two sections, firstly dealing with the GS series of samples and then with the CR series. Sample number GS6 is excluded from these comments, being a very fine sand with an almost total absense of clay.

The GS clays

The GS clays are all very high in organic content, which explains a number of very high losses on ignition. This is not a disadvantage for ceramic use as it will burn away totally on firing. However the very high level of +150# is a drawback as it will require very large screen areas to be installed by the customer if the intention is to supply crude clay to the factory. The 150# problem is exacerbated by the problems with dispersion as, although it is believed that much of the material reporting as 150# is in fact undispersed clay, the level of power input required to disperse this would again be beyond the practical limits for a commercial producer.

Having made the above reservations, the remaining properties are, for the most part, ideal for a producer of white tableware. Fired colour is good to excellent, and such factors as shrinkage, and absorption all within an acceptable range.

As much of the sampling was at surface the 150# problem may have been exagerated both by concentration and contamination and the sample described as a statigraphic section, GS7, having the lowest 150# level of all ,seems to confirm this.

In general we would expect levels of 5% greater than 150# to be acceptable to the market and some more intensive sampling will be required to determine if this is achievable.

As far as producing a processed clay is concerned, these clays have a number of possibilities. From our assessment to date, for example , most of the GS samples could be refined to yield a material competitive with a number of existing commercial clays. This comment being based solely on the fired colour and general range of other properties. At what level they could compete depends to a great extent on the chemistry.

Reference to Table 2, indicates that, chemically, these clays are typical ball clays with relatively high iron and titania contents. This is likely to limit their ceramic use to such applications as domestic whiteware. They would not be suitable, for example for the export porcelain market. Other significant features are high potash which will contribute to vitrification and save some felspar cost to the user, and high magnesium, this may signify the presence of plastic montmorillonite, or may

Simply be residual steatite or the like
from the serpentines mentioned by
your geologist

The CR clays

The CR clays are not encouraging, having poor fired colour and, apart from CR1, being heavily contaminated with grit.

Sample CR1 was exceptionally low in grit and had the whitest unfired appearance of all the samples. It was the only CR sample sent for chemistry. Neither the fired properties nor the chemistry fulfilled the initial promise. The clay was very high in free silica, with high iron and titania, the fired colour was not good. The only positive characteristic was the degree of self vitrification due to the high alkalis. If this material were next door to a tile plant it might have a future, but in its present location it can be eliminated along with the rest of the CR samples seen to date.

937022

MARAFIELD PTY LTD

AN EVALUATION OF TASMANIAN CLAY SAMPLES FOR PIGMENT PRODUCTION AND THE RESULTS OF PROCESS DEVELOPMENT STUDIES

John A. Hosking

22 February 1987

301 Lydiard St Nth, Ballarat, VIC 3350.

PREAMBLE

Some preliminary studies indicated that clays discovered by Savage Resources had qualities which could make them suitable for the production of calcined clay pigments for the paint, plastics, rubber and paper industries.

Further work was commissioned to confirm this using larger, representitive samples from the "GS" range of clays. During the course of this work, some parameters would be established for the required process route.

This document, in two main sections, describes the process route established to date, and the "products" resulting from these processes.

PROCESS DEVELOPMENT

The starting point for the process development study was data available to us on some American practices in this area. The Tasmanian clay had a number of features which suggested that it might behave in a similar way to the American equivalents.

In general, the requirements of the process were:-

1] To fully disperse the clay to result in a 10% to 20% solids slurry. In earlier work, dispersion was found to be a problem.

2] To then cut the clay at a suitable particle size to reduce the free silica to an acceptable level and to remove all coarse particles, which would interfere with the intended end use.

3] To dewater and dry the refined product.

4] To mill the dried clay to a fine powder.

5] To dehydroxylate the clay using a controlled heat process.(This would also burn out the dark organic staining.)

6] To again finely mill the calcined powder.

7] To air classify the powder to remove any oversize aggregates.

1] DISPERSION

In view of the difficulty in dispersing these clays during earlier studies, it was decided to increase the solids level to 50% and use ammonia to raise the pH to 9 to 10. A polyacrylate dispersant "Carybon" was also used at a dose rate of 0.5%

The dispersion was carried out in a 0.37 KW, high speed blunger so as to have a power imput of 25 KWHrs per tonne.

Under these conditions dispersion was relatively easy and a very fluid slurry was produced. This slurry was diluted to about 12.5% solids before further processing. (Subsequent mixes were made at even higher solids, up to 70% and these higher levels are recommended.)

2] REFINING

In previous work initial cuts were made at 100 microns and the effect of cutting at 10 microns was examined. The silica level was significantly reduced at the finer cut, but was still considered too high for pigment production. For the current study it was decided to lower the cut point again to 5 microns, and this was achieved using a "Mozley" 25mm cyclone fed by a 37mm centrifical pump.

The system worked well, but would be better in practice if a staged system were used. This would improve recovery which we estimated to be 30% using our system and 35% using a staged system.

The fine product was collected in large plastic drums and the underflow, a combination of extremely fine silica, clay, and organics was also collected and is being held pending any decision to examine or dump them.

3] DEWATERING

The fine product slurry was acidified to pH 5.0 to coagulate the clay to assist settling. However the aggregates formed were too small to promote effective dewatering and would have certainly caused problems in later filter pressing.

The use of a long chain anionic floculant (Alfloc 627) at dose rates of 400 ppm was extremely effective, forming large flocs which settled rapidly, and enabled slurry densities of 25% to be achieved.

3a] FILTER PRESSING

This is very much a trial and error process, as it is impossible to predict the ultimate bulk density of the filter cake or its moisture content. The samples were taken in numerical order, the first trial, on sample GS 30 resulting in an underfilled press which had to be topped up with GS 31. Further pressings gave no trouble and produced a firm, handleable cake. None of the common problems such as excessive pressing time, sticky cakes and filtrate losses, occured during the trials.

3b] DRYING

After a number of trials, involving drying, extruding, and milling in various sequences, it was decided that the material was most easily handled in the following way:-

a) Dry the filter cake, either whole or in large pieces.

b) Crush the dry cake to minus 5mm. (We actually used a modified industrial mincer for this process.)

4] MILLING

In practice either a Hosakawa or Bauer pulveriser would be used for this purpose, but these types of machine are not available at a small enough scale for this excercise. We simulated the effect by using two passes through a disc pulveriser, which, we feel, does not achieve the same degree of fineness.

5] CALCINING

The production calcining technique is very complex and concentrates on ensuring no hot spots, which produce abrasive particles, and also introduces a mixing action as the clay cascades though the kiln. At this stage we can only static calcine and cannot introduce the degree of thermal shock inherent in the high temperature gradients used in practice. (See accompanying graphs.)

Calcination trials were carried out under heavy and light oxidation and mild reducing conditions at peak temperatures ranging from 950 C to 1080 C. As a basis for comparison, all the samples were fired at 1030 C and reflectivities measured.

6] RE-MILLING

Again two passes though a disc pulveriser were used and fineness checked. Due to a number of reasons the material was too coarse and a purpose designed air classifier was built to separate the product.

7] CLASSIFICATION

This process was introduced to remove particles in excess of 20 microns and produced a consistant fine product which could be used for reflectivity measurement. It consists of elutriating the powder in an air stream and collecting the fines in a filter bag.

THE RESULTS

The aims of this phase of the project were:-

1] To establish whether the Tasmanian clays were suitable for the production of calcined products.

2] To identify any differences between the samples supplied.

3] To carry out preliminary work on establishing a production route.

4] To produce some pigment samples for testing by the paint industry.

5] To recommend a definative route for the development of a viable project.

The results will be discussed in two sections, the first relating to the clay potential and the second to the actual process. Both carry recommendations for the next phase.

THE CLAYS

The samples received fell into two visual categories, samples GS 30 to 33 were very dark in colour with a strong peaty odour, samples 34 and 35 were of a pale buff colour with less organic odour. Where, for various reasons, any samples were combined, only those of the same visual type were used.

None of the samples presented any particular problems and their behaviour was extremely uniform despite their superficial differences. Trials on recoveries yielded very similar figures and we expect a level of 30% recovery prior to calcining to be normal with a futher loss on ignition resulting in an overall product recovery of 25%.

We think that the refining residue would be capable of retreatment to produce a good ceramic raw material, but this would be the subject of a separate study .

The clays are extremely susceptable to slight variations in calcination conditions, and we do not believe that these have yet been optimised. However under identical conditions the various samples yielded the following reflectivities:-

SAMPLE	BRIGHTNESS	YELLOWNESS
GS 30	N/a	N/a
GS 30/31	77.6	8.7
GS 31	75.1	10.2
GS 32/33	75.3	7.5
GS 34	81.3	6.9
GS 35	77.5	8.9
GS 34*	81.7	8.3
ACCL Accfine	80.7	7.8

Note: GS34* was fired at a lower temperature at high speed
The Accfine sample is for comparison.

The work to date indicates that the colour of clays is of little use in predicting final brightness, but we are also aware that colour responds to calcination conditions and the optimum may not be the same for all types.

Chemistry appears to be the most significant factor in determining final calcined colour with iron and titania being the most important. With the process envisaged here, we feel that iron is the overriding contributor to fired yellowness and some systems for reducing it should be examined. The included table gives full chemistry.

The chemistry indicates some quite large variances between samples, with iron levels from less than 1% to more than 2% and titania varying from 0.8% to over 2%. In general the chemistry is very similar to earlier samples, and the alumina levels (especially after calcining) are very stable. On the basis of the work to date, it can be stated that feed for pigment production should be selected on the basis of low titania and iron levels.

CHEMISTRY OF SAMPLES

REFINED

SAMPLE NO	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	MnO	TiO2	L.O.I.
GS31	45.10	21.50	1.00	0.03	0.79	0.19	3.40	0.01	1.20	26.80
GS34	52.60	27.50	0.98	0.03	0.76	0.18	3.60	0.01	0.77	13.50
GS35	49.90	28.20	2.05	0.03	1.06	0.19	3.70	0.01	2.10	12.80
GS30/31	46.60	23.80	1.04	0.04	0.82	0.18	3.60	0.01	1.20	22.70
GS32/33	46.00	21.60	0.98	0.04	0.74	0.18	3.30	0.01	1.00	26.20
GS32/33 (bleached)	45.50	22.10	0.90	0.05	0.67	0.19	2.90	0.01	0.90	26.80

Different mean

CALCINED

SAMPLE NO	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	MnO	TiO2
GS31	61.61	29.37	1.37	0.04	1.08	0.26	4.64	0.01	1.64
GS34	60.81	31.79	1.13	0.03	0.88	0.21	4.16	0.01	0.89
GS35	57.22	32.34	2.35	0.03	1.22	0.22	4.24	0.01	2.41
GS30/31	60.28	30.79	1.35	0.05	1.06	0.23	4.66	0.01	1.55
GS32/33	62.33	29.27	1.33	0.05	1.00	0.24	4.47	0.01	1.36
GS32/33 (bleached)	62.16	22.87	1.23	0.07	0.92	0.26	3.96	0.01	1.23

ditto

THE PROCESS

The pilot plant studies have aimed at reproducing the system used in America for the production of clay based pigments. However, from the cost point of view, it was too early in the project to consider using any purpose designed equipment and the simulation has been carried out using available plant together with some fabricated modifications. ALL OF THE DIFFERENCES IN THE PROCESS ARE LIKELY TO CONTRIBUTE TO A WORSE RESULT THAN WOULD BE ACHIEVED IN PRACTICE.

The dispersion technique used was effective, but we would like to achieve a higher work input to ensure that all the available fine fraction is recoverable. For pilot purposes this would involve modifying the existing mixer to handle smaller volumes of material at higher solids. In a production unit we would aim for a work input of about 40 KWHrs per tonne.

The refining technique used to date is crude and somewhat inefficient. In practice the process would require a second stage comprising 10mm cyclones and a scavenger stage to reduce losses to tailings. This can be simulated, but the sample size available did not allow a more sophisticated approach. In view of the high level of relatively coarse organic trash, we would also introduce a number of screening stages into the circuit.

The dewatering and drying processes used also differed from the American practice, in that the clay was pressed in the floculated state rather than being directly spray dried. Our experience with small scale spray driers has not been happy and simulating this phase is a problem. It is possible that by employing a drum drier (which would have to be fabricated) that a direct dried, dispersed clay could be produced.

Milling was not a major problem but could probably be improved by using a small attritor mill (this could also be use for the final milling of the calcined product.)

Calcining is very difficult to simulate as the American process uses a Herreschoff kiln which contains a series of trays mounted on a vertical shaft and the clay cascades through a temperature gradient in about 35 minutes, it is then flash cooled. (See earlier graphs). To come close to this process would involve us in fabricating a small scale unit using high grade stainless steel and insulating fibre blanket.

Secondary milling presents no problem.

Air classification can be relatively easily simulated, we already have a serviceable unit which we will be making more flexible.

The accompanying flow diagram shows our best opinion as to a final process for full scale production.

THE PIGMENTS

The table of reflectivities indicates one of the most important properties of a mineral based pigment. In general the results to date have shown that brightnesses as good and better than existing clay extenders can be achieved, but these are still 4% lower than imported calcined clay pigments. The high yellowness figures are encouraging, as it is frequently possible to modify such pigments to increase brightness. Factors contributing to improved brightness are, finer particle size, better controlled calcining, and chemical iron reduction.

In other respects the pigments produced to date are too coarse,(a function of process rather than feed), and as a result of higher bulk density than is normal. However the density of 0.3 tonnes per metre lies between that of a clay, 0.4 tonnes per metre, and a pigment, 0.23 tonnes per metre.

Although we would be happy for a small sample to be examined by a paint manufacturer for comment, we believe that pigments of far better quality are produceable from selected feed.

PROPOSED PROGRAMME

A number of areas ranging from reserves to market now need to be examined.

Firstly some reserve needs to be established and we believe that this can be done on the basis of iron and titania. A number of auger drill holes will be required with chemistry on each 1 metre increment. The aim should be to establish a minimum of 500,000 tonnes of low iron/titania clay. The areas most promising at present are those comprising samples GS 2 (first series) and GS 34 , GS 32 and 33 also look interesting.

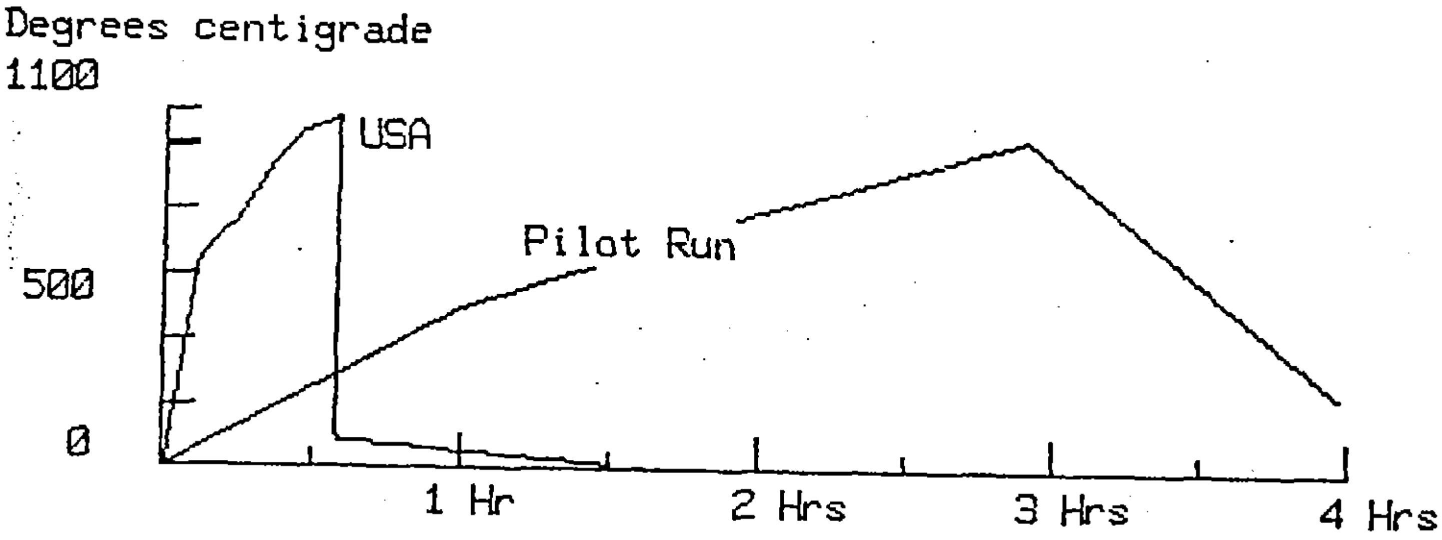
Secondly the market now needs closer examination. A study should be carried out of market size, paint, rubber and paper, for pigments and of the investment casting and insulator industry as potentially markets for oversize material.

Thirdly some further small scale work should be carried out using existing material , to optimise the calcination temperature and investigate chemical reduction of iron which could effectively bring unsuitable material into reserve. It might also be useful at this point to examine the residues with a view to producing further saleable products. We would particularly like to investigate their use in white casting slips.

After the completion of this work consideration should be given to the production of one tonne of pigment from the identified reserve for market sampling both here and overseas.

Only after the completion of these phases should detailed plant design commence.

Comparison of American and Pilot Run Temperature Profiles



SCHEMATIC FLOW SHEET

```
                DISPERSION
                  60 KW
                    |
                DISPERSION
                  60 KW
-----)-----------|
|               50 mm cyclone ----)----- Tail
|                    |
|---(------ 10 mm cyclone
                     |
                Spray Drier
                     |
                 Bauer Mill
                     |
             Herreschoff Kiln
                     |
        Pnuematic conveyor/cooler
                     |
                  Bagger
```

937043

World kaolins
Genesis, exploitation, and application

by Colin M. Bristow*

The mineral kaolinite is one of the commonest minerals in the uppermost 10 metres of the continental crust, ranking in abundance alongside minerals like quartz, mica, feldspar and calcite. Only very exceptionally does it possess all the necessary properties needed to make it worth commercially exploiting.

The terms "kaolin" and "kaolinite" are derived from a locality known as "Kau-ling", in Jiangxi Province, Peoples Republic of China; where samples of a white clay used by the Chinese to make porcelain were first obtained by European missionaries and explorers in the eighteenth century.

Kaolinite is the mineralogical name for a white hydrated aluminium silicate clay mineral, and the term "kaolin" is applied to a product principally composed of kaolinite (or in some cases halloysite), which is produced from a mineral deposit containing significant quantities of kaolinite. The term "china clay" is used for kaolin produced from the primary kaolin deposits of South West England.

Clays containing kaolinite as the principal constitutent may be used in an as-dug form, for example, to make bricks or ceramic products; or they may be refined to remove the coarse fraction or other deleterious minerals. Most statistics refer to refined kaolin production which world-wide now amounts to just under 20m. tpa, worth in excess of $1,000m. a year.

Most commercial paper kaolins are sold on the basis of their physical properties, such as brightness, particle size distribution and/or rheological characteristics; ceramic kaolins depend on both their physical and chemical characteristics.

Mineralogy of kaolin deposits

A commercial kaolin can be composed of either kaolinite or halloysite or a mixture of the two, together with smaller amounts of minerals such as mica, quartz/cristobalite, feldspar, alunite, smectite and various forms of iron and titanium oxide.

Kaolinite

Kaolinite is always fine grained and normally occurs as crystals anging in size from a fraction of a micron up to several hundred microns across. The structure of kaolinite shows it to be composed of a tetrahedral sheet (Si_4O_{10}) linked to an octahedral sheet $Al_4O_4(OH)_8$) to form a single layer. The relatively weak bonding etween the layers gives the mineral a platey character when iewed under the scanning electron microscope. The SEM also shows that kaolinite occurs in a variety of forms ranging from mall pseudo-hexagonal plates randomly oriented, through small acks of plates, to large curled stacks of plates with individual ates having an irregular outline. Within the crystal lattice here may be a degree of disorder, notably in the b-axis direction. Generally speaking, fine grained kaolinites formed under low mperature diagenetic conditions tend to be disordered and kaolinites found in massive hydrothermal deposits tend to be well ordered. The particle size distribution and particle shape are two of the most important characteristics which control the rheological properties of clay/water mixtures, interlaying of other clay minerals such as illite in the kaolinite crystal can also affect these properties. The presence of iron, either in the kaolinite lattice, or as an oxide coating on the kaolinite, is a bad feature, because of its effect on brightness, both raw and fired.

The overall composition of kaolinite is $Si_4Al_4O_{10}(OH)_8$ or, expressed as oxides, it is SiO_2 46.5%, Al_2O_3 39.5% and H_2O 14.0%. The crystal structure is generally resistant to attack by most corrosive fluids, so that kaolinite can be regarded as an inert white powder which will not react with most mediums in which it is placed, which is another important commercial property.

Figure 1. Kaolin stack.

Halloysite

The commonest form of halloysite has the same composition as kaolinite, but there is a rarer form which has an additional sheet of oriented water molecules between the layers. On heating to 100°C this water is lost and the composition reverts to a normal kaolinite/halloysite. The appearance of halloysite under the SEM is quite different to kaolinite and it is usually in the form of tightly rolled scroll-like tubes. In certain ceramic applications halloysite has advantages, but in most other uses its presence is neutral or disadvantageous.

Other minerals

Generally speaking the purer the kaolinite the better it is. Particularly disadvantageous minerals are the oxides of iron and titania which colour the clay and reduce its brightness. Too much

---

lin Bristow is Chief Geologist with ECC International Ltd, St Austell, Cornwall, UK.

silica can cause abrasion problems in paper applications.

Micas and feldspars may have some influence on the rheological, brightness, and abrasion characteristics. Smectite can cause severe rheological problems in a paper-making context, because of its effect on viscosity, but in some ceramic applications may be advantageous because it increases strength (modulus of rupture). Alunite is a nuisance in ceramic applications because on firing it decomposes and releases H_2SO_4.

Genesis and classification of kaolin deposits

The genesis and classification of kaolin deposits has been the subject of many papers (Bristow, 1980; Kuzvart, 1984); two broad divisions can be recognised:

Primary Kaolins
Secondary Kaolins

Primary kaolins are developed *in situ* by the alteration of minerals such as feldspar or other aluminium silicates to kaolinite, and secondary kaolins are laid down as sediments, usually in fresh water.

Primary kaolins

The classification of primary kaolins has been conventionally by their mode of origin (Bristow, 1977):

Weathering
Hydrothermal
Solfatara

The disadvantage of this classification is that in many cases there is considerable debate over which process has operated and in recent years it has been realised that many deposits have originated by a combination of processes (Bristow, 1977). However, let us look at the processes which operate in each case.

Weathering is a ubiquitous phenomenon, but it operates at maximum intensity in hot, humid tropical climates. In present day equatorial regions which have a high rainfall the decomposition of feldspars and other aluminium silicates in granites and metamorphic rocks can be rapid, and even other clays and shales can also be quickly altered to a mixture of kaolinite and quartz (Loughnan, 1969). We may look upon the process as essentially the hydration of anhydrous aluminium silicates accompanied by the removal of alkalis viz:

Potash Feldspar	Water	Kaolinite	Silica	Potash
$2KaAlSi_3O_8$	$+3H_2O$	$=Al_2Si_2O_5(OH)_4$	$+4SiO_2$	$+2KOH$

Illite	Water	Kaolinite	Potash
$2KAl_2(AlSi_3)O_{10}(OH)_2$	$+5H_2O$	$=3Al_2Si_2O_5(OH)_4$	$+2KOH$

The depth of alteration can vary from a few metres up to one hundred metres in exceptional circumstances. Iron-bearing minerals such as biotite mica lose their iron during the process of alteration and this released iron normally colours the altered material brown, yellow, pink or red, which makes it commercially of little value except for low value uses such as bricks, tiles and drainage pipes.

If the alteration involves particularly intense leaching, the process can move a step further and after the removal of all free silica in the matrix the kaolinite itself can be desilicated to yield one of the minerals of the bauxite group. viz:

Kaolinite	Water	Gibbsite	Silica
$Al_2Si_2O_5(OH)_4$	$+H_2O$	$=2Al(OH)_3$	$+2SiO_2$

However, under these circumstances the bauxite layer is usually underlain by a "pallid zone" which is dominated by kaolinite. Nearly all commercially exploited bauxites are underlain by kaolinitic clays, but most are too rich in iron oxides and other coloured minerals to be worth exploiting commercially.

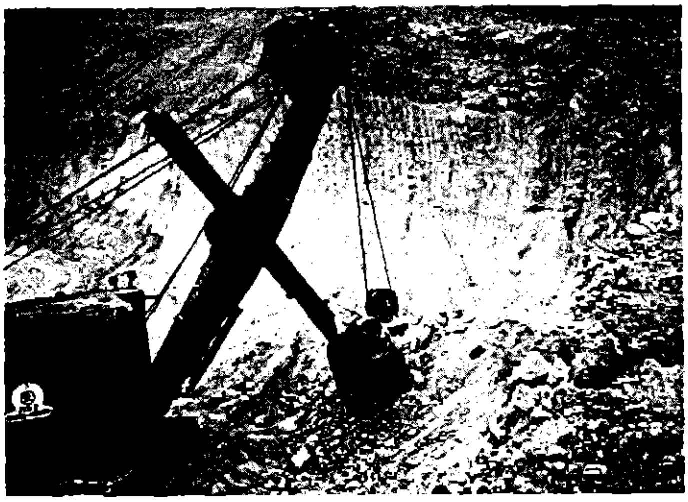


Figure 2. Horni Briza, Czechoslovakia Kaolinised Carboniferous Arkose.

In past geological times, especially in the Eocene and Oligocene (between 55m. and 35m. years ago), the Earth's climate was much warmer and deep lateritic weathering took place at latitudes of up to 50°. Sometimes these ancient weathering profiles are preserved beneath a layer of later sediments and may be used as a source of commercial kaolin. Still older weathering profiles, of early-Mesozoic age (around 100m. years ago) form the kaolin deposits exploited in the Crimean area of the USSR. If a bauxite was in one of these ancient weathering profiles it may be re-silicated by circulating ground water containing traces of silica to become neoformed kaolinite. This process appears to have operated in some of the Georgia/South Carolina kaolin deposits.

Hydrothermal alteration simply means the alteration of rocks by circulating hot water. The heat may arise from the cooling of a large intrusive mass, such as a granite, or it may arise due to deep circulation of water, or it may be due to heat generated by abnormal amounts of radiogenic elements (high heat producing= HHP granites). Surprisingly it is probably the last factor which is the most important, although to produce deposits on the scale seen in South West England it is necessary to invoke a whole series of events and circumstances. Permeability plays an important role for, without fracturing and/or granulation, the permeability will not be high enough to allow fluids to circulate through the rock and alter it.

Granites are by far the commonest host rock for primary kaolin deposits and granites with a low or non-existent biotite content are especially favourable, because of the effect of the iron released from biotite during kaolinisation on the colour of the kaolin.

The china clay deposits of the St. Austell granite in southwest England are the most spectacular example of kaolins in a granite setting. This Variscan granite has two micas — muscovite and a lithium-rich mica. The latter may well in part have been formed by metasomatic alteration of original biotite with the iron released being mopped up by boron-rich fluids to form tourmaline. After a high temperature hydrothermal mineralisation which involved extensive greisenisation, tourmalinisation, and Sn/W/Cu mineralisation, there followed the first stage of argillic alteration which involved saline fluids producing a softened-up granite with illite and smectite, not unlike the argillic alteration in some copper porphyries. A later prolonged period of circulating warm fresh water altered the softened up granite to the kaolinite dominated clay mineral assemblage we see today. The overall effect of the alteration is similar to weathering with the feldspars in the granite being converted to kaolinite with some fine mica and some of the primary mica also being altered to kaolinite in the more intensively altered areas. The heat source for the early stages may well have been mainly from intrusive bodies within the batholith itself and for the second stage of argillic alteration radiogenic heat from the abnormally high uranium and thorium contents of the granite.

High permeability was maintained by regular earth movements fracturing the granite in Mesozoic and Tertiary times, no doubt partly reflecting the plate margin position of southwest England. Some of the alteration may be partly due to deep lateritic weathering in lower Tertiary times.

Somewhat similar kaolin deposits occur in Bohemia, but weathering may be more important there. There are many smallish deposits of kaolinised granite in Brittany and North West Spain (Galicia), but these are not associated with HHP granites and weathering appears to have played a much more dominant role in their formation, although in most cases the kaolinisation can be related to some undoubted hydrothermal feature such as a major quartz vein or group of veins, which must have softened the granite up in some way.

In some cases a minor intrusive may be hydrothermally altered by fluids, possibly heated by the presence of the intrusion itself. The Burella occurrence in northern Spain and the Suzhou kaolin deposits near Shanghai in China are examples of this kind of deposit. Hydrothermal deposits associated with metalliferous sulphide mineralisation frequently have some alunite present.

e 3. Typical china clay pit in Cornwall.

Figure 4. Solfatara type Kaolin, D. Mojeneras, Mexico.

atara alteration is typical of the waning stages of acid ism. In these situations a pile of acid volcanics may be l by steam or hot water, rich in sulphur, passing through ks en route to discharge at the surface as steam jets, hot s, etc. Deposits in the Mediterranean, in the Rome area the island of Milos, are typical of this sort of alteration. e of the sulphur which is often present in the native form. s extensive formation of alunite. The crystal size of the these volcanic rocks, which are often devitrified glasses, is of a size comparable to the kaolinite particles so that it is impossible to remove the silica by particle size classification, thus making the product rich in silica, and abrasive. The main use for these solfatara kaolins is in the manufacture of white cement where their high silica and sulphate content does not cause problems.

Secondary kaolins

There are a very wide range of types of kaolin found in sedimentary rocks. We can broadly classify these into three groups:

Sedimentary kaolins (s. str.)
Kaolinitic sands
Ball clays, fireclays and flint clays

There are transitional types of secondary kaolin which link all the above main types and we can identify three continuous series (Bristow, 1980):

1. Sedimentary kaolins/ball clays etc.
2. Sedimentary kaolins/kaolinitic sands.
3. Ball clays/fireclays/flint clays.

Diagenesis plays an important role in the genesis of many secondary kaolins and some so called secondary kaolins such as kaolinitic sands may be produced *in situ* by alteration of the feldspars in an arkosic sand by circulating ground water. Furthermore weathering, especially in the tropics, can have a profound effect in converting a low quality clay into a useful kaolin deposit, so that in many cases kaolin deposits are both of primary and secondary origin. Let us, for simplicity, consider the three principle types – sedimentary kaolins; ball clays, fireclays, and flint clays; and kaolinitic sands.

Sedimentary kaolins

The essential characteristic of a sedimentary kaolin is that it yields over 60% of kaolin product and that this kaolin product is white enough, after appropriate beneficiation, to be used in applications such as paper where unfired brightness is important (an ISO brightness of over 75 after beneficiation would be considered the minimum acceptable brightness, see Tables 1 and 2). The classic locality for this type must be the sedimentary kaolins in Georgia/S. Carolina (Patterson and Murray, 1984). Late Cretaceous and Early Tertiary sediments were deposited in a tidal flat environment. The sedimentary material originated from deep lateritic weathering mantle developed from the crystalline rocks of the Piedmont eroded and transported to the coastal environment. High titania contents in many of the clays suggest that they were [illegible]

igure 5. Anglo American Georgia Sed Kaolin Washington ounty.

ontents which were greatly reduced by prolonged weathering nd leaching. The development of large vermicular growths of aolinite suggests considerable diagenetic development of aolinite has also taken place. There is evidence that some baux- es were developed as well and that in places these were re- licated to bauxitic clays and kaolins.

The older Cretaceous kaolins tend to be whiter and coarser ained, whilst the Tertiary kaolins are finer grained, slightly rey and have a range of other features which suggest they are oving towards the ball clay end of the series.

Most of the kaolin worked in Georgia and South Carolina oc- rs in the form of lenses in a generally sandy succession.

Other areas in the world where similar sedimentary kaolins are nd include Amazonia, where there are extensive late Tertiary ys which in almost every case have been modified by having auxitic weathering profile superimposed on their upper part. some cases the bauxites are sufficiently well developed to resent future potentially economic deposits.

he closest analogy to the US sedimentary kaolins in Europe the Eocene clays in the northern part of the Aquitaine basin the Charente Department of France. These, however are tran- onal towards ball clays and are not really bright enough for in paper, which is the principal use for the US clays. Indeed e of the Charente clays are true ball clays and are sold as h.

clays, fireclays, and flint clays

e showed above there is a progressive change from sedimen- kaolins towards ball clays in many areas. A true ball clay lly has good fired brightness (say over 50 at 1180°C or °C), good modulus of rupture and good plasticity, which is to its combination of extremely fine-grained b-axis rdered kaolinite and the presence of illitic mica and certain nic components, see Table 4. Ball clays are mainly used in mic applications, where their special properties are of real . Ball clays are almost invariably laid down in fresh water s or river flood plains and are frequently associated with ites.

most curious coincidence is that most are of ne/Oligocene age not only in Europe but in North America ell; a climatic reason for this coincidence is likely.

e of the reasons why ball clays are not often found in older tions than the Tertiary is that with a deeper and longer a ball clay will become lithified to form a non-slaking, non- ic, shaly material, which is, in effect, a fireclay. Whereas ball are associated with lignites, fireclays are usually associated higher rank coals, reflecting the greater lithification of the tion. However, many fireclays have compositions, notably rms of iron and titania, which make them unsuitable for whiteware production because of poor fired brightness, and many lignites have clays associated with them which are certainly not good enough to be regarded as commercial ball clays.

The term "fireclay" also has different usages in different countries. The term is of Anglo-Saxon origin and refers to the clays found in association with Carboniferous coals in Britain and the eastern USA. Because the type of kaolinite in fireclays in characteristic and distinctive (b-axis disordered), the term "fireclay kaolinite" began to be used. Subsequently it was found that most ball clays contained the same type of kaolinite. In Germany this had the unfortunate result that any clay which was used for refractory purposes and contained b-axis disordered kaolinite came to be called a "fireclay", at least in commercial circles. This includes a lot of material which most US and British geologists would call ball clay.

The term "ball clay" originates with the important ball clay industry in Devon and Dorset, UK. In earlier times the clay was worked by being cut out by hand in 1 cu. ft. cubes. In the course of handling the plastic clay these cakes became rounded into "balls", hence the term ball clay.

The deposits in Devon are of Eocene/Oligocene age and were deposited as lacustrine or flood plain deposits in fault formed basins. The South Devon deposits are associated with lignites. These clays are especially valuable for the production of high quality tableware and porcelain and are exported all over the world. The deep weathering which produced the raw material for these ball clays was in response to a climate unlike anything on this planet today. The clays were laid down at about 40°–50°N, and from pollen and other geobotanical studies we can deduce the climate, was warm, frost-free, seasonal and extremely wet. Much the same picture emerges for the main US ball clay producing areas in Kentucky/Tennessee and Troup, Texas (Patterson and Murray, 1984).

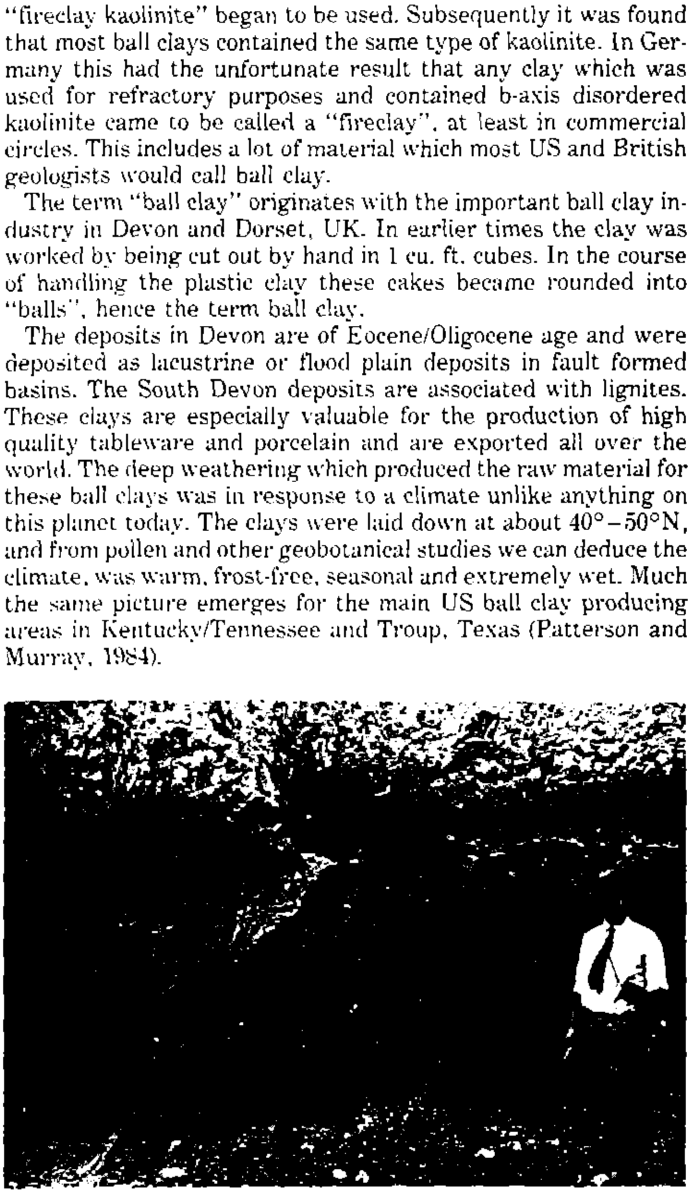


Figure 6. Ball clay, S. Devon.

The closest present day analogy with the original depositional environment of ball clays is found in SE Asia where deep lateritic weathering mantle is developed on the higher ground and the weathered material is washed down onto lower ground where the clay material is trapped in paddy fields. Chemical analysis of this clay shows it to have a similar composition to a ball clay, but its mineralogy is quite different, with gibbsite, halloysite and some well ordered kaolinite as well as some material which is best described as "degraded silicate lattice wreckage". This is, in effect, a clay which has not undergone diagenesis, in the process of which it can be expected that all the material will convert to a uniform mixture of b-axis disordered kaolinite, illite, and silica.

Fireclays are widespread in association with the Carboniferous coal measures of Western Europe and the eastern part of the USA. In previous times they were extensively used for refractories, but this use has declined sharply with the move towards basic oxygen steelmaking and higher duty basic refractories. Opencast coal mining could provide vast tonnages of fireclays, but most are now dumped along with the rest of the waste material, due to a limited market.

Flint clays are special materials which, although principally composed of kaolinite, are hard non-slaking rocks with a conchoidal fracture. Most flint clays are composed of comparatively well ordered kaolinite with low iron and other fluxing components. Generally they are highly refractory with PCE's in the mid-thirties. When fired in a refractory situation they yield a dense, strong material which is able to withstand a much higher duty than any ordinary clay based refractory, which seems in part to reflect important textural characteristics within the clay and its fired counterpart.

Flint clays seem to arise in two different ways. Most of the US examples (Missouri, Kentucky) seem to have arisen by prolonged leaching and recrystallisation, so that the alkalis were largely removed and the kaolinite formed large interlocking grains.

In Missouri the process of leaching has proceeded to the stage where some di-silication of the kaolinite has occurred leading to formation of bauxitic minerals such as diaspore and boehmite. These super heat-duty "burley" and diaspore clays are especially valuable refractory clays.

Some of the European flint clays, such as the lower Palaeozoic clays of the Oviedo area in northern Spain, appear to have been formed by regional metamorphism converting a clay, which must have started out something like a ball clay, into a dense, hard non-slaking material which can be calcined to yield a material similar to the US flint clays. Another important area of flint clay production is South Africa, which is probably similar in origin to the US examples.

By increasing metamorphism a kaolin will be converted to a slatey rock and eventually to a rock rich in Kyanite and andalusite. In Finland lower Proterozoic weathering mantle 2.3 billion years old, almost certainly originally kaolin, has now been converted by metamorphism to kyanite and andalusite which can be worked to provide refractory materials.

Kaolinitic sands

In many parts of the world kaolin is extracted from sands which have a kaolin content of less than 20%. Very often the accompanying sand can be used for constructional or industrial uses.

Some kaolinitic sands arise by the alteration of the feldspar in an arkose *in situ* by percolating ground water; others were originally laid down as a mixture of kaolin and sand.

Examples of kaolinitic sands are the Triassic Hirschau-Schnaittenbach occurrences in West Germany and the Cretaceous occurrences in Cuenca and Guadalajara provinces in Spain. Other similar occurrences in Tertiary and Carboniferous age are found in Poland and Czechoslovakia.

Many important oil reservoir rocks in the world are in kaolinitic sands, notably in the North Sea. The diagenesis of the clay minerals in the sands plays a very important role in determining the reservoir characteristics and, as a consequence, have been extensively studied (Johnson and Stewart, 1985).

Exploitation of kaolins

In view of the great diversity of types of kaolin deposit, the following will describe the working of each type of deposit separately.

Primary kaolins

Exploration for primary kaolins begins with a literature search for suitable parent rock types, such as leucogranites, in the area concerned, together with any indications of extensive alteration of the granite such as greisenisation, tourmalinisation, or tin-

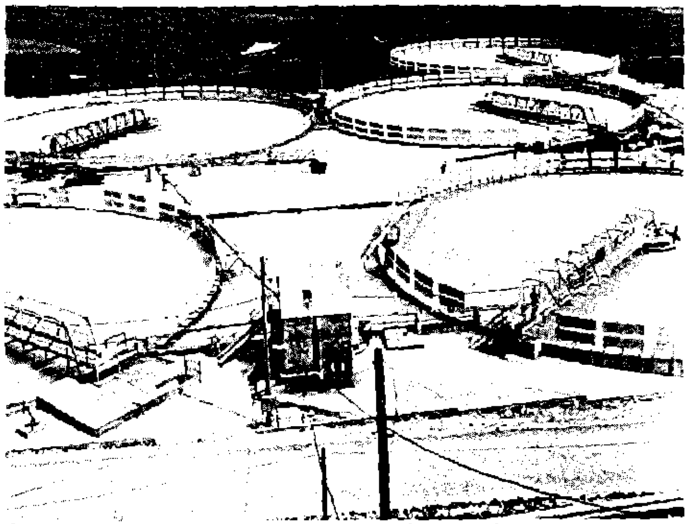


Figure 7. Blackpool china clay pit in Cornwall – 140 ft dewatering thickeners.

Source: ECC International Ltd.

geological analysis of the geomorphological characteristics with especial attention to lineament intersections and "soft" areas underlying the lower ground. This can then be followed by ground survey work and a programme of gravity and/or resistivity geophysical surveying accompanied by limited hand augering. Any samples obtained can be tested in the laboratory for their commercial properties such as brightness, particle size distribution, and rheological characteristics. In practise none of the above may be done because there is already a small clay pit in the area which shows where the clay is and what kind of quality is likely.

Evaluation of primary kaolins is usually the main exercise which a geologist is involved in and it is usually accomplished in the field by a programme of regularly spaced core drilling followed by a detailed laboratory test programme to reveal the fullest details about the clay. Because of the difficulty in obtaining cores people are sometimes tempted to make do with auger or percussion samples; in the opinion of the writer this is bad practise and can lead to seriously misleading results. The borehole and laboratory database can then be converted to statement on reserves and qualities by manual means or by the use of a suitable software programme. This may be taken further, so that a mining plan is also evolved as part of the same exercise.

At the same time as the drilling and laboratory testing are going on, large representative samples of the clay matrix ne-

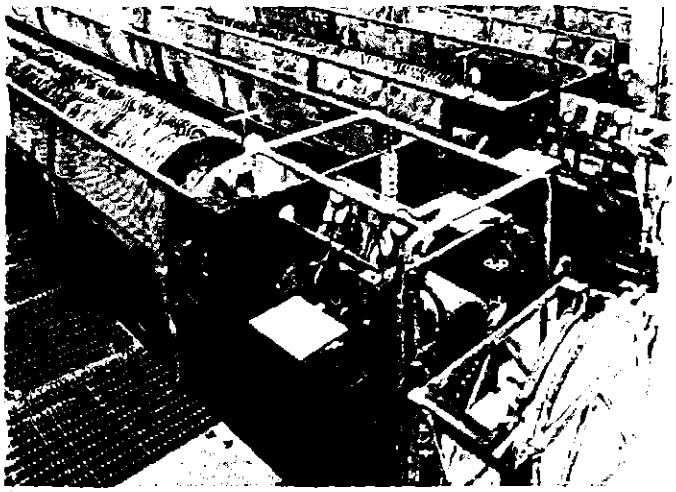


Figure 8. Rocks china clay works — high pressure plate p

937048

to be collected and brought back for pilot plant processing to determine the optimum flowsheet and to examine in great detail the behaviour of the clay in commercial applications. This must be allied to a detailed study of the marketing and distribution aspects. It is at this stage that most companies new to the kaolin business make mistakes.

Exploitation is usually by either washing it with a monitor or digging the matrix up and transporting it to a nearby plant where it is slurried in a trommel; followed by sand removal using spiral or rake classifiers, followed by hydroclones and/or gravitational refining in large tanks. For coating clays centrifuges are required to obtain the fine product. Some simple means of bleaching may be required, although this is by no means universal with primary kaolins. Dewatering, filter pressing, and drying then lead to a product at 10% moisture or less. In recent years the development of slurry shipments has tended to eliminate the drying step. Very close attention to product quality control is required at every step of the production process (Pemberton, 1983).

Secondary kaolins

Exploration for sedimentary kaolins, kaolinitic sands and ball clays is best done by straight forward geological research and mapping, although in nearly every case it will be found that a small existing operation will give away the presence of the deposit. Geophysical methods and photogeology are usually of very little use.

Evaluation is similar to primary kaolins, with a regularly spaced core drilling programme and detailed laboratory testing being needed. To save costs it may well be possible to open hole through the overburden on top of the clay seam.

Exploitation shows many differences with primary kaolins. In the case of sedimentary kaolins for use in the production of printing and writing paper, as in Georgia, the clay is excavated from a wide variety of locations which may be scattered over a large area, and taken to a central refining plant, this being possible due to the high recovery of product (oa 70 – 80%) in most sedimentary kaolins. Primary kaolins have to have their plant nearby as it is uneconomic to transport matrix containing only 20% product over large distances. Thereafter the refining follows a similar route, although there is usually more extensive colour beneficiation by flotation, selective flocculation, reductive bleaching, oxidative bleaching and/or high intensity magnetic separation. The extra cost of all this treatment compensates for the lower cost of extraction for sedimentary kaolins. Most sedimentary kaolins are spray dried to a very low moisture content.

Ball clays, fireclays and flint clays are excavated and used in the as-dug form, so great care is needed to control the mining operation, and blending of different qualities from covered stockpiles is needed to ensure consistent quality. With the higher quality ball clays and flint clays some underground mining may be worthwhile as in UK, France, and Spain.

Applications for kaolin

The most important use for kaolin in terms of value is in the paper industry. Kaolin is used in large quantities, 10m. tpa worldwide, as a coating and filling pigment for paper and board. Many grades of paper contain about 30 wt% mineral pigment of which a large proportion is often kaolin. The demand for kaolins for paper is still increasing although recent years have seen a rapid growth in use of alternative pigments such as calcium carbonate (Clark 1986).

Pigments are used as fillers in papers to improve optical properties such as brightness and opacity and to reduce costs by replacing expensive chemically refined pulp. Typical kaolin filler grades are shown in Table 1. Fillers are relatively cheap and must have acceptable abrasion and consistent optical properties. Kaolins are preferred for acid sized (rosin) papers and papers containing groundwood (or non-chemically refined) pulps, whereas, particularly in Europe, calcium carbonates are preferred for neutral and alkaline sized papers.

Coating pigments are used to achieve a smooth, glossy surface for printing. The requirements of gloss and certain specific properties to improve printed paper quality, and the rheological conditions involved in the modern, high speed paper coating process all place strong demands on pigment properties. Coating pigments including kaolins need to have consistent rheological and optical properties and to give consistent coated paper properties. Typical kaolin coating grades are shown in Table 2. Kaolins are preferred for high gloss papers particularly lightweight papers (used for mail order catalogues, magazines and inserts) and for papers printed by the rotogravure process.

Table 1: Typical filler clays

Grade *Producer/Country*	*Grade C* *ECCI (UK)*	*Arvors 20B* *Arvors (France)*	*Acme* *ECCI (USA)*	*Pittong* *ECCI (Australia)*	*Alphafill* *ECCI (Brazil)*
+10 micron %	5.4	15	6	3	41
– 2 micron %	50	49	74	78	30
ISO Brightness*	81.0/5.5	82.7/6.7	82.4/7.0	80.4/9.5	81.6/8.2
SiO_2	47.2	48	46	47	46
Al_2O_3	37.4	37	38	38	39
Fe_2O_3	0.96	0.78	0.89	0.62	0.52
TiO_2	0.14	0.09	1.5	0.63	0.04
CaO	0.11	0.04	0.08	0.03	0.05
MgO	0.18	0.2	0.10	0.1	0.06
K_2O	1.41	1.3	0.42	0.16	0.94
Na_2O	0.07	0.05	0.20	0.11	0.17
L.O.I.	12.5	12.3	13.4	13.7	13.5
Kaolinite	90	89	95	97	95
Mica	9	8	3	–	5
Quartz	1	2	–	1	TR
Feldspar	–	1	–	–	–
Anatase	–	–	1.5	1	–
Geological Environment	Kaolinised Granite (hydrothermal)	Kaolinised Granite (weathering/ hydrothermal)	Sedimentary Kaolin	Kaolinised Granite (weathering)	Kaolinised Granite (weathering)

*ISO brightnesses are about 1-2 units lower than the GE brightnesses widely used in the U.S.

See "English China Clays, Products for the Paper Industry – Test methods".

All results from ECCI Laboratories.

Table 2: Typical coating clays

Grade *Producer/Country*	*SPS* *ECCI (UK)*	*Alphacote* *ECCI (USA)*	*Betagloss* *ECCI (USA)*	*Amazon 88* *Caulim da Amazonia (Brazil)*
-2 micron %	78	89	94	97
ISO Brightness*	85.6/4.4	88.4/4.5	84.7/6.7	85.4/6.0
Viscosity*	69.7	74.5	74.0	74.4
SiO_2	47.2	46	45	46
Al_2O_3	37.6	39	38	37
Fe_2O_3	0.68	0.58	1.0	1.8
TiO_2	0.04	0.53	1.6	0.98
CaO	0.08	0.04	0.06	0.02
MgO	0.2	0.04	0.09	0.07
K_2O	1.39	0.07	0.13	0.0
Na_2O	0.08	0.18	0.29	0.08
L.O.I.	12.7	13.9	14.0	14.3
Kaolinite	93	100	99	99
Mica	7	—	—	—
Quartz	Tr	—	—	—
Feldspar	—	—	—	—
Anatase	—	Tr	1	1
Geological Environment	Kaolinised Granite (hydrothermal)	Sedimentary Kaolin	Sedimentary Kaolin	Lateritic Weathered Sedimentary Kaolin

*ISO brightnesses are about 1–2 units lower than the GE brightnesses widely used in the U.S.
For brightness and viscosity measurement methods see "English China Clays, Products for the Paper Industry — Test Methods".
All results from ECCI Laboratories.

Ceramics

The ceramics industry includes many different sectors; tableware, sanitaryware, wall tiles, floor tiles, electrical and industrial porcelain, etc. A wide range of different formulations are employed, with different firing conditions. Thus tableware can be produced as high quality bone china, as reduction-fired hard porcelain, as a variety of other vitreous products including aluminous porcelain or as porous earthenware. Other sectors such as tiles also cover a range of product types. The ceramics industry also uses a wide range of making and shaping methods, from plastic making to casting and dust pressing.

The majority of white coloured ceramics contain china clays and ball clays. *Both are selected for consistent chemical composition*, so that the firing and vitrifying characteristics of the body do not vary, and so that the brightness and translucency of the fired ware is satisfactory. In addition, the clays contribute to the green strength of the ceramic body, and to the plasticity and casting behaviour. Choice of a particular combination of china clay and ball clay will therefore depend upon the production methods employed as well as the final properties required. The properties of the clays available may modify the way in which they are used. The high organic content of some ball clays contributes to good casting behaviour, and modifies the deflocculants that are required in the casting process. The black colour is burnt out in firing, provided adequate time is allowed.

Table 3 shows the properties of a range of ceramic clays from around the world, and Table 4 shows a range of ball clays. The ceramics industry can make use of a much greater number of clays than can be used by the Paper Industry, and cheap local clays can often be used in combination with more consistent materials, not always with the best of results. However, industrial practice has coped with many differences. American ball clays tend to be coarser than their European counterparts, and may lead to formulations containing more ball clay and less kaolin in American compared with Europe.

Halloysitic clays have also been used in some applications. A few halloysites have been identified with good fired brightness, and these have been used for porcelain manufacture, often in combination with kaolins.

Refractories

The use of clay-based refractories has declined substantially in recent years with the switch from open hearth steelmaking to basic oxygen steelmaking, notably in Japan and Western Europe. Higher duty basic refractories, notably those based on high purity magnesia, have tended to take the place of clay-based refractories. However, clay-based refractories with an enhanced alumina content, have maintained their position in the refractories market. The special qualities of flint clays have also ensured that they maintain their position in the market. This has meant that the markets for low and medium quality fireclays in Western Europe have declined sharply, whilst in the USA a continued demand for alumina enriched refractory clays and flint clays has continued to exist.

Whilst quite large tonnages of flint clays are used in North America, its place in Europe is taken by calcined ball clays ("chamotte") and, to a lesser extent, by calcined fireclays.

The properties of some typical fireclays, flint clays and chamottes are given in Table 5.

Refractories used in other industries such as kiln furniture frequently consist of cordierite based materials. These are produced from china clays and talc, with suitable calcined grog.

Paint, rubber and plastics

Fillers plan an important role in many paints and polymers. There is much greater variety in the nature of the mineral fillers used by these industries, however, and carbonates, talc, mica, and a variety of other silicates are competitive with clays.

In paints, kaolins and calcined kaolins are used as extenders mainly in alkyd undercoats and in water-based paints. The scattering power of these extenders contributes to the optical properties of decorative paints — hiding power, opacity and whiteness — while the range of particle sizes and shapes enables the physical properties of the paint film to be influenced. These properties include surface finish (matt or gloss) scrub resistance, permeability, etc.

In plastics, and in rubbers, fillers are used in a variety of ways. Fine kaolins and ball clays provide some reinforcing properties in rubbers. Clays also affect permanent set and colour. Calcined

937050

Table 3: Typical ceramic china clays

Grade Producer/Country	*Standard Porcelain* *ECCI (UK)*	*Remblend* *ECCI (UK)*	*Zettlitz 1A KSNP* *(Czechoslovakia)*	*Pleyber GX* *ECCI/France)*	*Burella 201* *ECESA (Spain)*	*Cyprucast* *Cyprus IM (US)*
+ 10 micron %	2.2	17.6	7.3	6	–	17.4
– 2 micron %	70	39	67.5	61	39	57.6
Modulus of Rupture Kgf/cm^2	14.0	5.0	14.3	10	11.4	4.0
Casting Concentration %	63	65	59.8	65	63.2	70 app.
Casting Rate	0.35	2.0	0.46	2.0	1.95	1.4
Fired b'ness	91	86	89.4	91	91.3	90.4
1180°C Absorption	15	16	16.7	19	19.6	16.1
Contraction	9	7.5	7.9	8	5.5	6.3
Fired b'ness	88	87	91.4	89	92.2	87.8
1280°C Absorption	6	9	12.5	10	15.0	13.7
Contraction	14	11	10.9	12	7.5	10.4
SiO_2	47.9	48.1	47	48	51	46
Al_2O_3	37.2	36.7	37	36.8	36	38
Fe_2O_3	0.68	0.93	0.88	0.72	0.72	0.47
TiO_2	0.03	0.05	0.17	0.36	0.02	1.6
CaO	0.07	0.05	0.48	0.18	0.05	0.05
MgO	0.27	0.3	0.43	0.06	0.23	0.09
K_2O	1.59	1.92	0.94	1.76	1.3	0.16
Na_2O	0.08	0.08	0.09	0.06	0.03	0.10
L.O.I.	12.3	11.7	13.3	12.1	11.3	13.6
Kaolinite	88	87	89	89	74*	95–97
Mica	9	12	10	9	20	2–3
Quartz	1	1	1	2	6	1
Feldspar	1	Tr	–	–	–	–
Anatase	–	–	–	–	–	1
Geological Environment	Hydrothermally Kaolinised Granite	Hydrothermally Kaolinised Granite	Weathered Hydrothermally Altered Granite	Weathered Hydrothermally Altered Granite	Hydrothermal/ Weathered Felsite Sill	Sedimentary Kaolin

For test methods used see "EEC International. Ceramic Division. Test Methods for Ceramic Raw Materials", Modulus of rupture measured at 80% R.H.
All results from ECC Laboratories. *Halloysite present.

Table 4: Typical ball clays

Grade Producer/Country	*Hywite Superb* *S. Devon* *ECCI (UK)*	*Hymod Blue* *Dorset* *ECCI (UK)*	*1001* *S. Schmidt (FGR)*	*Bandy Black* *H.C. Spinks (US)*	*Troup, Texas* *ECCI (US)*
–2 micron %	80	86	65	62	61
–1 micron %	70	77	54	49	52
Modulus of Rupture Kgf/cm^2	24	36	25	21.8	34.3
Casting Concentration %	65	60	65	60	60
Fired b'ness	70	56	58.1	69.1	66.9
1180°C Absorption	6	3.0	6.4	12.7	11.1
Contraction	13	12.1	7.9	9.0	5.4
1240°C(A) Fired b'ness	68(A)	51/A)	55.5(A)	54.3(B)	63.6(A)
or Absorption	2.6	1.8	2.6	3.2	8.9
1280°C(B) Contraction	15	12.3	13.9	12.8	5.9
SiO_2	49	53	65	56.3	63
Al_2O_3	32	31	21	26.8	24
Fe_2O_3	1.1	1.4	0.95	1.17	1.5
TiO_2	0.9	0.9	1.4	1.54	1.3
CaO	0.2	0.3	0.2	0.08	0.13
MgO	0.4	0.5	0.75	0.35	0.58
K_2O	1.8	3.0	2.1	1.63	0.98
Na_2O	0.2	0.4	0.21	0.25	0.12
L.O.I.	14.0	9.1	8.3	11.9	8.2
Kaolinite	68	57	58	60	66
Mica	20	33	17	21	9
Quartz	7	8	24	17	19
Carbonaceous Material	4	1	–	–	–
Geological Environment	Fresh water lake or flood plain in fault basin	Fresh water/ Estuarine in wide shallow basin	Fresh water lake or flood plain	Fresh water lake or flood plain	Fresh water lake or flood plain

r test methods see "ECC International, Ceramic Division, Test Methods for Ceramic Raw Materials". Modulus of rupture measured at 80% R.H.
ll results from ECC Laboratories.

clays provide improved electrical properties for use in cable insulation. Fillers are also being designed to perform specific functions in polymers. Some functional fillers are surface treated in a way that improves dispersion and improves the bond between polymer and filler. They include treated calcined clays such as the Translink and Polarite series, which are finding applications in engineering plastics and the cable industry.

Other functions include providing anti-blocking properties in film and tapes, and absorption properties in agricultural film.

Significant quantities of cheap filler are used in other sectors, for example, floor coverings including carpet backing and flexible floor tiles.

Chemical uses, pharmaceuticals

A new and growing use for kaolin is in the manufacture of chemicals — catalyst manufacturers use kaolin as an ingredient in the manufacture of zeolite catalysts for instance. Kaolin is used in the pharmaceutical industry for the manufacture of medicines used to alleviate intestinal disorders and many white pills are mainly composed of a filler such as calcium carbonate or kaolin. Clays are used to provide a source of alumina in glass fibre production.

New uses

Whilst there has been a great deal of talk about the considerable amount of research going on in the field of "fine" or "engineering" ceramics; so far most of the new ceramic materials have utilised pure chemical components rather than naturally occurring minerals. To cheapen their products the use of natural minerals is desirable and research to make effective sialons from clays may lead to new applications for kaolin.

Already a very special grade of kaolin is used by Corning in the manufacture of the cordierite catalyst supports used in car exhaust systems.

Worries about the effect of too much phosphate getting into natural drainage systems from the detergents currently in use have led to suggestions that a form of zeolite could be used instead and this could be manufactured from kaolin and lead to new markets developing.

Acknowledgements

The assistance and advice of colleagues in the Research and Marketing Departments of ECC International is acknowledged, especially in the chapter on applications for kaolin■

References

Bristow, C. M. 1977. A review of the evidence for the origin of the kaolin deposits in S.W. England. Proc. 8th Int. Kaolin Symposium and meeting on Alunite, Madrid-Rome, September 7–16, 1977.

Bristow, C. M. 1979. A classification for sedimentary kaolinitic formations of economic importance. Acta Mineralogica-Petrographica, XXIV/1980, Supplementum Proc. 10th Kaolin Symposium, Budapest, 1979.

Clark, D. A. 1986. Minerals in paper — The quiet revolution. Trans. 7th Industrial Minerals Int. Congress, Monte Carlo, 1986.

Jepson, W. B. 1984. Kaolins: their properties and uses. Phil. Trans. R. Soc. Lond., A311, 411–432.

Johnson, H. D. and Stewart, D. J. 1985. Role of elastic sedimentology in the exploration and production of oil and gas in the North Sea; in 'Sedimentology — Recent developments and applied aspects' Geol. Soc. London, Special Publication ed P. J. Brenchley and B. P. J. Williams.

Kuzvart, M. 1984. Industrial Minerals and Rocks. Elsevier, pp. 307–316.

Loughnan, F. C. 1969. Chemical weathering of the silicate minerals. Elsevier, New York.

Patterson, S. H. and Murray, H. H. 1984. Kaolin, Refractory Clay, Ball Clay, and Halloysite in North America, Hawaii, and the Caribbean Region. U.S. Geological Survey Prof. Paper 1306.

Pemberton, M. 1983. The Processing of China Clays. Industrial Chemistry Bulletin.

Table 5: Typical fireclays, flint clays and chamotte

Grade Producer/Country		**Fireclay, Midlands, UK*	**Chamotte, Charente, France*	**Flint Clay Oviedo N. Spain*	*†Flint Clay Olive Hill Kentucky*	*†Flint Clay Missouri*
Fired/Unfired		Fired	Fired	Fired	Unfired	Unfired
Typical refractories or PCE		—	—	—	33–34	33–34 PCE
SiO_2		51.1	55.2	54.5	45.5	44.42
Al_2O_3		43.6	40.5	41.1	36.0	38.63
Fe_2O_3		2.35	0.97	1.17	1.18	0.55
TiO_2		1.37	1.41	1.22	2.0	2.12
CaO		0.21	0.16	0.11	0.08	0.04
MgO		0.4	0.24	0.10	0.36	0.1
K_2O		0.2	1.04	0.51	1.0	0.3
Na_2O		0.08	0.39	0.11	0.1	0.12
L.O.I.		0.70	0.14	0.2	13.0	13.90
Kaolinite	Unfired	42	*90	*86	90	Over 85
Mica		25	6	6	0.25–0.5	—
Quartz		32	2	7	0.5–1.0	—
Feldspar		—	—	—	—	—
Anatase		1	1	1	TR	—
Mullite	Fired	47	40	29	—	—
Cristobalite		24	25	—	—	—
Quartz		Tr	2	4	—	—
Amorphous Material		28	33	65	—	—
Geological Environment		Carboniferous Coal Measure Swamp	Eocene fresh water flood plain/lacustrine	Regionally metamorphosed L. Palaeozoic shale	U. Carboniferous Swamp	U. Carboniferous Swamp

*Testing in ECC Laboratories.

†From "Kaolin, Refractory Clay, Ball Clay and Halloysite in N. America, Hawaii and the Caribbean Region", S. H. Patterson and H. H. Murray, USGS Prof. Paper 1306, 1984.

**Mineralogy obtained from similar but different samples to the rest of the results.

937052

THE MINERALOGY AND CHEMISTRY OF TASMANIAN CLAY DEPOSITS

J. C. van MOORT

Geology Department, the University of Tasmania

Received July 28, 1978

Tasmanian Tertiary clayey sediments are largely kaolinitic. Clays developed on Triassic sediments are usually illitic with varying amounts of kaolinite and clays developed on Permian and older rocks are largely illitic with some kaolinite or no kaolinite at all. The Permian clays contain in places appreciable amounts of feldspar of detrital origin. Primary clays derived from igneous rocks are essentially kaolins.

Bulk chemical analyses confirm the presence of some natural kaolins of great purity (e.g. Tonganah and South Mt. Cameron), feldspathic kaolins (e.g. Surges Bay and Forcett) and the presence of the many illitic clays (e.g. Austins Ferry and Dulverton). Chemical analysis enables a more detailed mineralogical analysis than is possible with X-ray diffraction techniques only.

The relative proportions of the combined alkali and alkaline earth contents (as determined from the bulk clay analyses) compared to silica content and alumina content characterize the suitability of the clays as brickmaking materials. Comparison with chemical analyses of U.K. bricks tested on exposure resistance indicates that most Tasmanian bricks are too siliceous and/or aluminous (e.g. Port Arthur, Dover). The few Tasmanian clays of optimum chemical composition (Knocklofty, Giblin Street, Howden Yellow) have produced bricks of great resistance to weathering. The developed method of chemical evaluation of the value of a clay as brickmaking material appears to be of general applicability.

"These chemical analyses would be long and tedious and serve no useful purpose . . . . "

W.F. Ward (1904)
Government Analyst, Tasmania.

1 Introduction

In spite of general increases in building activity over the last three decades, the level of production of bricks, pipes and tiles in Tasmania has been more or less static since 1956, the first year in which production records were kept (Fig. 1). This lack of growth is largely caused by the introduction of cheap alternatives like concrete blocks and plastics. The present annual production of clay bricks in Tasmania is estimated at about thirty million, while the annual production of concrete blocks is about 5 x 10^6 (equalling in volume forty million clay bricks). Because of this competition the clay industry has become vastly more efficient and now applies rigid quality control. The aim of this paper is to provide some of the necessary chemical and mineralogical information for this quality control, not needed three quarters of a century ago.

In addition to the common ceramic clays, Tasmania has vast resources of kaolin in many forms. The kaolin industry, mainly oriented towards the production of paper fillers, collapsed in the sixties and has only recently recovered after the import of considerable capital and expertise. Some data pertaining to the mineralogical and chemical characteristics of these pure kaolins are also included.

2 Industrial Classification of Tasmanian Clay Deposits.

An industrial classification is given in Table 1, where the clays are listed according to their common industrial names. The localities are shown on Fig. 2. The indicated age of the parent material is not always relevant as in some cases the late Mesozoic and Cainzoic weathering products of the older material is quarried, e.g. the Permian clay used at present for making bricks at Dulverton and previously at Wynyard is a Tertiary weathering product.

3 China Clay

There has been a continuing and strong demand for china clay since the inception of the paper industry in Tasmania in 1938. Syenite at Surges Bay and Cygnet, some 30 km SW of Hobart, has been altered in situ into kaolin. In the Fern Tree River Valley west of St. Helens both sedimentary and residual clays are exposed in separate working of the previous Goshen Tin Mines. The Surges Bay clay and the Fern Tree River Valley clay have both been used as paper filler clay. Because of the high proportion of silica in the fine fraction and because of inadequate treatment facilities these deposits were ultimately found to be unsuitable (Cole and Carthew').

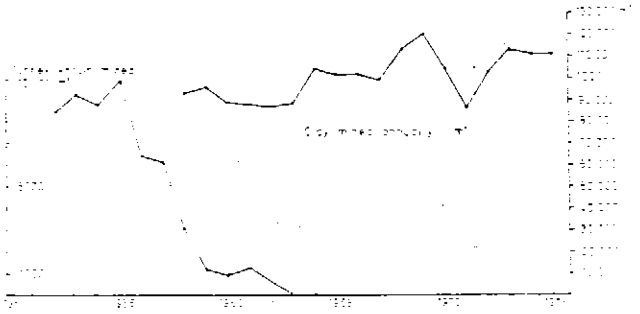


FIG. 1. Annual production 1950-1976 in Tasmania of clay mined for the brick, pipe and tile industry and annual production of kaolin as paper filler. Since 1976, 20,000 m^3 kaolin has been produced annually.

Of importance is the development since 1975 of the APPM Tonganah Clay Mine east of Scottsdale. The clay is mined in an open pit from decomposed granite consisting of 60% silica, 30% kaolin >12μm and 10% kaolin <12μm. After complex deflocculation, flocculation and mechanical sorting, a final rather pure kaolin paper filler is obtained of 90% <12μm. Annual production is 20,000 tonnes. Use of the ultra-fine fractions as coating clay is being studied by the company.

There is not much difference between primary kaolin produced in situ by weathering and kaolin transported over short distances. The 'drifts' overlying tin gravels in north-eastern Tasmania and Tertiary river and lake deposits in the area of South Mount Cameron, St. Helens and Pioneer contain coarse grained kaolins, which are in their behaviour largely china clays. All these clays have been used as filler clays in the past, and all were found to be too abrasive.

4 Ball Clays

Tasmania has two major ball clay deposits, one on the eastern shore of Georges Bay near St. Helens and one near Western Junction, immediately east of Launceston airport. Additional small ball clay occurrences are present throughout the Tamar basin. One of these, the Launceston ball clay in South Launceston, was the basis of a prosperous vitreous china and stoneware industry before being mined out. Another Launceston ball clay occurrence is near the oval at Trevallyn. The major occurrence in the Launceston area is a 3 km^2 outcrop immediately east of the railway line at Launceston

TABLE 1

Industrial Classification of Tasmanian Clay Deposits

China clay	(a) Tertiary drifts overlying tin gravels in N.E., (e.g. South Mt. Cameron, Pioneer). (b) Weathered Cretaceous syenite in Surges Bay and Cygnet area. (c) Kaolinised Devonian granite in N.E. area: e.g. Tonganah, Fern Tree River.
Ball clay	(a) Tertiary river and lake deposits in Launceston Basin, e.g. Western Junction and the mined out ball clay at South Launceston. (b) Tertiary river and lake deposits near St. Helens, (Georges Bay).
Fireclay	(a) *Tertiary drifts overlying tin gravels in N.E.* (b) Tertiary Western Junction ball clay. (c) Associated with Permian or Triassic coal measures (e.g. Dulverton and Sandfly). (d) Precambrian clayey siltstone in Mawbanna area, N.W. Tasmania.
Brick clay*	(a) Tertiary brick and pipe manufacture from Tamar sedimentary basin sandy clay (e.g. Kings Meadows, Prospect, South Launceston, Youngtown), and pipe manufacture from plastic clay in Derwent Valley (e.g. Hamilton), roofing tile manufacture from Reibia. (b) Triassic mudstone used in southern Tasmania for brick manufacture (e.g. Austins Ferry, Electrona, Hayes, old Knocklofty and Giblin Street quarries, Howden, Kingston, Ten Mile Hill). (c) Permian mudstone (unassigned) was used in Launceston area for tile manufacture. Bricks were made at Wynyard (L. Permian varved clay and Quamby Mudstone), Dover (Grange Mudstone = Cascades Group correlate, and Woodbridge Glacial Formation = Malbina correlate), Port Arthur and *Oyster Cove (unassigned Permian). Clay pits in* operation at present are at Haines Siding, Dulverton (Quamby Mudstone), Forcett (Ferntree Mudstone) and Manuka Road (unassigned). (d) Older Palaeozoic and Precambrian available but not used (e.g. Copee).

*Of these clays "Hayes Prison Farm" is used as earthenware potters' clay and "Kingston Springfarm" as a stoneware body, usually after treatment. Various china clays and ball clays were and are used as raw materials in the preparation of stoneware and porcelain bodies, e.g. Sth Mt. Cameron and Western Junction.

airport. Serious land-slides occur in the whole area (up to 20% gradient) and threaten constantly the Launceston-Western Junction railway link. The occurrence of the fine white or buff clays, interbedded with bluish white clays of coarser nature, white sands and lignites (once mined at Springvale) was first described by Johnston[13]. Extensive drilling programmes (to depths of 18m) have been carried out by the Commonwealth Railways. A general depth of at least 25 m can be observed in the deep valleys between the "Springs" rivulet and Springvale. More than ten percent of the sedimentary column drilled is pure ball clay. Reserves can be estimated to be not less than $6 \times 10^6 \, m^3$.

The periphery of the clay is partly covered by Tertiary basalt flows from Cocked Hat Hill, and locally overlain by the Sunnyside Hill basalt, which has intruded the clay at its base (where intrusive porcellanite-basalt breccias occur). Pollen dating from the Rose Rivulet nearby indicates Palaeocene to Eocene age (Gill and Banks)[9]. The Western Junction clay appears to be an early Tertiary filling of a dead arm of the South Esk (cf. Carey[4], Sutherland[20]), possibly dammed by still earlier basalt. It was used for whitewashing early this century.

The St. Helens ball clay on the peninsula east of Georges Bay was described by Twelvetrees[22]. Several bore holes up to 10 m deep were sunk without reaching the bottom. Outcrop is discontinuous because of dune cover. The colour of the clay is buff or bluish. Ceramic tests of this clay have been consistently disappointing because of the tendency to warp and crack. Pipe clay from Pipe Clay Lagoon was used till early this century as a polishing agent and for whitewashing.

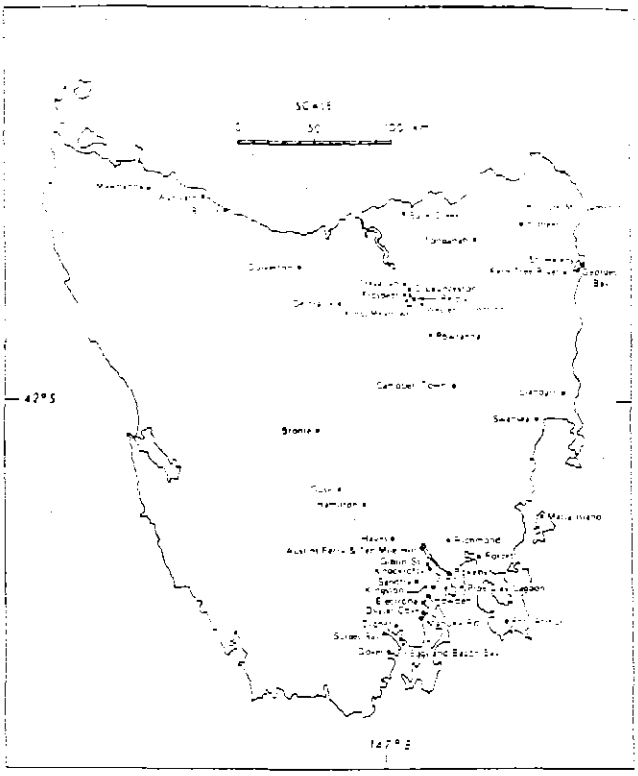


FIG. 2. Locality map (Tasmania).

5 Fireclays

Association of good quality fireclays with coal measures is common, but by no means a prerequisite. Examples of this association are the fireclay at Dulverton (north of Railton) where a bed of clay one to two metres thick overlies a seam in the Permian Mersey Coal Measures. Fire bricks made from it have been used at Mount Lyell and the Salisbury Foundry in Launceston. Similarly, the No. 3 seam at the defunct Sandfly Coal Mine (Triassic coal measures) overlies a white clay of moderately good heat resisting properties (Twelvetrees[22]).

Most production of firebricks in Tasmania, for use in boilers, came from the Powranna clay pit, an inconspicuous waterhole in Tertiary clays. The production of these bricks by Campbell's Pottery ceased after withdrawal of steam engines on the Tasmanian Government Railways, in the early sixties. The production was based on a conventional mixture of clay, grog and quartz sand.

Other clays suggested — but never actually used for firebrick production — include the Pioneer and South Mt. Cameron kaolins from the north-east and a Precambrian clay siltstone in the Mawbanna area. To this potential list may be added the Western Junction ball clay which vitrifies at 1710°C.

6 Potters' Clay

The Launceston ball clay and the associated coarser whitish clays have been the basis of a now defunct sanitary ware industry (with a Bristol glaze) at Campbell's pottery, mentioned earlier. The same works produced a variety of household articles like dishes, jugs, jars and some high precision articles like distillation apparatus (now in the Queen Victoria Museum; Fig. 3). In addition, electrical insulators were produced from the same source material, presumably mixed with residual kaolin from north-eastern Tasmania.

6.1 Cottage Industry

During the last decade a potters cottage industry has been rapidly growing in Tasmania, mainly in the south. Although to some extent dependent on imported prepared stoneware bodies from the mainland, most of the clay used is dug from the Kingston Springfarm deposit. This clay is presumably a Tertiary weathering product of Triassic mudstone; micaceous sandstones are exposed nearby. It features a high alumina content together with an exceptional high potash content, as will be discussed below. Such a clay comes as close to an ideal natural stoneware body as possible. Preparation of this clay involves removal of the fine quartz, addition of china clay, silica, some potash feldspar and a small amount of ball clay or bentonite. The clay pit is nearly worked out and extremely irregular. Scope exists for production of potters' clays by mixing local china clays (e.g. South Mt. Cameron, Tonganah) with local ball clay (Western Junction), silica derived from mine residues (Tonganah) and imported potash feldspar. A clay processing plant for this purpose has recently been developed at the Hayes Prison Farm near New Norfolk under a grant from the Australia Council (Crafts Board).

6.2 Other Uses

In addition to the cottage industry of pots a decreasing amount of vitrified stoneware, sewer and storm drain pipes are produced. Humes, the only *surviving producer in* Tasmania, obtains its clay from the Hamilton district.

Production of roofing tiles in Launceston (Wunderlich) is at present based on the occurrence *of a mottled quartz-rich* kaolin from the Lower White Hills Road, south of Ralbia. Potters' clay used for the production of earthenware is now rarely used and will be discussed (e.g. Hayes, Austins Ferry) *under brick clays.*

7 Brick Clays

It is generally not easy to find brick clays with a proper grain size distribution and the right mineralogical composition. It is particularly difficult to find consistent deposits and of sufficient size and fineness in the Hobart area (Threader[31]) or even non-*kaolinitic* clays in the Launceston area. Tasmanian clay deposits are often too sandy and kaolinitic, having an improper granulometric balance (Winkler[34]) as well as an undesirable mineralogical composition.

7.1 Northern Tasmania

The entire brick production for the *various Huttons brickworks* operating until recently around Launceston and now centralised at Longford (eight million per year) comes from the Tertiary Tamar and Cressy basins (Kings Meadows, Prospect and *since* 1977 *from* the Longford area). The clays used are sandy, usually iron-rich and kaolinitic, the iron depressing the high vitrification temperature of the kaolin. Because of inadequate blending techniques and use of ancient updraught kilns, quality control was poor and the result mottled. Consequently, the more important buildings in Launceston have always been stuccoed. Tertiary clay from Young Town, immediately south of Kings Meadows, is used for the production of agricultural drain pipes and flowerpots by Agripipe at Relbia.

7.2 Southern Tasmania

In Southern Tasmania illite-bearing Triassic and sometimes Permian mudstones and their weathering products have been traditionally used for brick production (Threader[31]). Although the grinding *cost of these shaley clays is* greater than of the Tertiary clays in northern Tasmania, quality control has always been better. Many bricks produced earlier this century have come from the Knocklofty quarry (Crisp *and Gunn) where* Lower Triassic shales were made into bricks and the sandstone was simultaneously quarried as building stone or fill. Upper Triassic shales were the source for the Hobart *Brick Company at its original quarry* and factory site at Giblin Street, Lenah Valley. Both big quarries are mined out and present production by the Hobart Brick Company is depending on a mix of various illitic or *muscovitic clays with* some kaolinite, derived from weathered Triassic mudstones in the Channel district (at present Kingston and Howden) mixed with a far more iron-rich Austins Ferry clayey shale of the same age. Oatmeal bricks are at present manufactured from the feldspathic and iron-poor Forcett clay (altered Permian Ferntree Mudstone). The total annual production of this sole southern producer is 16 million bricks a year.

Unlimited quantities of illitic Permian mudstone of sufficient quality are present around Hobart and elsewhere in Tasmania. The high grinding costs of this indurated material has virtually *prohibited* use of these mudstones, unless they are deeply weathered. Of historic interest are the rather kaolinitic feldspar-bearing weathering products of Permian rocks used in the penal settlements of *Port Arthur and Maria* Island and the kaolins at Dover used until about 1950. Firing occurred in clamps, or simple updraught kilns, the bricks were often underfired and the result very poor. Tertiary deposits exist *in the Hobart area,* but unlike those in the North have been little used because of their kaolinitic nature.

7.3 Other Areas

Weathered Permian mudstones were used at Wynyard, Zolati's *Brickworks at Haines Siding*, Dulverton, north of Railton, uses deeply weathered *Permian mudstones from the* Quamby Formation. Quality control at Dulverton is good, in spite of the simple downdraught kilns. The Dulverton works have sizeable clay reserves near the factory. Annual production is *five million bricks.*

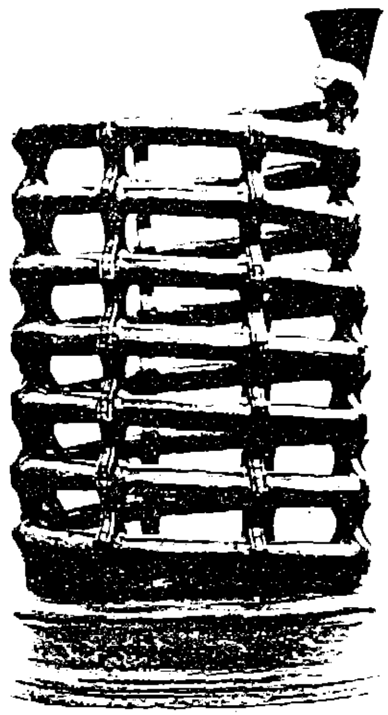


FIG. 3. Stoneware still by John Campbell (circa 1891) – 97 cm high, 53 cm diameter. By courtesy Queen Victoria Museum, Launceston.

Still older material is available in Tasmania (see Table 1), but has, in contrast to Victoria, rarely been used. The use in the past of weathered Precambrian dolerite dykes at *Burnie Brick Factory* (Cooee) should be mentioned for curiosity's sake.

8 Mineralogy

8.1 Previous Studies

Little is known of the clay mineralogy of Tasmanian soils and rocks. Cole and Carthew[6] described the Dover clays (essentially *derived from* Permian sandstones) as very siliceous kaolinitic clays with very small amounts of illite. Hale and Brill[11] had the clay mineral of shale intercalations in the Permian Berriedale limestone *identified as mixed layer* montmorillonite-illite. They suggested that the other Permian clay minerals were illite. The Grange Mudstone, of similiar age, contains some iron montmorillonite-nontronite.

The *lower Triassic shales of* the Knocklofty Formation near Hobart consist of ferrugenous sandstones interlayered with green and purple shales and mudstones. Van de Vusse[33] described their clay minerals tentatively as *illite-montmorillonite,* with some vermiculite and chlorite flakes.

Cole and Carthew[6] described the Surges Bay clays as derived from the breakdown of the feldspars of *the parent Jurassic syenite.* Although the illite and quartz contents of the Surges Bay clay are very low, one sample was found to contain appreciable quantities of a mixed-layer illite-montmorillonite. This mineral was *later defined* by Cole[7] as a partially ordered mica-montmorillonite clay, produced by a three component stacking of 18% single mica layers (A), 10% double mica layers (AA) and 72% allevardite layers (AB).

South Mt. Cameron and St. Helens clays are mainly kaolin with low illite and quartz content (Cole and Carthew[6]). Another Tertiary clay at Dunrobin Bridge near Hamilton contains mainly kaolin with some gibbsite. Tonganah consists of kaolinite plus 10% halloysite. Bahl's unpublished M.Sc. thesis[2] deals essentially with Tertiary clays of both residual and sedimentary origin. Clays studied were esentially kaolinitic with traces of illite and sometimes small amounts of illite-montmorillonite interstratifications. Bahl described in addition an "abnormal" montmorillonite, characterized by a dehydration peak at 550°C, in many of his samples.

8.2 Results from This Study

Table 2 was compiled from X-ray diffraction (XRD) studies.

TABLE 2

Mineralogical Composition of Some Tasmanian Clay Deposits

Age of Parent Material	Locality	Sample No.*	Clay Mineral (in order of abundance)
Quaternary	Wet Marsh, Swansea	44656	kaolinite and illite
Tertiary	Tonganah	44531	kaolinite, some halloysite
	Pioneer	44544	kaolinite
	South Mt. Cameron	44520	kaolinite
	Western Junction	44529, 44651	kaolinite
	Pipe Clay Lagoon	44517	kaolinite
	Hokeoy Hills	44655	kaolinite
	Machen, Kings Meadows	44565	kaolinite
Jurassic	Bronte Canal	44670	kaolinite
	Brady's Lagoon	44671	kaolinite
Triassic (upper)	Giblin Street	44564	kaolinite and illite
Triassic (lower)	Austin's Ferry	44561	illite, kaolinite, some feldspar
	Knocklofty	44558-45011- 45012 45027-45028	illite, some kaolinite and vermiculite
Triassic (undated)	Hayes, Prison Farm	44539	illite, little kaolinite
	Kingston, Springfarm	44526-44549	muscovite, kaolinite
Permian (Quamby Mudstone)	Haines siding, Dulverton	44601	illite
Permian (Ferntree Mudstone)	Forcett	44508-44541	kaolinite, feldspar
	South Arm	1084	illite, some kaolinite
Permian (undated)	Port Arthur, Brick Point Beach	44598	kaolinite, feldspar, illite
	Port Arthur, Prices Kiln	44599	kaolinite, illite, feldspar

*Numbers refer to specimens in Geology Department, University of Tasmania

8.3 Detailed Mineralogy

The mineralogy of the Forcett clay, the Kingston stoneware clay at Spring Farm and the Western Junction ball clay has been studied in some further detail. The Forcett clay is a very siliceous, kaolinitic clay, poor in iron oxides, used for the manufacture of oatmeal bricks by the Hobart Brick Company. It contains up to 40% potash feldspar; muscovite is very minor. Silicifications are frequent. Dropstones of granite and shale are frequent. The stratigraphic position of this arkosic clay corresponds to a washed-out horizon in the Permian Ferntree mudstone. Tertiary basalt covers part of the outcrop. The silicification and abundance of kaolinite indicate an intense pre-basalt weathering.

The Kingston Spring Farm clay, somewhat less siliceous than the previous clay, is also potassium-rich, in this case however due to the presence of up to 40% fine muscovite. The clay contains a smaller amount of kaolin. The clay is probably derived by weathering and reworking of muscovite-rich sheets in Triassic sandstone, which can be found outcropping in nearby Kingston.

The grain size distribution of the natural Western Junction material (as determined by APPM) is shown in Fig. 4 and is fine even for a ball clay (cf. Scott[11]). The 12% >2μm contains kaolinite, minor quartz and isolated grains of goethite (electron probe analysis). The clay fraction by XRD showed kaolinite and very little quartz. However, swelling up to 17.7 Å of a minor fraction in Mg-saturated material occurs. This material collapses progressively after heat treatment and reaches 11.0 Å at 550°C. At this stage it is impossible to comment on the nature of this minor mineral, which is certainly responsible for the rather high magnesium content of about 0.6% in the clay. A further enigma of the diffractogram is the persistent 4.80 Å spacing. The electron micrograph of Fig. 5b illustrates the wide range in particle size and the worn and jagged shapes of the kaolinite crystals as compared with the bigger and more hexagonal shape of the Tonganah kaolin used as paper filler (Fig. 5a).

8.4 Clay Mineralogy as a Function of Parent Material

The data given above in sections 8.1, 8.2 and 8.3 indicate that some relation exists between the nature of the parent material and the type of clay derived from it.

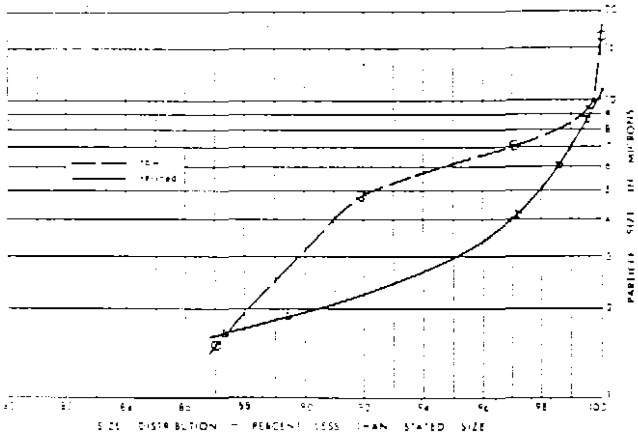
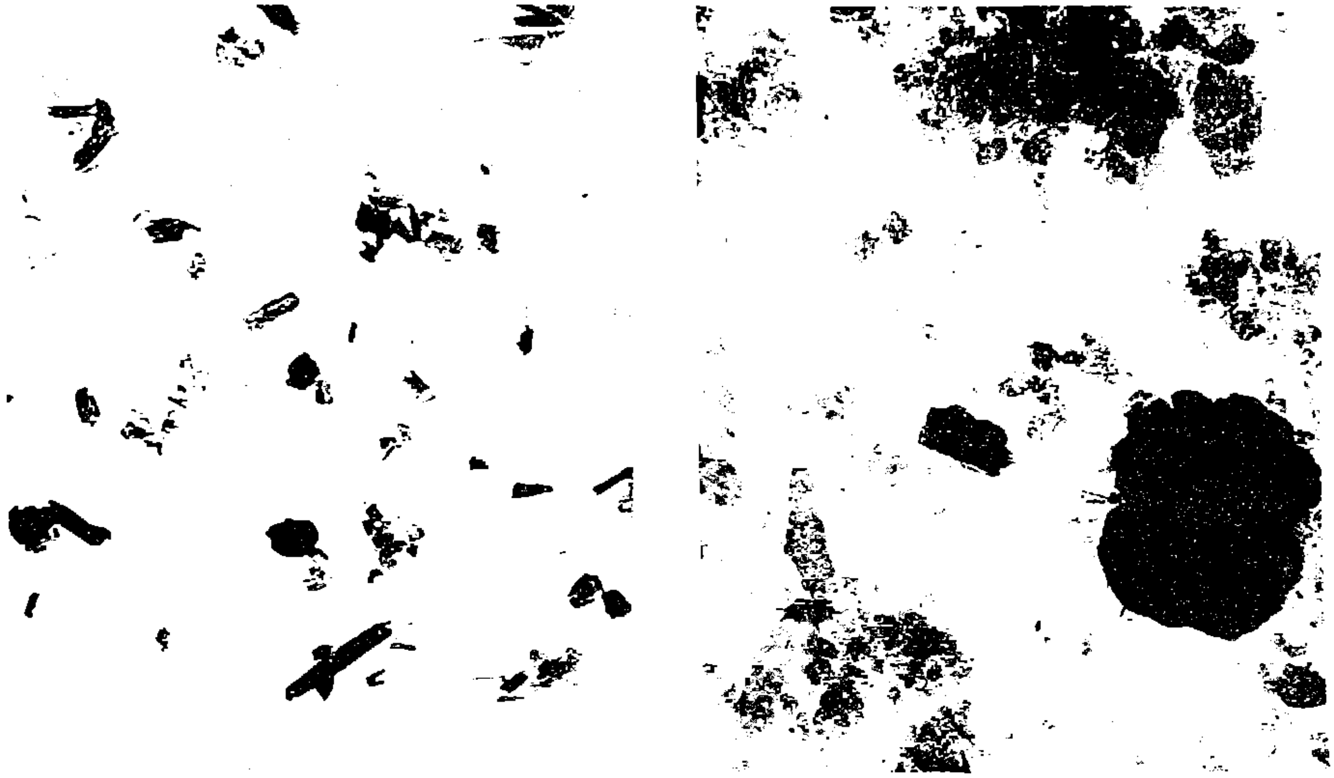


FIG. 4. Grain size distribution of Western Junction ball clay, raw and after removal of the >12μm fraction.

The Permian shales are derived from metamorphic source rocks and often contain a glacial component. The mineralogy of these shales is illitic with varying amounts of feldspar and quartz. Brick clays derived from these shales by Tertiary weathering are in most cases largely illitic, or even entirely illitic (e.g. Haines Siding, Dulverton). The more feldspathic Permian shales tend to yield more kaolinitic clays when deeply weathered (Port Arthur, Forcett), although appreciable amounts of illite or feldspar always remain. Only one case is known where little illite remained (Dover).

The Triassic shales used for brickmaking may contain, in addition to illite, some feldspar and sometimes minor original kaolinite (Hale[18]). The Tertiary weathering enhanced the kaolinite content, particularly in the clays derived from feldspathic upper Triassic shales (Giblin Street). The Lower Triassic Austin's Ferry brick clay, the Kingston clay, the Hayes Prison Farm clay, derived from Triassic material of unknown age, contain appreciable amounts of illite (muscovite). This is in accordance with the sometimes muscovitic
]



(a) Tonganah (12500X), Paper filler china clay (kaolinite and some halloysite). Note the relatively small range in grain size and the subhedral crystal outlines.

(b) Western Junction (12500X), well dispersed sample. Note the wide range in grain size and the often worn and jagged shape of the kaolinite particles in this ball clay.

FIG. 5. Electron Micrographs (microscopy by J. Ladru, Zoology Dept., University of Tasmania)

nature of Triassic rocks. Minor feldspar and vermiculite may persist when present in the parent rock.

The Tertiary weathering products of igneous rocks, notably Devonian granites, Jurassic dolerites and syenites, are kaolins. Weathering during the Tertiary must have been intense: the soils derived from the basaltic necks at Rokeby Hills are entirely kaolinitic.

Although veins in the dolerite of the Central Plateau are reported[2] to often contain montmorillonite, the essential weathering product of the dolerites is kaolinite (Bronte, Brady's Lagoon).

The sedimentary kaolins accumulated in the Tertiary grabens are entirely kaolinitic.

The sequence outlined above corresponds to an overprint of weathering on a parent rock mineralogy representing recycling and leaching of detritus on a rather stable shelf.

9 Chemistry

All known chemical analyses of Tasmanian clays are listed in Table 3. The "clays" range from very fine material containing 90% of particles smaller than 2µm (Western Junction – 44529, Sth Mt. Cameron – 44520) to sandy material containing less than 20% clay material (Oyster Cove – 44551). Some variation occurs in the composition of samples from the same occurrence (cf. the various Forcett and Kingston analyses).

The composition of the residual china clays at Tonganah (44531), Surges Bay (Cole and Carthew[6]; analyses 9 and 11) and the slightly transported clay at Sth Mt. Cameron (44520) correspond to almost pure kaolin, showing $Al_2O_3 > 37\%$, $SiO_2 \leqslant 47.5\%$ and ignition losses of 12-13%.

The Tertiary clays analysed are mature products of weathering and sedimentation: a mixture of kaolins and orthoquartzitic sands. In an Al_2O_3-SiO_2 variation diagram (Fig. 6) many of these clays lie consequently more or less on the tie line between pure natural kaolin (taken as Tonganah 44531) and proto-quartzite (assumed at 97% SiO_2). The points reasonably fitting this theoretical line are the two Surges Bay china clays mentioned earlier, Tonganah 44531, Dover 44554, Western Junction 44528, 44529 and 44570, St. Helens 44550, Pipe Clay Lagoon 44517, Major Back Reef at Back Creek 44535 and Oyster Cove 44551. Tonganah and Sth Mt. Cameron are natural pure kaolins and compare favourably chemically with Georgia and Cornwall kaolins (cf. Murray[12]).

The clays below this line are partly illitic, do not consist of mixtures of pure kaolin and quartz sand and should fall on or above the illite - protoquartzite tie line. *In cases of abundance of impurities* like iron oxide they may even plot below the illite - quartzite line.

Many of the illitic clays described above plot close to this tie-line, e.g. Brick Point Beach 44598, Kingston Spring Farm 44549, Hayes 44539, Knocklofty 45027, Austins Ferry 44561, Dulverton 44601, Knocklofty 45010, 45011, 45029. The iron-rich kaolinitic Kings Meadows Machen clay 44565 and the feldspathic and kaolinitic Forcett clay 44541 fall by accident on the curve. The only notable exception is the stoneware clay from Hamilton (44553), used for pipe manufacture.

9.1 Variation Diagrams

Brickmakers and potters have apparently found by trial or error that the more illitic clays give better results, because of the lower temperatures needed for vitrification and their better wet strength

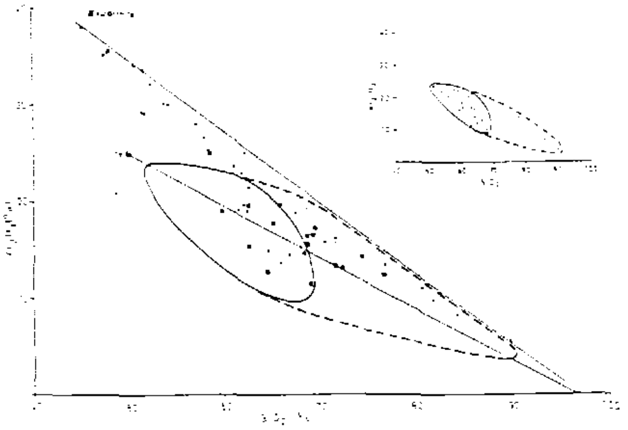


FIG. 6. Binary Al_2O_3-SiO_2 variation diagram of the composition of Tasmanian clay deposits (see Table 3). The asterisks refer to the ceramic clays used for brick, pipe and tile manufacture in the past and at present.

The inset refers to non-marly brick clays in the United Kingdom and in the U.S.A. The enlarged field includes composition of unsuccessful siliceous brick clays. For details see text.

TABLE 3 — CHEMICAL COMPOSITION OF TASMANIAN CLAY DEPOSITS

[illegible]

and plasticity. Plotting of the available brick clay analyses confirms this idea. Marly clays and marls, used in Europe and America for the manufacture of yellow bricks, have however been excluded from this compilation as they are not used in Australia. Data from Singer and Singer[15], Grimshaw[10] and one N.S.W. brick clay reported by McMeekin[13] have been plotted in the inset of Fig. 6. Two additional analyses on the extremely sandy side quoted respectively by Dolbear[8] and Cardew[5] at respectively 90% and 86% SiO_2 have been included to complete the field.

The amount of glass formed during firing of a ceramic product and its melting point depend largely on the relative proportions of alkalis and alkaline earths ("R_2O and RO"), Al_2O_3 and SiO_2 present. Accordingly, the molecular proportions of these groups have been used in specialised studies of glazes and refractories. These molecular proportions, called Seger values, have not been used for the calculation of the composition of brick, earthenware and stoneware bodies, probably because of the very wide range in chemical composition of these materials. The Seger values of all clays listed in Table 3 are plotted in Fig. 7 as molecular proportions of Al_2O_3 and SiO_2 *relative* to the sum of the molecular proportions of Na_2O, K_2O, MgO and CaO. With the exception of the very aluminous Dover clay and the siliceous Prospect and Kings Meadows kaolins, all useful brick, earthenware and stoneware clays group together in a very small field. However, except for the Knocklofty and Giblin Street shales, Tasmanian ceramic clays are short of fluxes compared with the English and American clays cited earlier (inner full line on diagram in Fig. 7).

9.2 Chemical Composition and Brick Durability

The argument can be carried further by considering the chemical composition of the lime-poor bricks from the United Kingdom listed by Bonnell and Butterworth[3]. The Seger values of these clays, largely derived from lower Jurassic, Carboniferous and older shales, were plotted in the inset of Fig. 7 (outer broken line). However, three-quarters of the observations fall in the narrow field outlined above (solid line of both inset and main diagram). In a test by the British D.S.I.R. only seventeen clays of this group gave frost- and moisture-resistant, durable bricks, reducing the field of desirable composition as shown by the inner broken lines. Most importantly, twelve out of these seventeen high quality clays again plot in the even smaller, innermost field.

Therefore it may be concluded that the chemical composition of quality brick is restricted to a small field of relative proportions of SiO_2, Al_2O_3, alkalis (mainly potassium) and alkaline earths. This field corresponds to the lower temperature (about 900-1000°C) part of the mullite and tridymite fields of the K_2O-Al_2O_3-SiO_2 and Na_2O-Al_2O_3-SiO_2 phase diagrams of Schairer and Bowen[16,17]. Potassium is usually more abundant than sodium in clays and can be considered to be the main glass former. Magnesium, calcium and iron are effective only at higher and uneconomical temperatures (cf. Grimshaw[10]).

Evaluation of Fig. 7 shows that some ceramic clays used in Tasmania fall outside the compositional field of the brick clays used in the United Kingdom. Of these, the Launceston ball clay and Hamilton clays are stoneware clays, whilst the very iron-rich Kings Meadows clay was mainly used for clinker manufacture at elevated temperature. The Dover kaolin was used for the manufacture of "oatmeal" bricks, giving an inferior product which flakes and frets badly. The very siliceous Kingston variety (Spring Farm North) has also produced bricks prone to decay, whilst all other clays outside the field have given trouble, either in production or in testing.

Material of ideal composition are the Giblin Street, Knocklofty and Howden Yellow clays, which all give bricks of outstanding quality, not showing any decay after up to seventy years of exposure. The first two clay quarries are mined out; Howden Yellow is at present mixed with equal amounts of Austins Ferry and with some additional Kingston Spring Farm clay as a lubricant for the production of terra cotta bricks. Slightly outside the optimum compositional field are Kingston Spring Farm South and Port Arthur Brick Point Beach. Decay of the latter brick has been attributed by Roberts and Kallend[12] to underfiring and use of sea water in the preparation of the bricks. After less than fifteen years, some of these Kingston bricks show also severe fretting, which cannot be attributed to salt water or underfiring.

The composition of most other Tasmanian brick clays fall within the outermost field of established composition, as calculated according to the method outlined above. This field however has not produced durable bricks according to the listing of Bonnell and Butterworth[3]. It is of interest to note the severe decay of the historic Port Arthur Prices Kiln brick, whose composition falls inside this field. Some concern may consequently be expressed about the future of the red Austins Ferry, Dulverton, Howden black and Hayes bricks and the yellow Forcett bricks. These clay pits have all been opened within the last decade and it is consequently too early to determine whether premature decay will occur. The composition of the Prospect brick is outside the acceptable field.

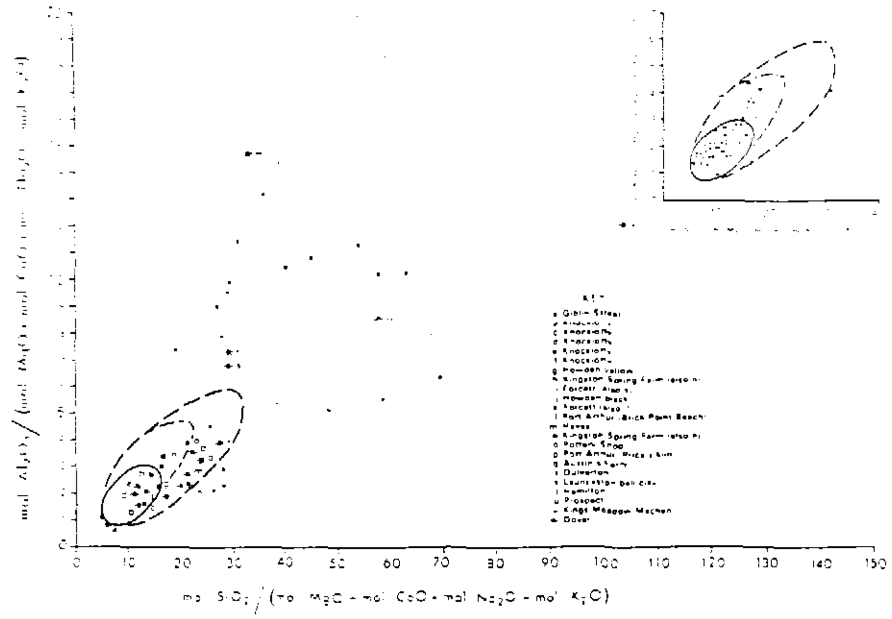


FIG. 7. Seger values of Tasmanian clay deposits (see chemical data in Table 3). The ceramic clays are marked with an asterisk in the main diagram. The molecular values of alumina and silica are taken relative to (moles R_2O + moles RO) = 1. The inner ellipse includes the ideal brick clay field for United Kingdom and U.S.A. clays: this limited field comprises 75% of all durable lime-poor bricks produced in the U.K. (cf. Bonnell and Butterworth[3]). The inner broken line includes all durable U.K. brick compositions. The outer broken line includes the composition of all lime-poor U.K. bricks. The individual U.K. data are plotted in the inset; the durable bricks listed by Bonnell and Butterworth are marked with crosses.

10 Conclusions

Tasmanian Tertiary clayey sediments are largely kaolinitic, clays developed on Triassic sediments are usually illitic with varying amounts of kaolinite and clays developed on Permian and older rocks are largely illitic with some kaolinite or none at all. The Permian clays contain sometimes appreciable amounts of detrital potash feldspar (e.g. Forcett). Primary clays derived from igneous rocks are largely kaolins, sometimes of great natural purity (e.g. Tonganah and Sth Mt. Cameron).

The relative molecular proportions of the combined alkalis and alkaline earths compared with the proportions of silica and alumina (as calculated from raw clay chemical analyses) characterise accurately the suitability of the clays as brickmaking material. Comparison with chemical analyses of U.K. bricks tested on exposure resistance indicate the most Tasmanian brick clays are too siliceous and/or aluminous (e.g. Port Arthur, Dover). The few Tasmanian clays of optimum chemical composition (Knocklofty, Giblin Street, Howden Yellow) show great resistance to weathering. The developed method of chemical evaluation of brick clays appears to be universal and can be applied for the calculation of suitable clay mixtures for the production of bricks.

Acknowledgements

It would not have been possible to write this article without information obtained from a wide range of persons and organizations. I acknowledge in particular the help of Associated Pulp and Paper Mills Ltd. (APPM), Tonganah and Wesley Vale, several members of the Australian Potters Association (Tasmanian Division), Campbell Potteries Pty. Ltd., Launceston and the Hobart Brick Company Pty. Ltd. I acknowledge in particular the assistance of Mr. P. Robinson, analyst, Geology Dept., University of Tasmania.

References

1. Anonymous, Catalogue of the minerals of Tasmania; Tas. Dept Mines, Geol. Surv. Rec. **9**, 110 pp, 1970.
2. D.P. Bahl, Mineralogical and physical properties of some Tasmanian Cainozoic clays (Unpubl. M.Sc. Thesis, University of Tasmania, 165 pp, 1957).
3. D.G.R. Bonnell and B. Butterworth, Clay building bricks of the United Kingdom (Ministry of Works, National Brick Advisory Council, Paper Five; H.M. Stationary Office, London, 169 pp, 1950).
4. S.W. Carey, Geology of the Launceston district; Rec. Queen Vict. Mus. **2** (1946) 31.
5. M. Cardew, Pioneer pottery (Longmans, London, 327 pp, 1969).
6. W.F. Cole and A.P. Carthew, The mineralogical composition of some Tasmanian clays; Pap. Proc. R. Soc. Tas. **87** (1953) 1.
7. W.F. Cole, Clay Minerals **6** (1966) 261.
8. S.H. *Dolbearl, Industrial minerals* and rocks (Am. Inst. Min. Met. Petr. Eng., New York, 156 pp. 1949).
9. E.D. Gill and M.R. Banks, Cainozoic history of Mowbray Swamp and other areas; Rec. Queen Vict. Mus., New Ser. **6** (1956) 1.
10. R. Grimshaw, The chemistry and physics of clays (Benn, London, 1024 pp, 1971).
11. G.E.A. Hale and K.G. Brill, Clay minerals from Permian strata in Tasmania; Pap. Proc. R. Soc. Tas. **89** (1955) 231.

11a. G.E. A. Hale, J. Geol. Soc. Australia **9** (1962) 217.

12. Johnston, Geology of Tasmania (Government Printer, Hobart, 408 pp, 1888).
13. I. McMeekin, Notes for potters in Australia, Vol. 1 (New South Wales University Press, Sydney, 205 pp, 1967).
14. H.H. Murray, Clay; Trans. Am. Pulp and Paper Ltd., Monograph Ser. **38** (1975) 69.
15. N.K. Roberts and P.W. Kallend, J. Aust. Ceram. Soc. **12** (1976) 5.
16. J.F. Schairer and N.L. Bowen, Am. J. Sci. **245** (1947) 193.
17. J.F. Schairer and N.L. Bowen, Am. J. Sci. **253** (1955) 681.
18. A. Scott, Ball clays; Spec. Rep. Min. Res. Gr. Britain, Vol. XXXI (H.M. State Office, Lond, 73 pp, 1929).
19. F. Singer and S. Singer, Industrial ceramics (Chapman and Hall, 1963).
20. F.L. Sutherland, The geology and petrology of the Tertiary volcanic rocks of the Tamar trough, Northern Tasmania; Rec. Queen Vict. Mus. **36** (1971).
21. V.M. Threader, The clay resources of the Hobart area; Tasm. Dept Mines, Techn. Rep. **14** (1969) 38.
22. W.H. *Twelvetrees, Report on deposits* of clay at George's Bay and elsewhere (Unpubl. Rep. Govt. Geologist's Office, Tas. Dept Mines, 10 pp, 1904).
23. M.M.A. van de Vusse, A study of glauconite and related layer silicates in some Tasmanian rocks (Unpubl. Hons. Thesis, Geology Dept, University of Tasmania, 196 pp, 1976).
24. H.G.F. Winkler, Ber. Dtsch. Keram. Gesellsch. **31** (1954) 337.

CLAYS COMPARATIVE ASSAYS ON L.O.I. FREE BASIS

Assay value	Hywhite Superb	Hymod blue	1001 S Schmidt	Bandy Black	Troup Texas	GS 34 calcined	GS 30/31 "
SiO_2	55.0	57.8	70.4	63.0	68.2	60.81	60.28
Al_2O_3	35.9	33.8	22.7	30.0	36.0	31.79	30.79
Fe_2O_3	1.2	1.5	1.03	1.31	1.62	1.13	1.35
TiO_2	1.0	1.0	1.5	1.72	1.41	0.89	1.55
CaO	0.22	0.32	0.22	0.09	0.14	0.03	0.05
MgO	0.45	0.55	0.81	0.39	0.63	0.88	1.06
K_2O	2.0	3.3	2.27	1.82	1.06	4.16	4.66
Na_2O	0.22	0.44	0.23	0.28	0.13	0.21	0.23

937060

TABLE 3: CHEMICAL COMPOSITION OF TASMANIAN CLAY DEPOSITS

Locality		Type of Clay	Sample Number	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	H_2O+	H_2O-	CO_2	C	Total
Forcett		white brick & stoneware clay	44508	74.27	14.22	1.27		0.31	0.00	0.42	4.16	0.52	0.04	0.00	3.11	0.79	0.02	0.20	99.28
Pipe Clay Lagoon [1]		pipeclay - ball clay	44517	57.01	28.12	1.56		0.70	0.13	0.23	1.16	1.09	0.02	0.01	8.66	2.84	0.06	0.26	101.84
South Mt. Cameron		transported china clay (pug)	44520	47.50	37.26	0.80		0.00	0.00	0.00	0.45	0.72	0.03	0.00	13.27	0.75	0.00	0.00	100.78
Kingston Spring Farm (southside)		stoneware clay	44526	62.68	21.61	2.58		0.60	0.04	0.20	3.65	1.00	0.18	0.00	4.67	2.59	0.02	0.53	100.33
Western Junction, No.1	West of Railway at Springs Rivulet.	ball clay	44528	61.81	23.03	2.07		0.52	0.07	0.20	0.34	1.43	0.01	0.02	7.72	2.24	0.07	0.54	100.12
Western Junction, No.2		ball clay	44529	51.55	29.40	2.04		0.66	0.27	0.35	0.49	1.13	0.01	0.00	10.17	3.83	0.10	0.37	100.37
Western Junction, No.2		ball clay <120um	44530	51.65	29.20	2.10		0.65	0.25	0.32	0.38	1.17	0.02	0.00	10.07	3.41	0.22	0.24	99.57
Torcaman, A.T.F.M.		china clay	44531	45.51	38.25	0.89		0.00	0.00	0.25	0.91	0.38	0.10	0.00	11.89	0.87	0.00	1.15	100.20
St. Helens Point gravelpit		ball clay	44532	57.99	26.66	1.65		0.29	0.02	0.11	1.54	1.78	0.12	0.00	7.29	2.06	0.02	1.49	100.82
Back Creek, Major Reef		hydrothermally altered slate, white	44534	81.36	11.29	0.83		0.59	0.00	0.24	2.75	0.50	0.00	0.00	2.01	0.25	0.02	0.28	100.10
Back Creek, Major Reef		hydrothermally altered slate, black	44535	80.69	11.06	0.83		0.60	0.00	0.22	2.77	0.48	0.00	0.00	1.74	0.24	0.22	0.88	99.52
Hayes Prison Farm		earthenware clay	44539	66.88	14.63	5.28		0.85	0.22	0.39	2.18	0.67	0.03	0.04	4.28	3.82	-	-	99.28
Ouse		stoneware clay	44540	48.50	20.93	2.24		3.01	3.81	0.36	0.92	0.64	0.02	0.12	12.28	7.52	-	-	100.54
Forcett		white brick & stoneware clay	44541	72.44	13.16	2.35		0.68	0.04	1.44	2.84	0.47	0.03	0.01	3.06	2.62	-	-	99.13
St. Helens Beach		siliceous ball clay	44542	58.31	25.47	1.05		0.32	0.05	0.07	1.01	1.79	0.05	0.00	8.77	2.88	-	-	99.76
Llandaff		stoneware clay	44543	65.79	19.85	1.61		0.64	0.01	0.00	2.60	0.91	0.04	0.00	5.29	2.94	-	-	99.68
Pioneer		transported kaolin	44544	53.80	30.20	0.72		0.17	0.03	0.00	0.92	1.45	0.07	0.01	10.64	2.04	-	-	100.15
Eggs and Bacon Bay		stoneware clay	44545	84.35	8.27	1.14		0.13	0.01	0.06	0.18	0.70	0.00	0.00	3.22	1.21	-	-	99.27
Campbell Town, Quarry Hill		stoneware clay	44547	65.90	19.90	0.96		0.46	0.02	0.13	0.63	1.34	0.01	0.01	7.07	2.64	-	-	99.07
Western Creek, Deloraine		stoneware clay	44548	71.61	15.80	1.42		0.77	0.08	0.05	2.61	0.78	0.02	0.00	4.31	2.17	-	-	99.63
Kingston Spring Farm (southside)		stoneware clay	44549	62.39	19.11	3.82		0.65	0.99	0.19	3.26	0.78	0.00	0.00	5.13	3.59	-	-	99.91
St. Helens Point		ball clay	44550	54.05	30.09	1.57		0.15	0.01	0.00	0.62	0.79	0.02	0.00	10.50	2.11	-	-	99.91
Oyster Cove		very siliceous white brick clay (HBC)	44551	88.90	5.65	0.59		0.18	0.00	0.00	0.37	0.70	0.00	0.00	2.07	0.69	-	-	99.14
Manuka Road		siliceous stoneware clay	44552	67.88	18.86	2.02		0.34	0.01	0.00	0.92	0.78	0.00	0.00	6.44	2.85	-	-	100.09
Hamilton (Cleveland)		stoneware clay	44553	59.48	25.19	2.23		0.79	0.02	0.12	1.17	1.03	0.02	0.01	8.75	2.22	-	-	100.03
Dover [2]		white brick clay	44554	48.00	35.84	0.76		0.22	0.00	0.34	1.29	0.43	0.07	0.00	12.24	1.17	<0.2	-	100.36*
Howden		yellow brick clay (HBC)	44555	68.85	16.63	5.53		1.13	0.14	0.65	3.50	0.82	0.10	0.10	3.67	2.42	<0.2	-	100.55*
Howden		black brick clay (HBC)	44556	68.87	14.38	6.61		0.69	0.17	0.55	2.59	0.80	0.00	0.00	3.60	1.27	<0.2	-	100.64*
Kingston Spring Farm (northside)		brick clay (HBC)	44557	76.70	12.34	4.48		0.30	0.0	0.16	1.22	0.67	0.00	0.00	4.28	1.66	<0.2	-	101.81*
Knocklofty Quarry		mixture of green & purple shale	44558	65.31	17.95	5.61		1.36	0.25	0.95	3.30	0.84	0.10	0.10	3.72	1.93	<0.2	-	101.43*
Powranna		fireclay	44560	76.95	13.55	3.52		0.38	0.0	0.27	0.43	0.87	0.00	0.00	5.09	1.54	<0.2	-	102.59*
Austins Ferry		brick clay (HBC)	44561	69.45	16.63	5.02		0.16	0.30	0.69	2.80	0.73	0.02	0.07	3.67	1.25	-	-	100.79*
South Launceston (Campbells Pottery)		"Launceston ball clay"	44563	60.94	23.70	2.37		0.69	0.14	0.39	0.83	1.22	0.00	0.00	7.93	2.94	<0.2	-	101.17*
Lenah Valley		Giblin Street Quarry - HBC	44564	67.27	15.69	5.59		2.19	3.69	1.45	2.69	0.74	0.12	0.13	4.37	1.42	<0.2	-	100.45*
Kings Meadows		Machen's brick clay pit	44565	68.28	12.16	9.33		0.21	0.00	0.00	0.46	0.70	0.00	0.12	6.36	1.95	-	-	99.57
Richmond (below St. John's cemetery)		siliceous kaolinitic clay	44566	80.95	9.91	1.70		0.63	0.16	0.82	0.81	0.89	0.00	0.00	3.29	1.39	<0.2	-	101.09*
Prospect		brick clay (Hutton's)	44569	69.55	17.23	4.65		0.34	0.00	0.30	0.56	1.23	0.00	0.00	6.30	2.03	<0.2	-	102.2 *
Port Arthur, Brick Pt. Beach		brick clay	44598	61.64	19.39	5.26		0.50	0.22	1.21	3.52	0.78	0.00	0.01		ignition loss 6.90			99.43
Port Arthur		white brick clay	44599	68.66	19.28	0.86		0.46	0.08	0.13	2.25	0.85	0.05	0.01		7.34			99.97
Clay from pottery shop, Chemistry Dept.		stoneware clay	44600	69.20	15.75	3.84		0.47	0.20	1.03	2.20	0.68	0.01	0.01		6.02			99.51
Dulverton ("bush pit")		brick clay (Zolati & Son)	44601	69.45	16.63	5.02		0.16	0.30	0.69	2.80	0.73	0.02	0.02	3.67	1.25	-	-	100.79
Western Junction, No.32	East of Railway at Springs Rivulet.	ball clay, 1-2um	44651	62.16	25.33	1.76		0.55	0.16	-	0.35	1.47	0.02	0.01	-	-	-	-	-
Western Junction, No.32		ball clay, 1-0.2um	44652	53.85	33.71	2.28		0.70	0.25	-	0.37	1.24	0.02	0.01	-	-	-	-	-
Western Junction, No.32		ball clay, <0.2um	44653	52.33	32.22	2.36		0.79	0.25	-	0.37	1.17	0.02	0.01	-	-	-	-	-
Surges Bay Quarry [3]		china clay	*44648	50.27	32.61	1.31		0.20	0.04	<0.1	3.73	0.49	0.10	0.00	10.46	1.29	-	-	100.50
Knocklofty Quarry	Brick clays from old Crisp and Gunns works.	purple mudstone	45010	59.88	19.03	6.09	3.03	1.06	0.19	0.49	4.19	0.77	0.03	0.04	3.67	1.49	-	-	99.96
Knocklofty Quarry		green shale mudstone	45011	62.53	19.47	2.33	2.33	1.42	0.30	0.78	3.87	0.90	0.07	0.05	3.77	1.50	-	-	99.32**
Knocklofty Quarry		green & purple fine micaceous siltstone	45027	68.35	15.26	1.94	2.88	1.12	0.74	0.90	2.71	0.66	0.03	0.08	3.45	0.91	-	-	99.02**
Knocklofty Quarry		green micaceous siltstone	45028	64.63	14.84	3.27	3.42	1.32	0.43	1.14	3.00	0.74	0.05	0.08	3.92	1.29	-	-	98.14**

[1] This clay was saturated with salt and had to be washed prior to analysis.

[2] Cole and Carthew (1953) give three additional analyses of the Dover clay.

[3] Cole and Carthew (1953) give three additional analyses of the Surges Bay clay. Our analysis is very much like their no.9 analysis.

- not determined

Iron values represent total iron as Fe_2O_3, with exception of the last four analyses.

Analyses marked * by J.L. Walshe in 1977, those marked ** by H.M.A. van de Vusse. All other analyses by P. Robinson, Analyst, Geology Department, during 1976 and 1977.