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CLAYS AND BRICKS OF THE PENAL SETTLEMENTS AT PORT ARTHUR AND MARIA ISLAND, TASMANIA

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(with four tables, one text-figure and two plates)

ABSTRACT

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The making of clay bricks was a major industrial activity at the penal settlements of Port Arthur and Maria Island. The silicate minerals in the clays used were mainly illite and kaolin as is usual in brickmaking. All bricks examined had more than 1.2% K_2O and so the surface clay at the Port Arthur settlement, which is montmorillonitic and low in potassium, was not used. Many of the bricks made at Port Arthur are soft due to underfiring and unaltered clay minerals have been detected in some.

Much of the brickwork of the ruins at Port Arthur has disintegrated due to the lack of strength in the bricks and due to the presence of more than 1% salt, mainly NaCl, which, as the result of exposure to rain, wind and sun, has crystallized near exposed surfaces. Bricks, collected from inside a continuously occupied building and thus not exposed to any source of salt or water, were sound but contained 1 - 2% salt. As the salt is similar in composition to that of seawater, it is concluded that at least some of the bricks were made from clay that had been puddled with seawater.

An old photograph of the Penitentiary with its roof still intact and hence taken before the 1898 bushfires shows deterioration of the exposed bricks at that early date. It would appear that a large number of the bricks manufactured at Port Arthur during occupation of the settlement were of such inferior quality that they could not be expected to last for centuries.

INTRODUCTION

At a Workshop on Building Materials Conservation held in Hobart during April 1975, Cripps and Spratt (1977) reported that the deterioration of many of the buildings at the penal settlement at Port Arthur could be attributed largely to two factors; firstly to the badly made and underfired bricks which contain soluble salts and secondly to water movement which conveyed the salts through the masonry. At exposed surfaces, where evaporation takes place, salts are left behind and erode the bricks as crystallisation proceeds (Pla e 1). In 1979 Crawford, de Bavay and Cripps, Architects, in association with Fowler, England and Newton, engineers, submitted a detailed report entitled "To Conserve Port Arthur" to the Director, Tasmanian National Parks and Wildlife Service. This report gives the results of the extensive research initiated by them into many aspects of the conservation of the ruins at Port Arthur.

A documentary search (Glover 1978) into the history of Port Arthur showed that brick manufacture was a major industrial activity with 68 300 bricks being manufactured in March 1834, 160 700 bricks in December 1841 and an average of 14 000 per month during the decade 1858 to 1869. Besides their use in the large number of buildings erected at Port Arthur, the bricks were exported to Hobart and possibly to other centres. From 1830 until 1845, most of the bricks were made south of the settlement on the southwestern shore of Carnarvon Bay using clay from nearby shallow pits. After 1845, brickmaking was transferred to a site on the hill beyond the church, locally known as Brickfields Hill.

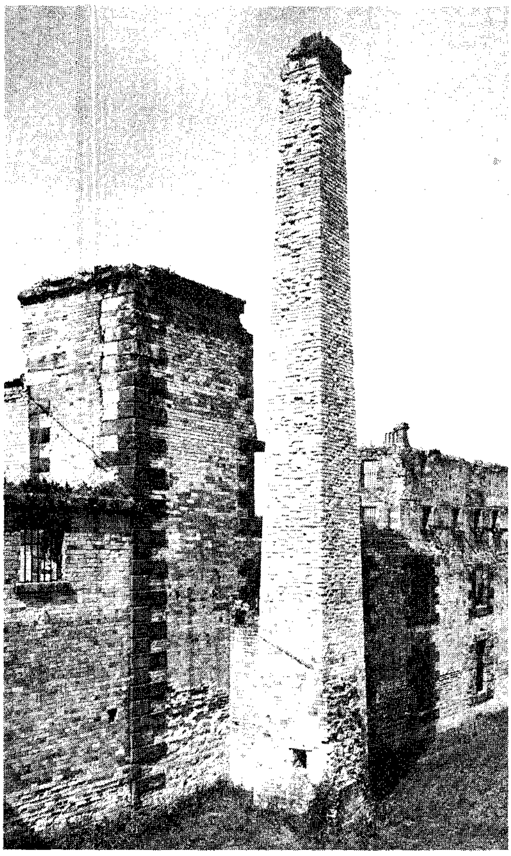

PLATE 1.- Recent view of southern wall of Penitentiary. (Photograph by courtesy Tasmanian Film Corporation).

During inspections at Port Arthur and Maria Island by the Tasmanian Restoration Advisory Committee, the author, a member, collected samples of bricks and clays for laboratory examination.

In June 1975, Dr. N.K. Roberts, University of Tasmania, was engaged by Messrs Crawford, de Bavay and Cripps to undertake some investigations into the decay of bricks and sandstone from Port Arthur and his results are included in the report "To Conserve Port Arthur" (V. Sup.). Surfaces of some of the bricks from the Penitentiary were examined under a JEOL scanning electron microscope and the salt efflorescence was found to be crystals of sylvite (KCl) (Roberts and Kallend 1976).

SAMPLES AND METHODS OF ANALYSES

Five samples of clay were collected from Port Arthur area during visits by the committee, and in addition, the Tasmanian Department of Mines kindly made available samples taken during a detailed clay survey of the area by Threader (1976). Figure 1 shows the location of the Tasmanian Department of Mines' bores, the other clay sampling sites, and the boundaries of the main geological formations as mapped by Cromer (1976). From Maria Island, two samples of clay were collected from the shallow clay pits one km east of Darlington near the arched kilns. In all, eleven bricks have been sampled, five from Port Arthur and six from Maria Island. Two bricks from Port Arthur, brick 1 (red) and brick 2 (white), were collected from under the floor of the Roman Catholic Chaplain's cottage which is one of the buildings that has been almost continuously occupied since the early days of the settlement. Brick 3 was taken about 2 m above ground level from the northeastern corner of the Penitentiary at Port Arthur.

The soluble salts present in the bricks 1, 2 and 3 were extracted with water from the finely-crushed bricks and the respective solutions absorbed onto cellulose powder. The wet cellulose was then dried, ground and pressed into suitable discs for analysis by XRF methods such as those described by Norrish and Hutton (1977) for the analysis of plant tissue.

The analysis of the clays and bricks for major elements was also made by XRF methods in this case using the fusion technique of Norrish and Hutton (1969) and applying their inter-element correction factors.

The minerals present in the fine fraction (< 2 μm) of the clay samples were identified by a combination of X-ray diffraction methods and additional chemical tests (Norrish and Pickering 1977).

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RESULTS

Several samples were analysed from each of the cores taken by the Tasmanian Department of Mines and the results have been averaged for each bore hole. The results given in table 1 have been restricted to five major elements and to five minerals. Details of the chemical analysis of the bricks are not presented here but the ratios of silicon, potassium and titanium to aluminium together with the same ratios for some of the clay samples are given in table 2. Table 3 gives the ionic analysis of the salts extracted from bricks 1, 2 and 3 from Port Arthur and from three of the clay samples (A, G and J). The ratios of the chloride, potassium, magnesium and calcium ions to sodium are given in table 4 and similar data for rainwater, groundwater and seawater are included. (Full details of the results are available on request to Chief, CSIRO Division of Soils, Glen Osmond, Sth Australia 5064).

DISCUSSION

Cromer (1976) described three major rock units near the penal settlement at Port Arthur, namely Permian marine pebbly mudstone and sandstone, Triassic non-marine sandstone and mudstone and Jurassic dolerite which has intruded both groups of sedimentry rocks. The results given in table 1 show that the composition of the clay deposits is related to these rock types. In particular the potassium content varies from less than 1.0% K_2O for clays on dolerite to more than 3.0% for clays on the marine sediments. Montmorillonite and kaolin are the dominant clay minerals in the material weathered from dolerite and both illite and quartz are absent. In the clays derived from the sediments, illite and kaolin are the dominant minerals and quartz was detected in four of the seven samples. The small amounts of montmorillonite in the samples of clays on the non-marine Triassic sediments at Brickfields Hill could possibly be derived from the dolerite which is mapped within 30 m of the sample sites.

The colour of bricks is largely due to the iron oxide content and as seen in table 1 there is very considerable variation in the amount of iron in the clays associated with the two sediments and thus from either of these clays it was possible to manufacture white, red or attractively mixed red and white bricks.

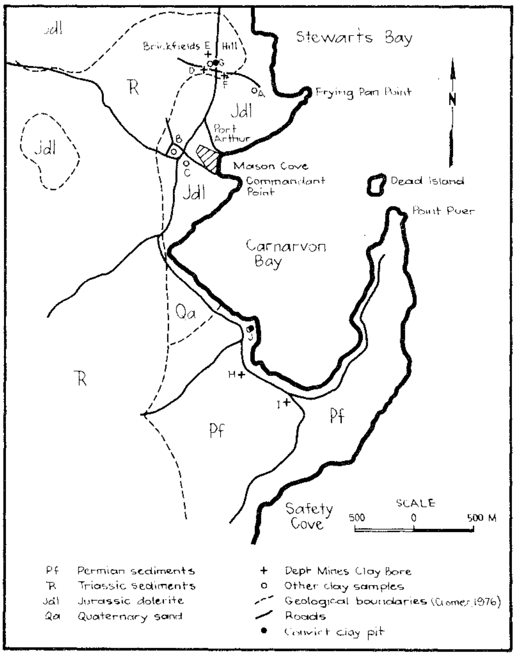

FIG. 1- Location of clay sampling sites at Port Arthur.

Dr W.F. Cole, CSIRO Division of Building Research, Highett, Victoria, (*pers. comm.*, 1974) has estimated the firing temperature of two Port Arthur bricks he examined to be between 800^{o} and $850^{o}C$, at least $200^{o}C$ below the optimum for the clay used. At temperatures above $1000^{o}C$, illite and kaolin, which are phyllosilicate clay minerals with hydroxyl ions in their crystal lattice, are irreversibly changed to minerals of other structures. If, however, the temperature does not exceed 700-$800^{o}C$, the phyllosilicate structure is not fully destroyed and some of the

TABLE 1

CLAYS FROM PORT ARTHUR

Underlying geological formation	Jurassic dolerite			Triassic sandstone & mudstone				Permian sandstone & mudstone		
Location and bore number	500m W of Frying Pan Point	Near R.C. Chaplain's cottage	Near model prison	Bore 2	Bore 7	Bore 5	Brick-fields Hill	Bore 8	Bore 9	N face shallow pit southwest Carnarvon Bay
Sample identification	A	B	C	D	E	F	G	H	I	J
Depth, m	1.0-1.5	0-0.5	0-0.5	3.7-5.5	3.7-4.6	0-7.0	0-0.5	0.9-1.8	0-0.9	0.5-1.0
Chemical analysis, %:										
Fe_2O_3	14.7	7.7	15.6	5.4	1.2	7.7	0.9	0.9	2.6	5.0
TiO_2	0.82	0.89	1.08	0.99	0.79	0.75	0.90	0.49	0.83	0.74
K_2O	0.80	0.68	0.26	1.74	2.51	2.74	2.52	2.85	3.07	3.58
SiO_2	47.5	64.1	49.4	51.5	68.5	63.3	62.2	70.1	59.3	60.5
Al_2O_3	21.6	14.9	21.8	23.6	19.0	16.9	24.0	17.5	23.3	19.0
Loss on ignition	12.4	10.2	12.8	14.7	7.3	7.8	9.3	5.5	9.5	7.1
Particle size <2μm, %		58	64	30	53	42		50	75	
Mineralogical analysis of <2μm fraction, %:										
Quartz							10	15	5	10
Kaolin	80	20	80	80	30	5	25	55	60	40
Illite				5	70	75	60	25	35	50
Montmorillonite	5	80	10	15		20	5			
Feldspar	15							5		

clay mineral may be reconstituted by the slow incorporation of water and hydroxyl ions (Grim 1962). This appears to be taking place in some bricks at Port Arthur and the presence, in the centre of one brick from the southwestern wall of the Penitentiary, of considerable unaltered illite and kaolin (identified by sharp X-ray diffraction peaks) suggests that parts of some bricks did not reach 400°C.

TABLE 2

RATIO OF ELEMENTS SILICON, POTASSIUM AND TITANIUM TO ALUMINIUM

MATERIAL	SAMPLE	Si/Al	K/Al	Ti/Al
	Port Arthur			
Clays	A	1.9	0.058	0.043
on dolerite	B	3.8	0.072	0.068
	C	2.0	0.019	0.056
	(mean values)	2.6	0.050	0.056
Clays on	Port Arthur			
sediments	D	1.9	0.12	0.048
	E	3.2	0.21	0.047
	F	3.3	0.25	0.050
	G	2.3	0.16	0.043
	H	3.5	0.26	0.032
	I	2.3	0.21	0.040
	J	2.8	0.30	0.044
	(mean values)	2.8	0.22	0.043
Clays on	Maria Island			
sediments	O	5.1	0.19	0.064
	P	5.8	0.21	0.065
	(mean values)	5.5	0.20	0.065
Bricks	Port Arthur			
	1	3.0	0.11	0.041
	2	4.2	0.22	0.053
	3	3.8	0.20	0.052
	4	4.0	0.12	0.043
	5	3.1	0.14	0.044
	(mean values)	3.6	0.16	0.047
	Maria Island			
	6	6.5	0.23	0.069
	7	8.1	0.22	0.083
	8	5.2	0.31	0.057
	9	7.3	0.21	0.071
	10	8.9	0.22	0.088
	11	7.4	0.30	0.067
	(mean values)	7.3	0.25	0.072

Although the structure of the clay minerals is lost during the manufacture of adequately fired bricks, most chemical elements present in the original clay deposit are retained. For example, the potassium content of all the bricks examined from Port Arthur is above 1.2% K_2O and thus clays from within the settlement and derived from dolerite and with an average of 0.7% K_2O (on ignited basis) have not been used exclusively for the bricks manufactured there. For practical reasons, clays developed on dolerite are not suitable for brick making as they contain montmorillonite. This clay mineral requires considerable water to make it sufficiently plastic to be moulded into shape and then on drying, before firing, extensive shrinkage occurs. Illitic and kaolinitic clays are widely used for brickmaking and the early brickmakers at Port Arthur must have carefully sought suitable clays which, unlike the surface clays within the settlement, are situated below a coarser-textured surface soil. For a better comparison of the chemistry of clays with that of bricks, it is more satisfactory to compare ratios of elements rather than absolute values. For example, the data in table 2 show clearly the marked difference between the K/Al ratio for the clays derived from dolerite and those of all other samples. The element titanium is usually retained during the surface weathering of a rock (Hutton 1977) and is not lost during the firing of a brick so that it can be a useful element in relating clays and bricks. From table 2 it can be seen that the Ti/Al ratios of the two samples of clay and the six bricks from Maria Island are all above 0.056 whereas all samples of bricks and brickmaking clays from Port Arthur have a Ti/Al ratio below 0.054. The difference between the clays and bricks from the two settlements is more pronounced in the Si/Al ratio. All samples from Maria Island have a Si/Al ratio above 5.0 and all from Port Arthur have a ratio below 4.3. The data available are limited but it would appear that there are significant differences in the chemistry of the samples from the two penal settlements and that this could be used to identify the source of clays and/or bricks in these two places and possibly others.

TABLE 3

COMPOSITION OF SOLUBLE SALTS IN CLAYS AND BRICKS (g/kg)

SAMPLE	Na	Mg	K	Ca	Cl	SO_4	Total (from conductivity)
Clay A on dolerite	0.66	0.03	0.03	0.04	0.72	0.2	2.5
Clay J on sediments	0.03	0.04	0.02	0.03	0.03	0.08	0.2
Clay G from Brickfields Hill	0.06	0.01	0.1	0.04	0.14	0.1	0.4
Brick 3 from Penitentiary	7.3	0.35	0.56	1.9	14	0.2	26
Red brick 1 from R.C. Chaplain's cottage	2.6	0.04	0.26	0.2	3.0	0.3	9
White brick 2 from R.C. Chaplain's cottage	2.6	0.6	0.35	1.6	6.7	0.1	13.8

During an on-site examination of the salt content of bricks at Port Arthur (July 1976) by using about 1 g crushed brick, 5 ml water and a simple portable conductivity meter, it was found that 12 bricks had less than 0.1% soluble salts, another 12 had between 0.1% and 1% salts and the majority (26) had more than 1%. Some of the bricks were from walls of roofless buildings situated near the sea, others were from ruins on high ground and some were from a roofed building that has been occupied since erection in 1836 and situated at least 20 m above sea level. Many bricks from under the floor of this latter building, some on the ground and some on timber joists, were tested and found to be in the highest salt category. The salts from two of these bricks and a third from the Penitentiary have been analysed and the results are given in table 3 together with data on the salts in three of the clay samples. The results have been summarised in table 4 and again expressed as ratios, in this case of the chloride, potassium, magnesium and calcium ions to the sodium ion. For comparison, the same ratios for seawater, a sample of groundwater from near the church at Port Arthur and rainwater collected within 15 km of the coast of Victoria (Hutton and Leslie 1958) have been included. The Cl/Na, K/Na, and Mg/Na, ratios are similar to those of seawater and not to the local groundwater and this chemical similarity suggests that seawater had been used during the fabrication of some of the bricks. Seawater contains about 3.5% salts and if in order to puddle the clay to mould the "green" bricks, seawater was added in the ratio of 1 : 3 or 1 : 2 (water : clay), this would yield 1 - 2% salts in the finished brick. Both sodium chloride and potassium chloride melt at about 800°C and do not appear to be significantly volatile at this temperature. As many of the bricks have not been heated above 850°C, most of the added seasalt has been retained. Roberts and Kallend (1976) also concluded from the salt glaze on some of the bricks that seawater was used, at least on some occasions.

Alternatively it has been suggested that the bricks, after incorporation into the walls, have absorbed salts from the rain. A photograph taken before the bushfires of January 1898 shows that some of the bricks in the west wall of the bakehouse and near the top of the tall chimney had at that date already disintegrated to some extent (Plate 2).

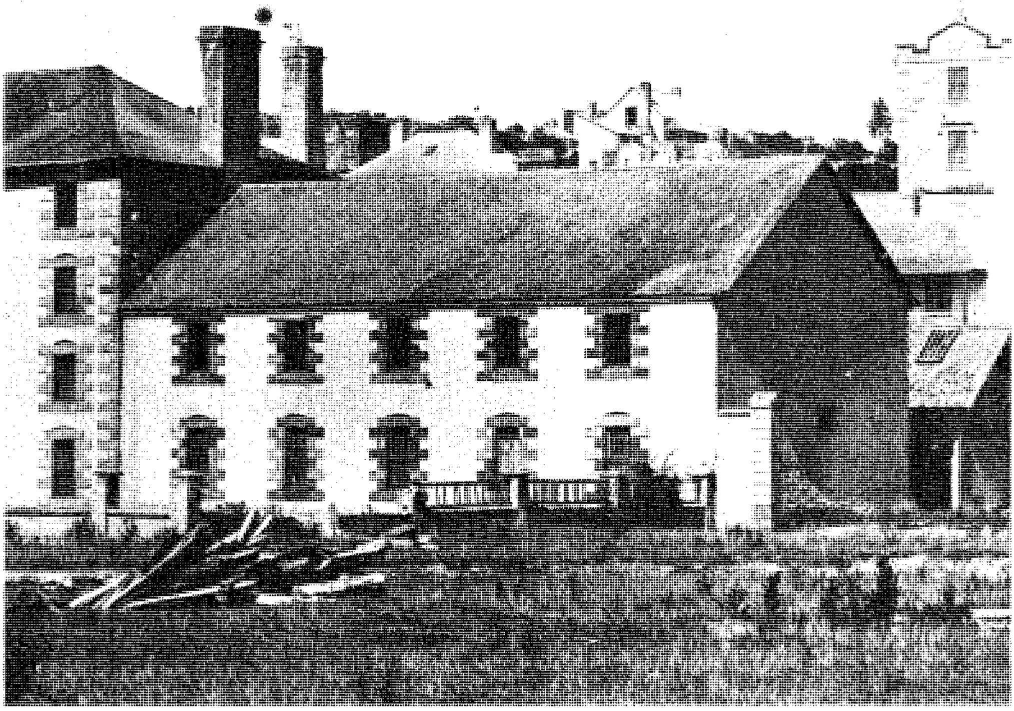

PLATE 2.- Early view of north-west corner of Penitentiary. (Photograph from Port Arthur Collection, National Parks and Wildlife Service).

TABLE 4

IONIC RATIOS OF SALTS IN BRICKS, ETC.

	Cl/Na	K/Na	Mg/Na	Ca/Na
Bricks (av. of 1, 2 & 3)	1.22	0.060	0.19	0.37
Rainwater[1]	1.06	0.025	0.24	0.13
Groundwater[2]	0.67	0.030	0.94	0.80
Sea Water	1.16	0.021	0.24	0.04
Clays (av. of A, G & J)	0.96	0.46	0.99	0.66

[1] Data for Cape Bridgewater, Warrnambool & Heywood, Victoria (Hutton and Leslie 1958)
[2] Dr N.K. Roberts. (In report "To conserve Port Arthur", Crawford, de Bavay and Cripps 1979) (V. Sup.).

Thus after 45 years of exposure to sun and rain but protected to some extent by the overhanging roof, the bricks in this west wall were crumbling due to lack of strength and the action of salt. The bricks near the base of the wall could have absorbed salts from the groundwater (seawater) but for those close to the roof the most probable external source is the rain. Salt in the rain is largely derived from the ocean waves breaking near the shore during periods of strong winds, usually from the west or southwest and so the exposed west wall might receive more salt than other areas. Hutton (1976) has shown that the average salt content of the rain is related to the distance from the ocean by the expression NaCl (mg/L) = $(58 \div \sqrt[4]{d}) - 13.5$ where d is distance in km from the ocean. As Port Arthur is about 12 km northeast of Storm Bay, the rain, on the average throughout the year, can be expected to contain about 18 mg NaCl per litre. Spratt, in the report "To Conserve Port Arthur" (V. Sup.), has shown that the Port Arthur bricks absorb about 160 g water per kg and thus a dry brick weighing about 3 kg will take in about 8.6 mg NaCl if saturated with rain. If the bricks were not dry they would absorb less and if saturated they will lose some salt by surface run-off. The disintegrating bricks in the west wall of the Penitentiary before the bushfires of 1898 probably contained 40 to 60 g salt per 3 kg brick (the average salt content of a disintegrating brick) and so to obtain this in 45 years from the rain it would be necessary for the brick to dry out completely and then absorb the rain 100 to 150 times per year. It is doubted if this is possible.

Although the salts extracted from the three bricks have Cl/Na, K/Na and Mg/Na ratios similar to those of seawater, the salts that crystallise in a given part of a wall may range widely in composition. Due to the porosity of the bricks, evaporation may take place within the bricks as well as on their surfaces. As the volume of the solution becomes smaller due to evaporation, the liquid will fill only the finer pores within the brick and eventually the sodium and chloride ions, which form the bulk of the dissolved species, will crystallise out as halite (NaCl). The growth of these halite crystals within the fine pores of the brick will produce the pressure to cause disintegration, particularly if the brick is not hard burnt. Eventually as more water and halite are lost the solution will become saturated in respect of other salts. The occasional addition of rain may or may not dissolve some of the halite crystals but will delay the crystallisation of the other compounds. The solution may even be washed away from the surface of the bricks by excess rain or, at the other extreme, during periods of excess evaporation or if the brick is dried in the laboratory, a wide range of salts may appear on the surface. Indeed Roberts and Kallend (1976) have demonstrated the presence of crystals of sylvite (KCl) on the surface of a brick from the northeastern part of the Penitentiary and to explain the sylvite they ascribe the soluble potassium to the action of ion exchange in the brick. This seems unlikely as the value they use for exchangeable potassium, 4.6.m.equiv./100 g brick, is ten times the value of 0.44 m. equiv./100 g reported by Graley and Nicholls (1979) as the median value for the surface 0-10 cm of 13 yellow podzolic soils on mudstone. These soils are similar to those near the clay pits at Port Arthur and the clay minerals present in these yellow podzolic soils are illite and kaolin, the same as in the Port Arthur clays on the sedimentary rocks (table 1). Although exchangeable potassium may have contributed, there are other sources of soluble potassium that might be significant in the bricks. For example, the destruction of the illite clay mineral structure during the firing of the bricks may have released some of the potassium normally considered to be insoluble, the ash of the timber used to fire the kilns contained both potassium and calcium salts and as shown in table 3 the original clay may have contributed about 1/3 of the soluble potassium in the final bricks. The potassium from these sources would remain soluble if the bricks were not heated above 800°C, i.e. high enough to melt potassium chloride and possibly form a glass.

The disintegration of the bricks at Port Arthur is not a recent event. There is little doubt that most of the bricks were underfired and that movement of water in and out soon caused them to decay due to the salts present. The composition of the salts in some bricks strongly suggests that seawater was used for the puddling of clay and that the introduced salts remained essentially unaltered during the low temperature firing. The loss of the roofing of the buildings during the bushfires since the closure of the settlement may have accelerated the disintegration but Plate 2 shows some obvious rotting of the bricks in the west wall of the Penitentiary before the loss of its roof.

The quality of the bricks made at Port Arthur no doubt varied greatly. It appears to have deteriorated markedly towards the close of the settlement for Hunter (1876), reporting on the bricks brought up from Port Arthur for the building of the gaol at Cascades, wrote "and they are of such a wretched and worthless description that I cannot consent to their being used for any building purpose."

A detailed knowledge of the materials used in the buildings of the penal settlements of Port Arthur and Maria Island is essential before sound decisions can be made regarding their preservation or possible restoration. The high salt content, the high porosity and low strength in the bricks create unique problems at Port Arthur.

ACKNOWLEDGEMENTS

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REFERENCES

Cripps, P.E. and Spratt, P.E., 1977: Port Arthur Conservation - the past, the present, the future. Report of the workshop on building materials conservation, Hobart, April 1975, 16-19. *Aust. Heritage Commission,* Canberra. (Unpublished).

Cromer, W.C., 1976: Geology of the Port Arthur area. In: Geology of Port Arthur. *Dept of Mines, Tasmania, Rept 1976/36.* (Unpublished).

Glover, M., 1978: Historical research notes on Port Arthur. *National Parks and Wildlife Service, Tasmania.* (Unpublished).

Graley, A.M. and Nicolls, K.D., 1979: Use of exchangeable potassium in assessing potassium availability in Tasmanian soils. *Aust. J. Exp. Agric. Anim. Husb.,* 19: 72-81.

Grim, R.E., 1962: APPLIED CLAY MINERALOGY. McGraw-Hill, New York.

Hunter, H., 1876: Report on gaol buildings, Cascades. *Tasmania, House of Assembly, Journal* Sept. 12, 1876, No.46.

Hutton, J.T., 1976: Chloride in rainwater in relation to distance from ocean. *Search,* 7: 207-208.

Hutton, J.T., 1977: Titanium and zirconium minerals. In Dixon, J.B. and Weed, S.B. (Eds): MINERALS IN SOIL ENVIRONMENTS. Soil Sci. Soc. Amer., Madison.

Hutton, J.T. and Leslie, T.I., 1958: Accession of non-nitrogenous ions dissolved in rainwater to soils in Victoria. *Aust. J. agric. Res.,* 9: 492-507.

Norrish, K. and Hutton, J.T., 1969: An accurate X-ray spectrographic method for the analysis of a wide range of geological samples. *Geochim. Cosmochim. Acta,* 33: 431-453.

Norrish, K. and Hutton, J.T., 1977: Plant analysis by X-ray spectrometry. *X-ray Spectrom.,* 6: 6-11.

Norrish, K. and Pickering, J.G., 1977: Clay mineralogic properties. In Russell, J.S. and Greacen, E.L. (eds): SOIL FACTORS IN CROP PRODUCTION IN SEMI-ARID ENVIRONMENTS. Univ. of Qld, Brisbane.

Roberts, N.K. and Kallend, P.W., 1976: Selective salt efflorescence as the result of ion exchange on convict-made brickwork at Port Arthur. *J. Aust. Ceram. Soc.,* 12: 5-7.

Threader, V.M., 1976: Clay deposits. In: Geology of Port Arthur. *Dept of Mines, Tasmania, Rept 1976/36.* (Unpublished).