Innovation in the Manufacture of Salt in Eastern Australia: The 'Thorn Graduation' Process

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Salt production in nineteenth-century Australia was often based on the evaporation of sea-water by boiling. This required large quantities of fuel because of the low salt-content of sea-water, and there were obvious advantages in pre-concentrating the brine before boiling. Although solar evaporation was a well-established way of doing this, a handful of Australian manufacturers attempted to use the 'thorn graduation' process, in which water was evaporated from the brine by trickling it through high walls of brushwood. In this paper Brian Rogers, of the Institute of Advanced Education, University of Wollongong, shows that this was a technology with a long history at salt springs in continental Europe but that its use in eastern Australia for concentrating sea-water appears to have been a significant innovation. The author suggests that the lack of success of this process in Australia resulted as much from economic factors as from any technological shortcomings.

Although manufacture of salt from sea-water was a quite common activity in eastern Australia between 1788 and 1900, it has not yet been studied systematically. To obtain any account of the industry it is necessary to seek out the many minor references in archival materials, in published accounts of the colonies at various periods, in biographies, and in recently published economic histories.[1]

As there were neither rock salt deposits nor salt lakes in eastern Australia, the salt industry was necessarily based on sea-water, which on average contains only 2.5 per cent common salt. In principle, most operators used the same simple technology. Sea-water was boiled so as to evaporate it and bring the concentration of sodium chloride to the saturation level of 27 per cent, and then the evaporation was slowed down by reducing the heat. As the process continued, sodium chloride crystals were thrown out of solution, while other salts, not having reached saturation, remained in solution in the mother liquor. The equipment used, which ranged from simple wood-fired try-pots to elaborate large pans of riveted iron plates set in brickwork and heated by coal fires, did not alter the process. Few proprietors were prepared to venture the investment required to embellish the basic process by providing some means of pre-concentrating brine before it was boiled. Only John Blaxland made provision for solar evaporation, his Newington works having some eight acres (3.2ha) of shallow basins for this purpose in 1807.[2] In linking solar evaporation and boiling, Blaxland merely adopted the process which had long been used at Lymington (England), but a handful of operators introduced a quite foreign pre-concentration technology called 'thorn graduation'. Borrowed from the salines of Europe, this process consisted of allowing the brine to trickle slowly downward through high walls of brushwood supported in a strong framework. As the brine spread over the brushwood its total evaporative surface was greatly increased, accelerating the evaporative action of wind and sun and hastening the concentration of the brine. The first of seven known attempts to use this process in Australia was made at A.W. Scott's Stockton salt-works, which operated for about a decade from 1838 to 1848. Two small undertakings established in Moreton Bay (Queensland) about 1870 were the next to adopt the idea, but with no success. After another interval of over two decades, the idea was again taken up by no less than four salt-making undertakings in the Illawarra region, between 1892 and 1896.[3] Given the preference of colonial manufacturers for British technology, and in particular for salt-makers to draw upon processes used in Cheshire, Hampshire and Scotland, the marriage of graduation technology to the more familiar processes from 'home' represents a significant innovation.

GRADUATION TECHNOLOGY

Strictly speaking, the term 'graduation', used in the context of salt manufacture, refers to any process by which weak brines are concentrated prior to boiling, and would subsume solar evaporation, freezing, and several more unusual processes.[4] General usage has narrowed the meaning of the term so that it refers more particularly to 'thorn graduation',[5] a process which was once widely used in Europe to concentrate brines from salt springs, some of which contain only 1 or 2 per cent of salt.[6] The process does not appear to have been used in Europe to produce salt from sea-water.

Development of thorn graduation

The process of extending the surface area of the brine, by spreading it over walls composed of faggots of brushwood to promote maximum evaporation, can be traced back to the 16th century, when many of the European salines had resorted to distributing weak brines over large straw-filled boxes (*Scheidekasten*) similar to that in Figure 1a.[7] Brine raised from the wells or reservoir (B) ran along a perforated distributing duct (C) from whence it showered onto the straw heaped in the box (D). Despite the crudity of this system, it concentrated brine sufficiently to effect worthwhile reductions in costs of boiling, and it became quite widely adopted. By the 17th century the *Scheidekasten* had evolved into a nascent form of graduation house (*Lepperwerk* or *Leckwerk*), in which the loose piles of straw were replaced by walls made of bundles of straw arranged in a timber framework (Fig. 1b). Compared to later forms of graduation works, *Lepperwerk* were both low and short, and it seems that the straw did not permit air to circulate freely. Early in the 18th century, the straw was replaced by faggots of blackthorn (*Prunus spinosa*), which was selected because its particularly crooked, angular character and its many thorns helped to maximise the evaporation surface.

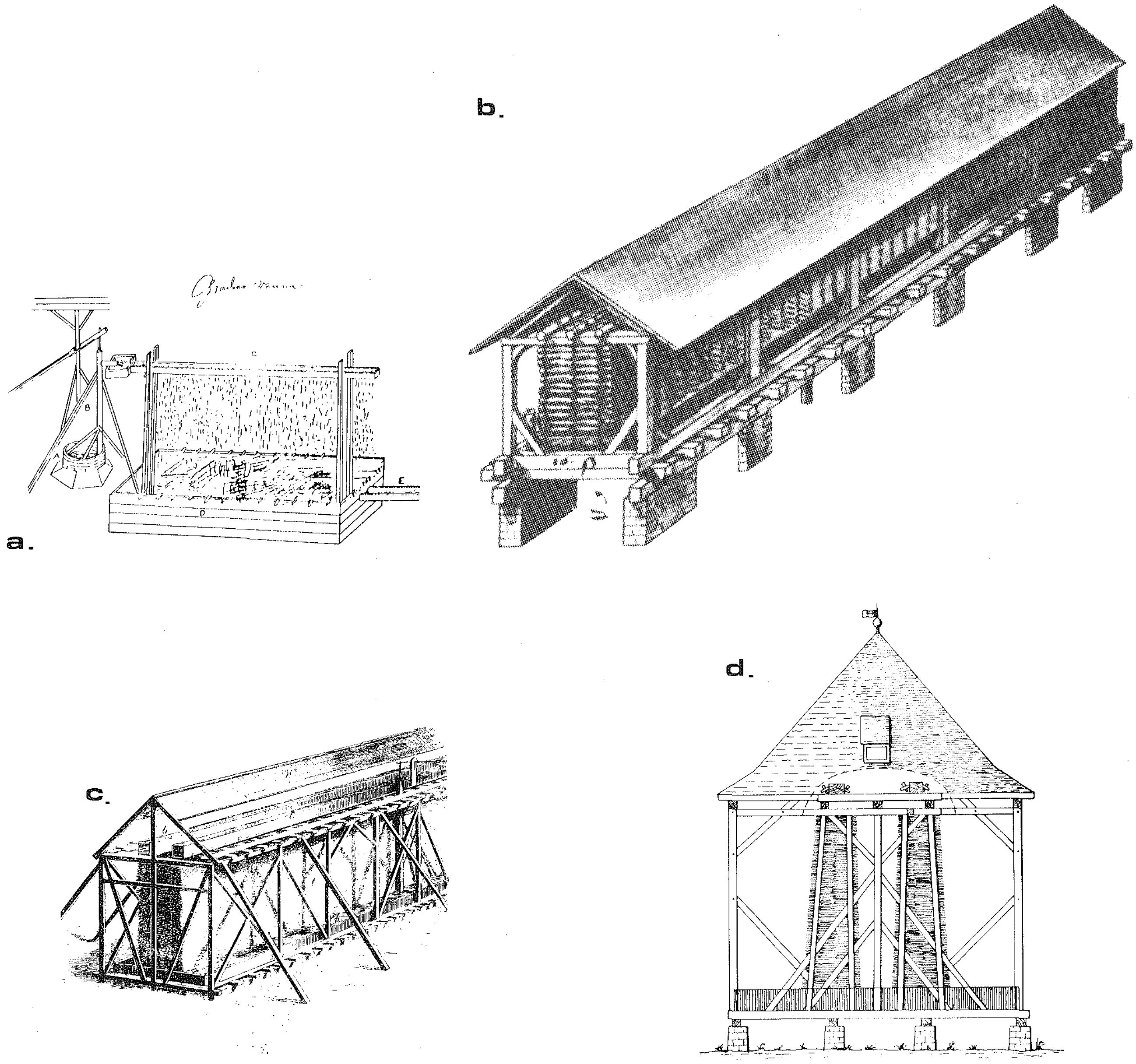


Fig. 1: Stages in the evolution of thorn graduation. (a) Boxes filled with loosely piled straw (Scheidekasten). *(b) Bundles of straw built into walls* (Lepperwerk). *(c) An early thorn graduation works in which faggots replaced straw within a framework similar to that of the* Lepperwerk. *(d) A product of maturing graduation technology: two thorn walls with an air space between. Unlike more fully developed examples, each wall in this structure was made up of a single row of faggots. (Sources: (a) Swedenborg [c.1728]; (b) Carlé 1963b; (c) Tomlinson 1868; (d) Carlé 1963a.)*

This rudimentary form of graduation house (Fig. 1c) did not differ greatly in appearance from its straw-filled prototype, but from it evolved the very elaborate graduation works built during the late 18th and early 19th centuries. Figure 1d illustrates an intermediate form which had two walls, well separated and with sloping surfaces, and the whole roofed over; brine distribution had made little advancement on that employed in the *Lepperwerk.*

Although the use of twigs did not at first produce startling changes in the appearance of graduation works, the innovation greatly enhanced the efficiency of the process, and laid the foundation for a period of experimentation and invention which quickly brought the technology to an advanced state of development. During this period double and triple walled forms of graduation house were tried, and even a circular design was tried, steam power was introduced to pumping operations, and efficient mechanisms were devised for directing the flow of brine to one wall or the other. By the commencement of the 19th century the principles of graduation technology and the basic forms of graduation structure had been established.[8]

Graduation structures (Figs 2–4)

The principles and structures embodied in mature graduation technology permitted a good deal of variety in the final design of graduation works. Figure 2a illustrates a basic two-walled arrangement which was widely adopted. A strong timber framework, heavily braced and buttressed to resist the great pressure exerted by the wind, supported two walls of faggots. The bundles of branches were laid with a downward inclination of 1 in 6 to the outer faces, so as to direct the movement of brine to the outer surfaces, where air circulated most freely. The outer ends of the faggots were trimmed to an even surface, with a batter of between 1 in 12 and 1 in 8, the purpose of this arrangement being to reduce the loss of brine through it being carried away from the walls by air currents. The whole structure was surmounted by a railed work platform supporting a central brine reservoir. From this reservoir brine flowed to one of the brine distributors which extended the full length of the structure, above the outer faces. In this relatively uncomplicated example, brine would be distributed only to the windward wall. After passing down the wall, the brine

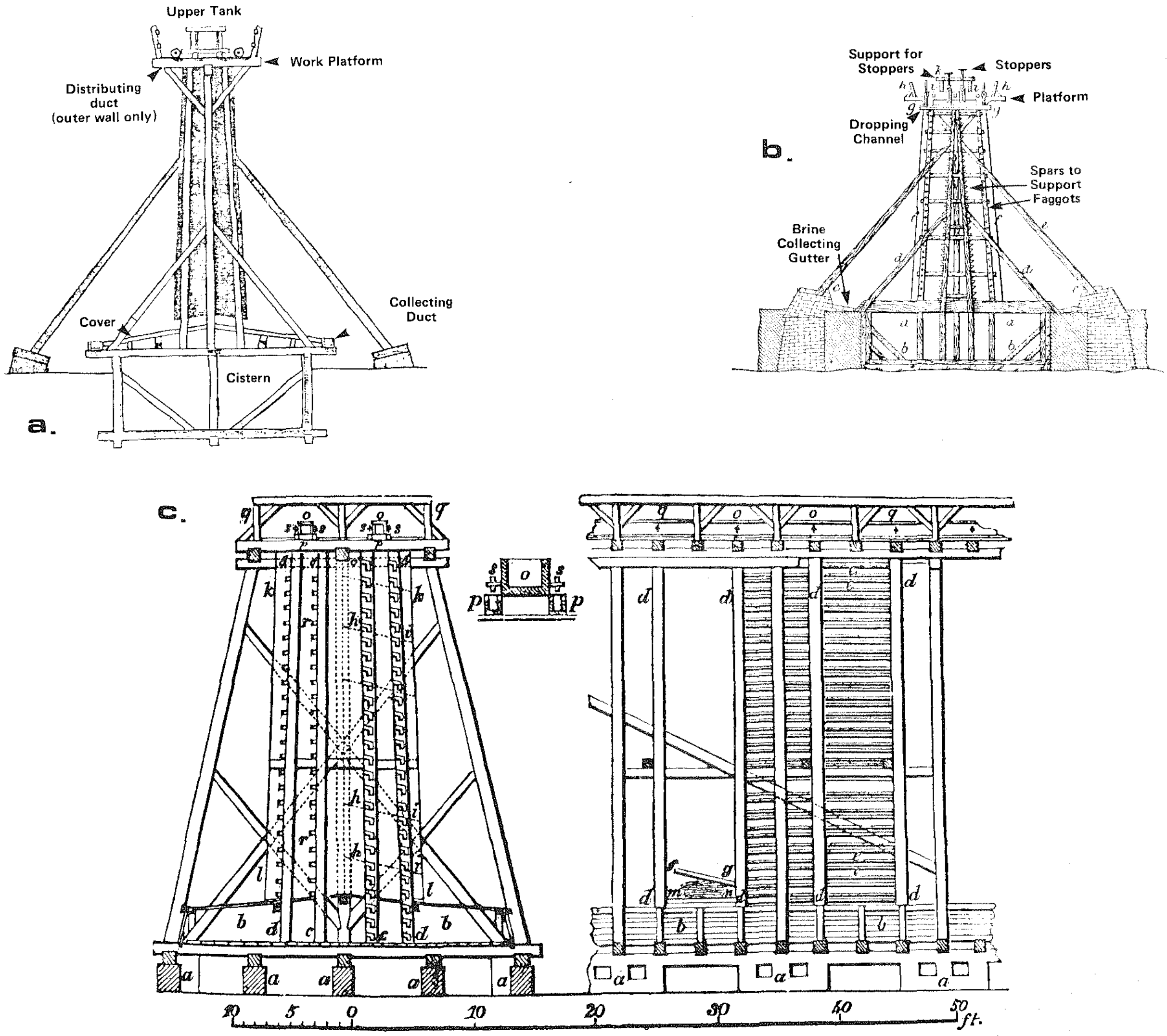


Fig. 2: Variations in the design of graduation works. (a) General arrangement of a graduation works with provision for distributing brine to the outer surfaces only. (b) Graduation works at Schönebeck, showing arrangement of the spars on which the faggots were laid. (c) Graduation house at Dürrenberg, illustrating arrangement for the faggots: the inset shows the arrangement of the upper brine ducts and the dropping channels which supplied both inner and outer surface of each wall. (Sources: (a) Adapted from Cancrin 1788–1789; (b) André & Lock 1879–1882; (c) Hunt 1878.)

was gathered in a lower cistern which was covered with boards to direct the brine into the collecting gutters and also to protect the concentrate from dilution by rain-water. The extension of the cistern and its collecting surfaces well beyond the wall itself was a means of gathering a good proportion of the drops of brine carried off the wall by the wind, thereby minimising loss of salt. The graduation works at Bad Rothenfelde (Fig. 3) would have been typical of this basic form of graduation works. This illustration highlights the impressive scale on which these structures were engineered.

The works at Schönebeck (Fig. 2b) was in some respects more elaborate than that already discussed. This structure was 838m long and 10 – 13m high. The two walls of faggots were together 5.0 – 6.9m thick at the base, tapering to 3.2 – 5.0m at the top. The effective graduation surface of 36,231m^2 had an average capacity for the evaporation of almost half a million cubic metres of water in a working year (258 days). The basic elements were similar to those in Figure 2a, and the double wall of faggots, upper and lower cistern and collecting arrangements can be readily seen in Figure 2b. It will be noticed that this structure had a more elaborate arrangement for showering the brine over the wall, this being used so that the inner surfaces of the walls could be employed as well as the windward outer surface. The framework within the reservoir carried two rows of simple stoppers fitted into tapered seats: these controlled the flow of brine to the ducts beneath the cistern and thence to both the inner and outer surfaces of the walls, as wind direction may dictate.

The diagram of the graduation works at Dürrenberg shown in Figure 2c is of particular interest not only for the additional detail shown, but also because it was reported to be the pattern used by at least one salt-works in the Illawarra region of Australia. The brief description accompanying the diagram indicates that:

'. . . *a, a, a,* are low stone pillars for supporting the brine-cistern *b*, called the *soole-schiff*. *c, c,* are the inner, *d, d,* the outer walls of thorns; the first have perpendicular sides, the last sloping. The spars *e, e,* which support the thorns, are longer than the interval between two thorn walls from *f* to *g*, . . . whereby they are readily fastened by their tenons and mortises. The spars are laid at a slope of 2 inches in the foot, as shown by the line *h, i.* The bundles of thorns are each 1½ foot thick, from 5 to 7 feet long, and are piled up in the following way:— Guide-bars are first placed in the line *k, l,* to define the outer surface of the thorn wall, the undermost spars *m, n,* are fastened upon them, and the thorns are evenly spread after the willow-withs of the bundles have been cut. Over the top of the thorn walls are laid, through the whole length of the graduation-house, the brine spouts *o, o,* which are secured to the upper beams; and at both sides of these spouts are the drop-spouts *p, p,* for discharging the brine by the spigots *s*, *s*, as shown upon a larger scale . . . [inset]. The drop-spouts are 6 feet long, have on each side small notches, 5 inches apart, and are each supplied by a spigot. The space above the ridge of the graduation house is covered with boards, supported at their ends by binding-beams, *q*. *r*, *r*, show the tenons of the thorn-spars. Over the soole-schiff *b*, inclined planes of boards are laid for conducting downwards the innumerable showers. The brine, which contains at first 7.692 per cent of salt, indicates after the first shower, 11.473; after the second, 16.108; and after the third, 22.'[9]

This diagram shows very clearly the arrangement of the horizontal supports for the faggots, which prevented the lower layers from being crushed and the permeability of the wall to the air reduced. The supports were arranged in such a way as to facilitate their removal when the faggots required replacement. In this graduation house, as with that at Schönebeck, the inner surfaces of the walls were used in conjunction with the outer surfaces in the process known as cubic graduation. This practice increased the rate of evaporation in the ratio of 5 to 8 or 9.

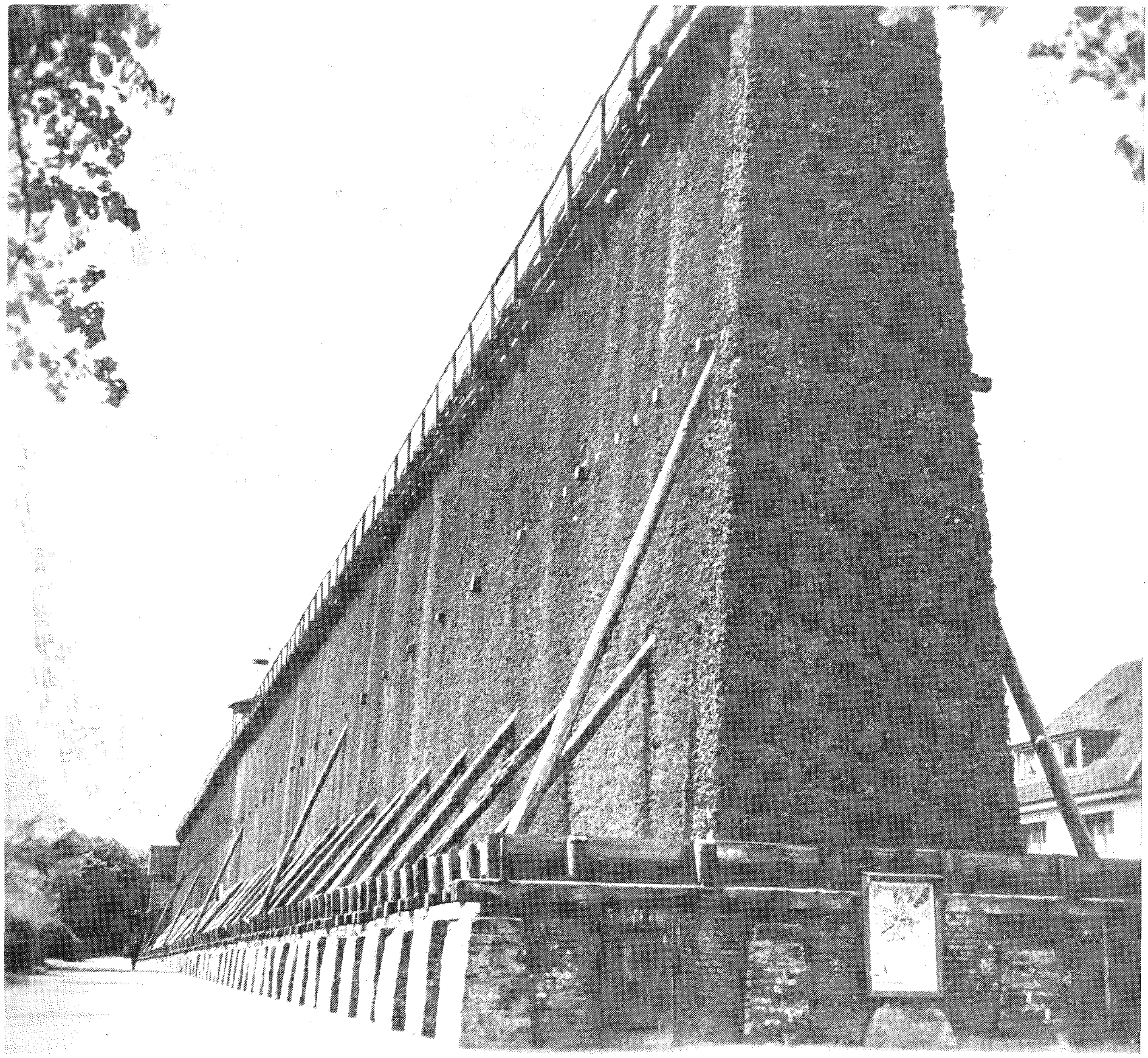


Fig. 3: A modern photograph of the graduation works at Bad Rothenfelde, West Germany. The headworks, braces and collecting cistern can be clearly seen. The scale of the structure is highlighted by the figure in the middle distance. At the far end can be seen the stone building which housed the pumping equipment. The flag flying above the structure serves to indicate wind direction. (Photograph: Niedersächsisches Landesverwaltungsampt, Hannover.)

Further variations in structures and appearance of graduation works, all representing solutions to essentially the same problems are to be seen in Figure 4. Some hint of the degree to which the basic graduation process was elaborated is provided in Figure 4d, which depicts what is in essence a four-walled unit, each side having two walls of faggots. Even in this unit the basic components are clearly discernible, but it will be noted that the illustrated arrangements for distributing the brine over the walls are necessarily quite elaborate, because provision was made for using inner surfaces of the walls in conjunction with the windward outer wall on both halves of the structure. Some idea of the scale of graduation works in Europe is conveyed in Figure 4e which shows part of one of four graduation houses employed at Moutiers in France. The structure, illustrated at only half its actual length because of limitations

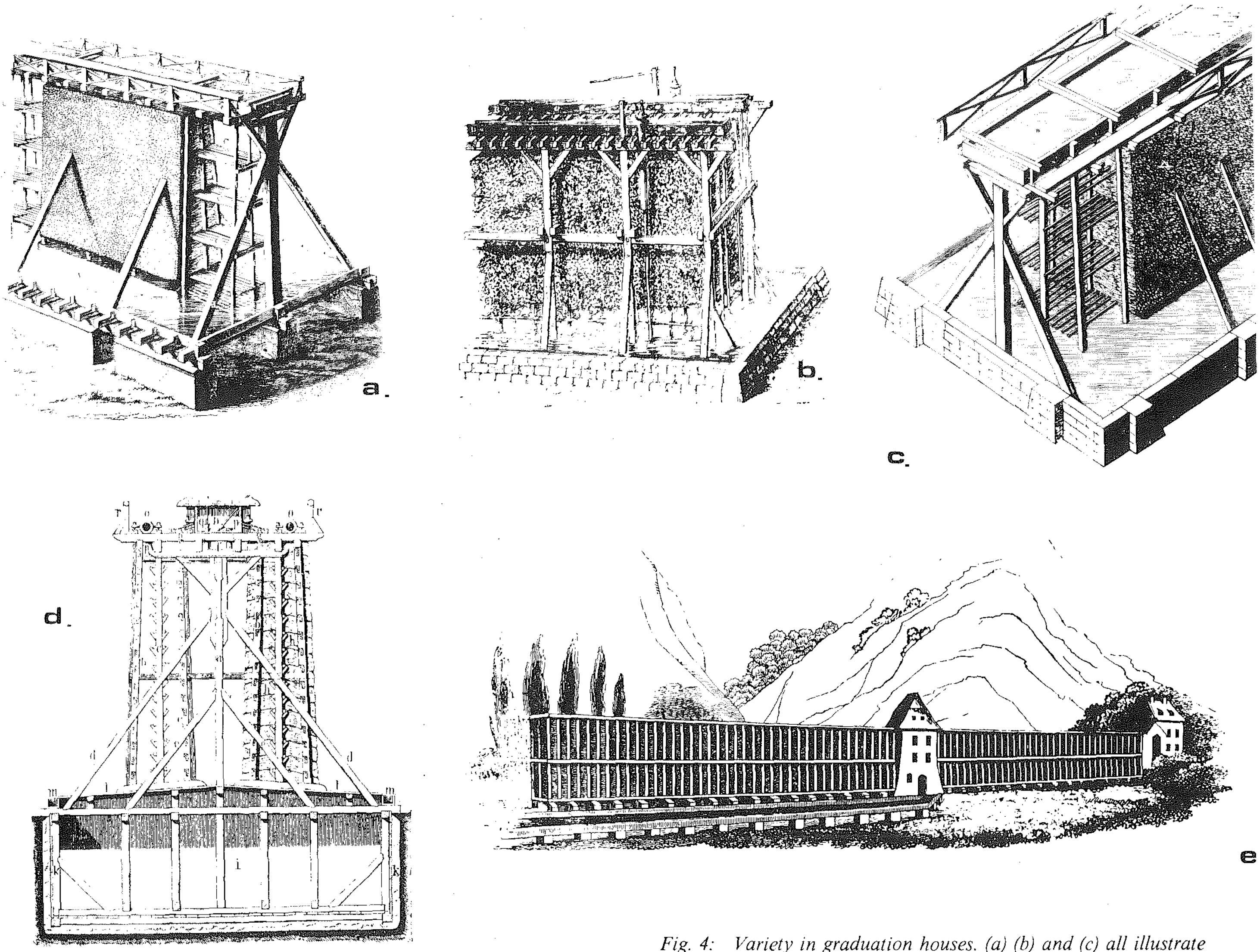


Fig. 4: Variety in graduation houses. (a) (b) and (c) all illustrate houses with two walls, but they exhibit considerable diversity in their support structures, upper work platforms and collecting cisterns. (d) A particularly elaborate form of graduation house with two pairs of 'thorn walls', well separated, and having elaborate headworks to permit cubic graduation on each half of the works. (e) Bakewell's illustration of the Number 1 graduation house at Moutiers, drawn to about half its length because of limitations of his page. This structure was about 350m long, 8m high, and the wall was 3m wide at the base. The structure had no roof. (Sources: (a) Richardson & Watts 1863; (b) Wurz n.d.; (c) Muspratt 1860; (d) Meyer's Konversations—Lexicon *1893–1898; (e) Bakewell 1823.)*

of space, was 350m long, 8m high, and it tapered from 3m in breadth at the bottom to 2m at the top, with pumping machinery housed in the stone structures. This group of illustrations also shows some of the variety in the construction of headworks and collecting cisterns. Figure 4b depicts the kind of hand-pumping arrangement which was sometimes used in smaller works.

Ideal conditions for graduation would be created by a constant wind of moderate velocity blowing squarely onto the dripping face of a graduation works. Nature not being sufficiently co-operative to provide such conditions, graduation works were aligned at right angles to the direction of the most prevalent wind.[10] Maximum evaporation was maintained by having the brine flow over the wall receiving the most direct air movement; this arrangement also minimised the loss of brine through it being blown off the wall, by allowing the leeward wall to be used as a collector. In most of the examples discussed above, arrangements for directing the flow of brine consisted of a series of manually operated stoppers or taps which required a considerable labour force to effect rapid changes in the brine-flow when the wind changed. To speed the change, and to cut labour requirements, many graduation works employed elaborate mechanical devices (called *Geschwindstellung*) to redirect the flow on large sections of the works at the pull of a lever. In the example in Figure 5 the brine flowed from the taps in the upper cistern into the dropping channels, which extended (in sections) the whole length of the graduation house. Perforations in the dropping channels produced thin streams of brine which broke up into drops as they fell to the twigs below. Should a wind-shift require brine to be directed to the opposite wall the lever was pulled, moving the wooden rod and the deflecting boxes which were attached to it, so that the brine flowed into the boxes, thence into cross channels which conducted it to the dropping channels on the opposite wall.[11] This arrangement is of course only one of many devices used for the purpose.

Some operational aspects of graduation works

Given the aim of graduation to be reduction in fuel costs, it was undoubtedly effective. Multhauf cites reports showing that at some German salines introduction of thorn graduation reduced wood consumption by one half to two thirds, while Bakewell recorded that at Moutiers it slashed the fuel used at the pans by 94 per cent compared with the quantity required for directly boiling the brine, which had a strength only half that of sea-water. Calculations made by Berthier, at this latter saline, indicated that under average conditions evaporation took place at the rate of 635kg of water per square metre of thorn walls every 24 hours, while at Schönebeck, under favourable conditions, the daily rate of evaporation was 1,128kg/m^2.[12] The rate of evaporation at any given saline was of course subject to a good deal of fluctuation in consequence of weather conditions, state of the faggots and related variables. Calculations based on fifteen years observation at six graduation works showed that evaporation in the poorest years ranged from 50 to 84 per cent of that in the best years.[13]

To bring brine to the required concentration normally required that it pass over the walls a number of times. Under European conditions, where the graduation works were very extensive, it was common practice to use a separate section of the wall for each cycle. Either a single graduation house was divided into segments, or separate structures were used for each stage, or not infrequently, a combination of these approaches was used.

The graduation works at Moutiers operated on the latter principle, four structures being used for the ten falls which raised the strength of the brine from about 1.5 per cent to 18 – 22 per cent.[14] Such an arrangement allowed greater continuity in the production process than would have been possible if brine had been recycled over the same wall several times.

The number of falls required to prepare brine for boiling depended upon the strength of the original brine, on atmospheric conditions, on the efficiency of the particular graduation structure, and on the final strength required. The ten falls employed with the very weak brines at Moutiers were not required at all salines. Table 1 compares the progress of graduation at four German salines, where graduation of brines with strengths ranging from 4.2 to 10.4 per cent required from three to six falls, to produce brines suitable for boiling.[15] The changes in strength from fall to fall were fairly uniform, except at Sulz where the first three falls showed marked fluctuation. Long term unevenness of this kind reflected differences in the efficiency of each part of the works, which often were designed and built at different periods.

As graduation proceeded the volume of brine was reduced dramatically. At Moutiers the graduation of brine to a strength of 18 per cent required removal of 90 per cent of the original water. Because the water evaporated from the brushwood surface was proportional to the area exposed, a smaller area was needed for each successive fall. These changes are clearly illustrated in Figure 6, which shows the theoretical changes in a body of brine graduated from an initial concentration of 5g/l to 230g/l. The area of graduation surface at each stage is sufficiently large to permit continuous flow through all stages.[16]

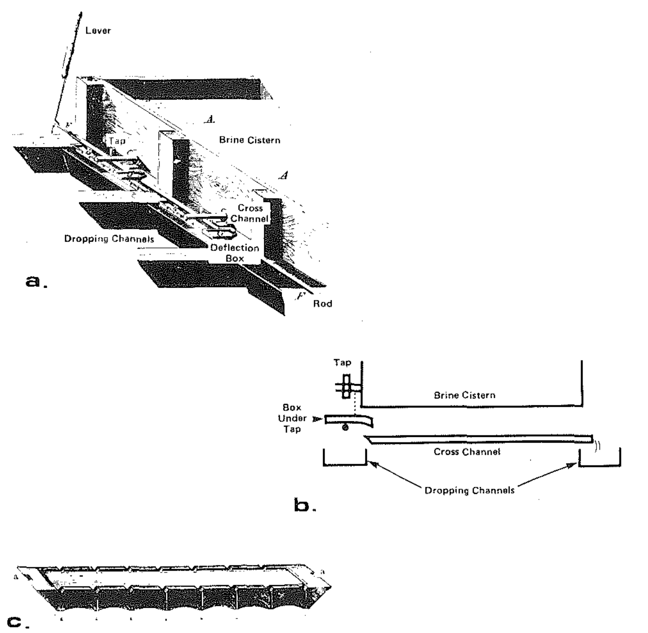


Fig. 5: (a) One form of mechanical contrivance for rapidly switching the flow of brine from one side of a graduation works to the other (Geschwindstellung). *(b) Cross-section of the device shown in 5(a). (c) A simple form of dropping channel showing notches and grooves by which the brine is conducted to the surfaces of the thorn walls. (Sources: (a) modified from Richardson & Watts 1863; (b) Drawn from description in Richardson & Watts 1863; (c) Fremy 1883).*

Disadvantages of thorn graduation

In addition to reducing fuel costs in the boiling process, graduation assisted in the production of pure salt by eliminating the greater part of the much less soluble calcium sulphate in the brine, together with any iron oxide which would discolour the salt if not removed. These were deposited in a stone-like coating (thornstone) on the sticks. Unless otherwise removed these materials formed a scale in the boiling pans which seriously impaired their fuel efficiency, and necessitated frequent laborious and costly chipping.

These advantages were not without cost. The structures occupied a good deal of space (though not so much as might be required for solar evaporation) and they absorbed a great deal of capital, particularly when it was necessary to roof them over to offset adverse effects of weather. Replacement of faggots was an expense, as those used for graduating weaker brines rotted very quickly, and required renewal every four to seven years. In the advanced stages of graduation the twigs were preserved by the strong brine but on the other hand, thornstone quickly blocked up the interstices between them, reducing air-flow and hindering the evaporative process. This necessitated replacement of the faggots every five to eight years.

The saving in fuel costs at the pans was further eroded by the heavy costs of maintaining the elaborate main structures and servicing the pumps and other ancillary equipment, which required skilled workmen. The necessity for quickly changing the brine flow from one side of the wall to the other in response to wind-shifts required either a considerable work force to be available to act at a moment's notice, or a considerable investment in *Geschwindstellung* was needed.

By no means the least disadvantage of thorn graduation was that a good deal of salt was dissipated by the wind, making it necessary to increase considerably the quantity of brine processed for a given quantity of salt. The handling of the additional brine of course required a bigger graduation works than theoretically necessary, and necessitated increased outlays for pumping and other handling. Part of

Table 1: Effect of graduation on brine strength (%)

Graduation Works at	Initial strength of brine	Graduation fall					
		1	2	3	4	5	6
Schönebeck	10.4	15.5	19.0	23.5	25.2		
Dürrenberg	7.5	10.6	15.7	22.0			
Kosen	4.3	8.5	13.2	19.9	25.8		
Sulz	4.2	5.5	8.5	9.5	12.4	15.4	19.2

(data from Fremy 1883)

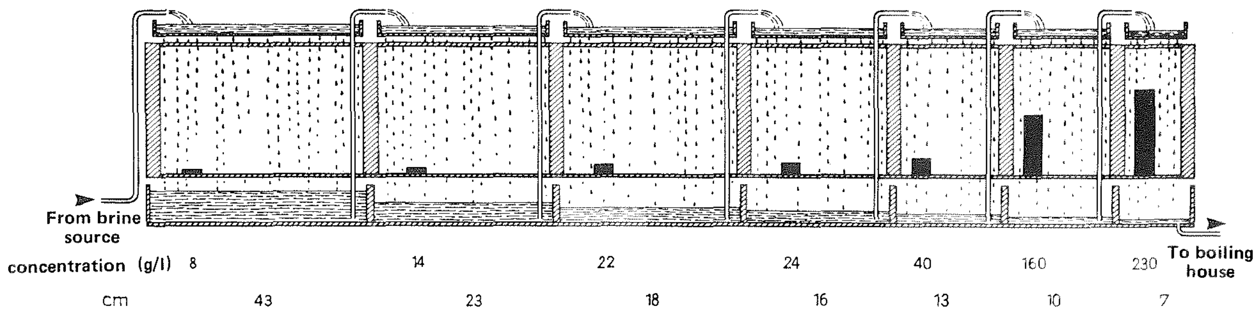


Fig. 6: Diagram of a graduation works, illustrating the relationship between brine volume, brine strength and area of thorn walls required as brine undergoes seven falls to increase its strength from 8 per cent to 23 per cent. The black column represents the brine strength, the shaded portions in the lower cisterns illustrate the extent of change in brine volume with each successive fall. (Adapted with permission from Carlé 1961.)

this loss could be attributed to fine drops of brine being carried from the works by the mechanical action of the wind, but a certain amount of it was the result of atmospheric diffusion, which could not easily be controlled.[17] Total salt lost from these causes was commonly in the order of 20 to 33 per cent of that in the original brine.[18] The rate at which the loss occurred varied with the strength of the brine being graduated, and for this reason the process was never carried to the saturation level of the brine. In many cases graduation was stopped when the brine contained between 14 and 18 per cent salt, but in areas where fuel was especially expensive it might be carried on to 22 – 25 per cent. The exact strength aimed for would be determined by the point at which the salt lost in the graduation process and the costs incurred in circulating additional brine offset the saving of fuel used for boiling.

The widespread use of thorn graduation in conjunction with the relatively weak brines from salines in various parts of Europe testifies that the advantages of the technology far outweighed the disadvantages, at least while salt was needed primarily for food preservation and culinary use. The advent of the Industrial Revolution brought a demand for salt for use in the soda industry which the salines could not meet, and the salt industry moved into mining of rock salt, rendering graduation technology obsolete almost as it matured. By 1880 the process was of little more than historical interest in Europe,[19] and even in the 1830s when the first graduation works was built in New South Wales, the decline was well under way.

APPLICATION OF GRADUATION TECHNOLOGY IN AUSTRALIA

Marriage of a preconcentration process to the boiling of sea-water occurred at only eight sites in eastern Australia. With the exception of Blaxland's works, graduation was the chosen technology for this. The relatively rainy climate in this coastal strip, lack of adequate capital to establish solar evaporation on an economic scale and a level of demand for salt unlikely to make such investment remunerative, all militated against a full solar process. Even as an auxiliary technology solar evaporation would have been ruled out by unsuitable sandy soils (Stockton, Moreton Bay) and restricted or steep sites (Illawarra). However, the limited information at present available makes it difficult to generalise about the circumstances that led to a choice of graduation technology. In all, only seven small salt-works are known to have made use of this process (Fig. 7).

A.W. Scott's salt-works, Stockton (Fig. 7a)

No less than five salt-making operations were established in the Newcastle area between 1800 and 1850. A government salt-works operated in conjunction with the coal pits between 1804 and 1808. In 1827/28 Gregory Blaxland invested some 1500 pounds in a venture which lasted only a few months. Between 1830 and 1836 the Australian Agricultural Company invested at least 1300 pounds to establish a plant with two salt pans, to make use of small coal which it believed to be unsaleable: discovery that a good market existed for this coal resulted in the salt project being still-born. About the same time, A.W. Humphrey had a salt-works built on 'Moscheto Island', but this also appears to have had little success.[20]

On the northern side of the Hunter estuary, near the water's edge, A.W. Scott established an industrial estate on land taken up in 1834. An account written in 1844 notes that the estate included, in addition to the salt-works, a woollen mill and an iron foundry, and preparation was in hand for making soap, and for construction of a sugar refinery.[21] It is evident that Scott was an enterprising individual, and it is consequently not surprising that he sought to enhance the efficiency of his salt-making by incorporating a graduation works. So far as presently can be ascertained, he was the first to make use of the process in Australia. Details of his graduation works are scarce, a contemporary report noting only that salt water was:

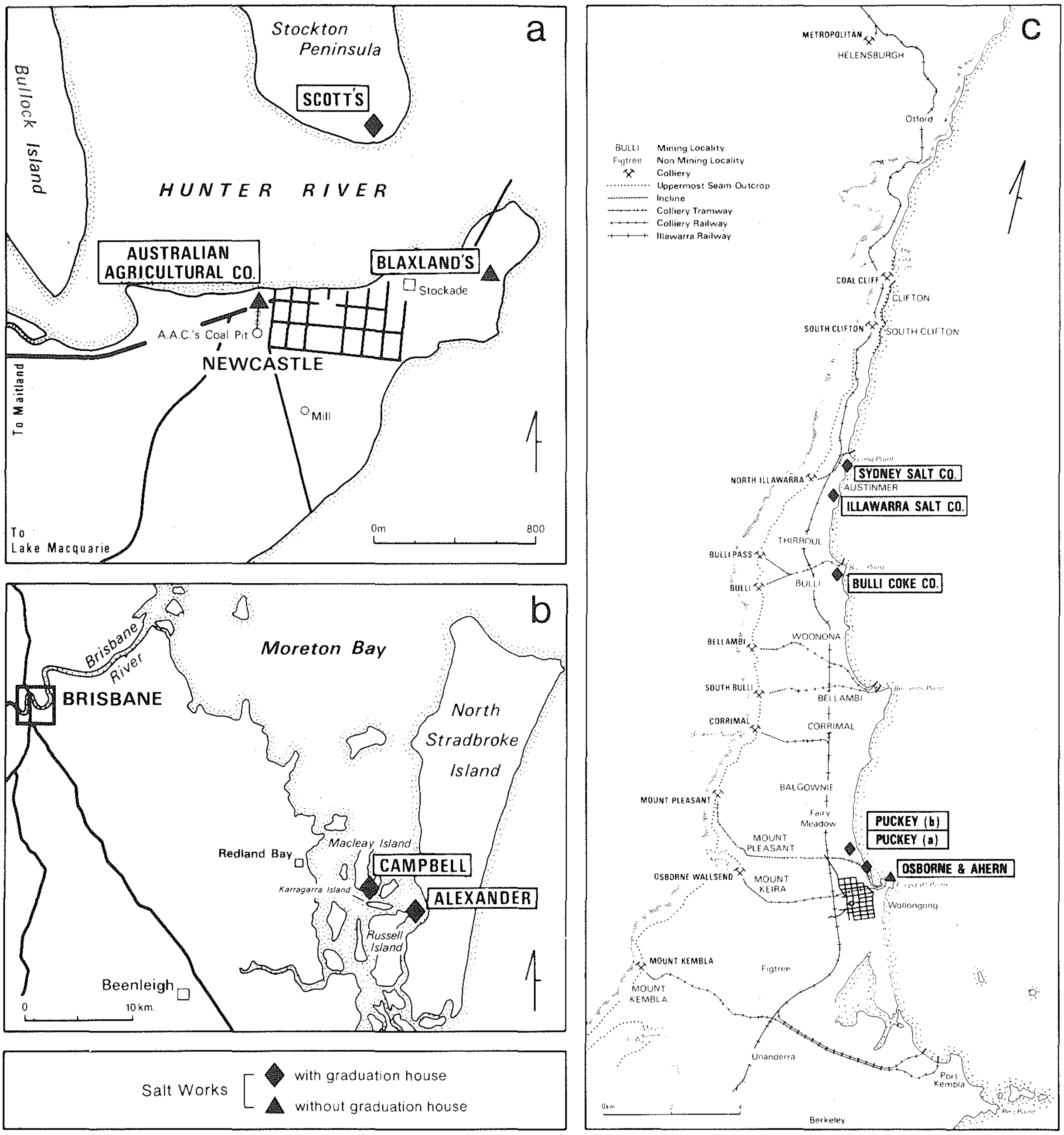
> '. . . pumped by a steam engine to a trough about 40 feet high, from this trough it is allowed to trickle slowly through a sort of fence or hedge of bushes, and the evaporation that takes place as it descends nearly doubles the strength of the water . . .'[22]

This structure was remarkable on the one hand for its height (12m) and on the other for the arrangement of the brushwood in the walls. In Europe graduation structures 40 feet (12m) high would not have been uncommon, but Scott's works was the only one in Australia to be built on such a scale; it was 3 – 6m higher than the other colonial examples discussed in this paper.[23] The additional height would have enabled advantage to be taken of freer air circulation at the higher levels, but would also have required considerable extra investment, particularly in the form of bracing. The scale of the structure suggests that Scott had intended to be in the salt-making business on a long-term basis.

The arrangement of the brushwood faggots within the walls of Scott's graduation works is also of interest. Explorer Ludwig Leichhardt, who was Scott's guest at Stockton for some time, wrote that:

> '. . . the branches are disposed vertically instead of being horizontal, though a horizontal position would certainly expose the fluid more to the atmosphere, as it had continually to drop from one branch to the other.'[24]

A similar disposition of faggots had been used in some parts of Europe in the earlier stages of development of graduation works but, by the end of the 18th century, it had been superseded by the horizontal arrangement already described. It may well be that the designer of Scott's graduation works had drawn upon an older publication, such as the *Archives of useful knowledge*, which in 1812 described a graduation house as:



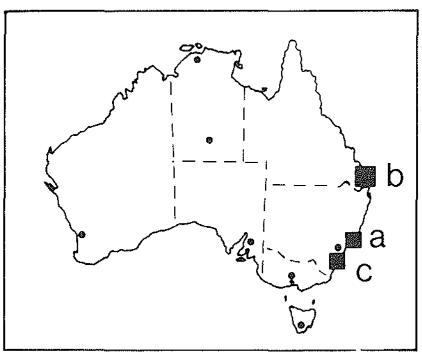


Fig. 7: Location of salt manufacturing sites at (a) Newcastle c.1830–1848, (b) Moreton Bay c.1870 (c) Illawarra 1875–1896.

'... very long range of rows of faggots placed perpendicularly, and rising to a height of about 25 feet and disposed in cones, the summits of which are about 6 feet in diameter, and the bases about 10. Just above the faggots is a trough perforated with holes at small intervals, furnished with stopcocks, and the whole is covered with a pent-house roof. At the bottom of the faggots is another trough to catch the brine.'[25]

Despite the apparently outmoded and inefficient arrangement of the graduation plant, Scott's salt-works was technically successful and apparently produced good salt for about a decade. On the other hand, it seems not to have been financially successful, at least in its later years, for when the graduation works was destroyed by wind in 1848, it was not rebuilt, and the salt-house was eventually turned over to other uses.[26]

Macleay and Russell Islands, Moreton Bay (Fig. 7b)[27]

A small salt-works was erected on Macleay Island, Moreton Bay, about 1869–1871 by one John 'Tinker' Campbell, a man with a history of unsuccessful business ventures. Little is known of this operation, except that it used a graduation process to compensate for reduced concentration of salt in the inshore waters. Thomas Welsby, a Moreton Bay boating enthusiast and amateur historian, noted that the works were built at the southern end of Macleay Island.

'Here the water was not so dense as near the Stradbroke shore, Campbell having to erect his buildings on a high slope to reduce the water, allowing it to fall through the air through bushes to raise the density two or even three degrees. For five years the works were carried on with no monetary result, so closed down they also were, . . .'[28]

The oral tradition on which Welsby relied for his information, in describing the graduation works as a building for allowing water to 'fall through the air through bushes', hardly does justice to the arrangement employed in European graduation works.

Close by, on the north-eastern point of Russell Island (Canaipa) another salt-works was established in 1871 by W.R. Alexander, at the considerable cost of 1500 pounds. This was subsequently operated by R.S. Hurd and C.R. Hervey.

'The plant referred to consisted of a "Thorn" house, some 20ft high, with a shallow wooden receiver, some 15ft by 8ft, to hold the sea water. From this receiver the water percolated to the layers of brush wood, of which there were three, some 4ft apart. A centrifugal pump drew the sea water from a well fed by pipes from the sea, and then forced it up to the receiver on the "Thorn" house. In percolating through the different layers of brush wood the wind is supposed to evaporate a good deal of the water and increase the density. From the "Thorn" house the water reached a large cemented tank, built in the ground, and of an estimated size of 12ft long by 8ft wide and 4ft deep. The water was then pumped by a small engine into a large iron pan, some 8ft by 6ft by 3ft, and after boiling until salt crystals appeared, it was run into steam jacketed wooden troughs or pans, allowed to granulate, and then collected in another wooden trough and dried.'[29]

The graduation house apparently was of the single-walled design, and a mere 15 feet (4.5m) long and 20 feet (6m) high. No explanation is offered for the peculiar gaps (1.2m) between the layers of brushwood, which departed from the densely packed and unbroken walls of the European structures. The unfilled portions of the wall would have reduced the graduation surface by 40 per cent from 27m^2 to 17m^2. Unfortunately this plant never had a chance to show what it could do in the way of evaporation, for on their first attempt to use it Hurd and Hervey spent some hours pumping water over the 'wall', only to find that the concentrated brine had all leaked from the bottom tank. Unable to bear the expense of sealing the tank, the two men proceeded with direct boiling of sea-water. While the boiling process lies beyond the scope of this paper, Hurd does mention one aspect which had technical and economic consequences directly attributable to the abandonment of graduation. He recalls that:

'The first week that the writer was on duty he was startled by hearing a loud bang, which caused him to seek a place of safety behind the wood heap, thinking that a blow up was about to occur. On looking up our mechanic, he stated that the report was caused by the deposit of lime over the hottest part of the furnace, this deposit forming gas, which would blow off from time to time. It may now be stated that after each boiling the large boiling pan had to be chipped, as lime had formed a thick coating all over it, which would, of course, decrease the heating power of the furnace.'[30]

Had the sea-water been graduated most of the less soluble calcium salts would have been deposited on the twigs, the efficiency of the pan would have been maintained over longer periods, and the labour costs of chipping the pan would have been significantly reduced.

The establishment turned out good quality coarse salt, which sold readily in Brisbane in a market heavily protected by a tariff duty of two pounds per ton. Even on this basis the operation was not profitable, and the partners abandoned the enterprise after a few months' operation. The failure was ascribed principally to the cost of wood, which was consumed in large quantities partly because of a poorly designed pan-setting and flue, which allowed flame and heat to escape up the chimney, and partly because of the large quantities of water to be removed by boiling before salt would form. Efficient graduation would have reduced the cost of fuel considerably, and could well have turned financial loss into profit.

The subsequent history of the salt-works is clouded. Welsby, relying on oral tradition, suggests that it operated for 'a number of years', before eventually being closed down, but this has yet to be verified.[31] The statement does raise the interesting question as to whether the plant was eventually operated sufficiently to allow the repair of the receiving tank of the graduation building, and its subsequent inclusion in the process.

Bulli, Austinmer and Wollongong (Fig. 7c)

The final section of this survey focuses on four separate salt-making operations clustered in the Illawarra region of New South Wales in the 1890s. Although they varied in scale and general technology, they are linked by their adoption of graduation technology to concentrate sea-water. The first to become operational was a pilot plant built in 1893 by the Bulli Coke Company on Bulli Point, behind the Bulli coal jetty. The Bulli Coke Company collapsed late in 1893, before the trials were complete. Following that collapse its manager, who had been conducting the experiments, collaborated with A.A. Lycett, who was to become the promoter of the Sydney Salt Company, in at least the preliminary stages of establishing that company. A third firm, the Illawarra Salt Company, established at about the same time as the Bulli Coke Company's experiments were commenced, initially had planned to operate without a graduation works, but subsequently purchased the structure built by the Bulli Coke Company and transferred it to Austinmer. The fourth of these works was erected near Wollongong Harbour in 1895. Its owner was a local pharmacist, Courtney Puckey, who operated the plant on an experimental basis for many years.

The Bulli Coke Company: Early in 1893 it was announced in the local press that the Bulli Coke Company was to spend the significant sum of 1000 pounds in constructing a salt-works, which would use waste heat from the coking process to make salt from sea-water which had been concentrated by graduation. It was stated by the Company that the purpose of the project was to provide data concerning the effectiveness of the graduation process in the context of the climate of Illawarra, and it was intended that if results were favourable a much larger plant would be installed.[32]

The graduation works was built on high ground near Bulli jetty, where full benefit could be obtained from winds from all directions. The structure understandably was small, being a mere 33 feet (11m) high and 8 feet (2.4m) wide. It was reported to be built to the description contained in *Ure's dictionary of arts, manufactures and mines* (Hunt 1860), already considered in the discussion of graduation technology.[33] Although the reference is to a two-walled type of graduation house (Fig. 2c), it is not clear whether the Bulli structure's width of 8 feet (2.4m) allowed for a double wall as illustrated, or whether only a single arrangement of branches was used.

The company commissioned its graduation works in June 1893, with the intent of testing the process 'at all seasons from mid winter to mid summer'. By August the manager of the coke works was able to display some 'fine-looking salt' produced at his works, and he expressed confidence that he could make salt profitably. The graduation experiments conducted during the colder months were reported to be 'highly satisfactory'.[34] Unfortunately, the testing did not continue beyond this point. Overtaken by financial difficulties precipitated by general depression in the coal and coke industries, the Bulli Coke Company ceased operation late in September, and went into liquidation. The graduation plant was subsequently sold to the Illawarra Salt Company, dismantled and removed to Austinmer.[35]

The Illawarra Salt Company[36] had been formed in December 1892, some months prior to the announcement of the Bulli Coke Company's project, by a handful of petty capitalists, most of whom were colliery managers or engineers. A small firm with a capital of only 500 pounds, the company intended to produce at first a mere five or six tons of salt weekly, later increasing to thirty tons per week. The works, built on land owned by two of the shareholders, was located at the southern end of Austinmer beach, where a small triangular platform 22m × 13m × 25m was cut into the headland.

The 'shoestring' capital of the company meant that every opportunity was taken to minimise expenditure on plant. Initially it was not intended to install a graduation works, but instead to utilize a direct boiling process which included pre-heating and some pre-concentration of the sea-water using waste heat from the pans, by means of coils of pipe installed in the flue. In May 1894, the proprietors radically altered their plans and purchased the disused graduation house of the Bulli Coke Company. Whether the purchase was motivated by problems with the direct boiling process, or simply by the opportunity to purchase the disused structure at a bargain price, is not made clear.

Little is known about the installation or operation of this structure. In January 1895 it was reported that the company's works had 'made another start with the natural evaporation process, having added a brush house to their works, but not so far satisfactorily'. After this date, the tiny struggling enterprise was eclipsed in newsworthiness by the announcement of the formation of the Sydney Salt Company, which had the backing of Sydney capitalists. The next reference to the Illawarra Company was in effect its obituary, in the form of an advertisement in November 1897 by the Company's liquidators calling for tenders to purchase the materials and equipment at the works. The Company's plant was entirely dismantled, leaving the site bare.

The Sydney Salt Company: An initial capital of 2500 pounds (later increased to 3500 pounds) made the Sydney Salt Company a relatively large concern. Its principal promoter was one Andrew Arden Lycett, who was stated to have been part-owner of and 'had control of' three extensive salt-works in Cheshire, England.[37] As the brines used in Cheshire required no graduation (or similar preconcentration) Lycett's promotion of this technology is noteworthy. It is probable that he had been associated with the graduation process used by the Bulli Coke Company, but his role in the innovation is not clear.[38]

The formation of the Sydney Salt Company was announced in January 1894, but construction on its site at Long Point (Hicks Point) near the Austinmer jetty, and about one kilometre north of the Illawarra Salt Company's works, did not begin until the following December. Once installation began, progress was rapid and the works was almost completed by the end of March 1895.

An extensive report on the firm's operations, published at the end of that month, includes what is possibly the most complete description of an Australian graduation works available.

'The works stand on Long Point, a high bluff about 180 feet above the sea level. One of the erections are on the edge of the cliff. The first stage visited was the pumping house, reached by a tortuous path down the cliff side to the beach, where there is a Tangye pump, capable of throwing 16,000 gallons of water per hour. This pump is worked from the main shed by an 8hp boiler, which is situated about 150 feet away. This pump draws water from the sea and throws it up a three inch pipe on to the top of the graduation house. This "house" is a structure 32 high by 150 feet long, and is a series of horizontal racks or trays upon which tea tree boughs are laid, and which serve the purpose of spraying the water in its fall to the receiving, or graduation tank. The water, upon leaving the pipes, runs into a tank at the top of the graduation house, and is then distributed into two shallow boxes running the whole length of the house. These boxes are fitted with 180 taps, and they allow the water to spray down gently over the tea trees, and into the graduation tank, whence it goes by a return pipe back to the pumping house and from which it is again sent to the top tank, and the process repeated: each passage increases its density by evaporating the water. From the graduation tank (which is 300ft × 30ft × 3ft 6in., and which receives the water after spraying) the water is sent to a second tank, 150ft × 20ft × 2ft. There it passes from the storage tank just mentioned to two boiling pans 30ft × 6ft × 3ft made of iron.'[39]

This operation was intended to have an initial output of 100 tons of salt per week or about 5000 tons (5080 tonnes) per year.

On the bluff at Long Point the works was well situated to take advantage of both the south-westerly and north-easterly winds so prevalent in the region: perhaps it was too well situated for this end, because the plant was barely commissioned before the graduation works was completely demolished by a storm, and flung over the cliff to the beach below. Operations were suspended until 1896 when the works re-opened under lease to Lycett, trading as the Austral Salt Company. Although no explicit indication is given, it may be assumed that in the interim the graduation works had been rebuilt. Despite having a product of high quality and taking an energetic approach to marketing, Lycett still could not make the operation pay, and in 1896 he suffered the indignity of having the few effects of the Austral Salt Company sold up at a police sale. The works of course still belonged to the Sydney Salt Company, and twelve months later the plant and building materials were offered for sale, the Company being in liquidation.[40] The failure may be ascribed to two almost contradictory forces. On the one hand there was a market resistance to colonial products—unless the prices were sufficiently low—and on the other there was a very rapid increase in imports of inexpensive salt from South Australia's salt lakes.[41] The effect of this South Australian salt in the market place was greatly magnified from 1 July 1896 by the removal of the twenty shillings per ton *ad valorem* duty on salt imported into New South Wales.

The financial difficulty encountered at the Sydney Salt Company's works raises doubts about the efficiency of the graduation plant and its capacity to reduce fuel costs by bringing brine to an adequate strength. The dimensions of the structure give little cause for confidence. Although no data concerning the actual operation of the plant is available, it is possible to make some reasonable estimates on the basis of European experience.

Sea-water contains an average 2.5 per cent sodium chloride, but not all of this can be recovered: as noted previously some is lost through spray drift and more remains in the bitterns (mother liquor) when the salt is removed from the pan. Depending on the recovery rate, the planned output of the Sydney Salt Company would require treatment of some 290,000 to 406,000 tonnes of sea-water yearly (Table 2).[42] This would mean that, depending upon the strength of brine to be achieved, the amount of water to be removed by graduation would range from approximately 220,000 tonnes to 350,000 tonnes annually, a mighty task for a graduation works with a maximum surface area of only 446m^2 (4800 square feet).

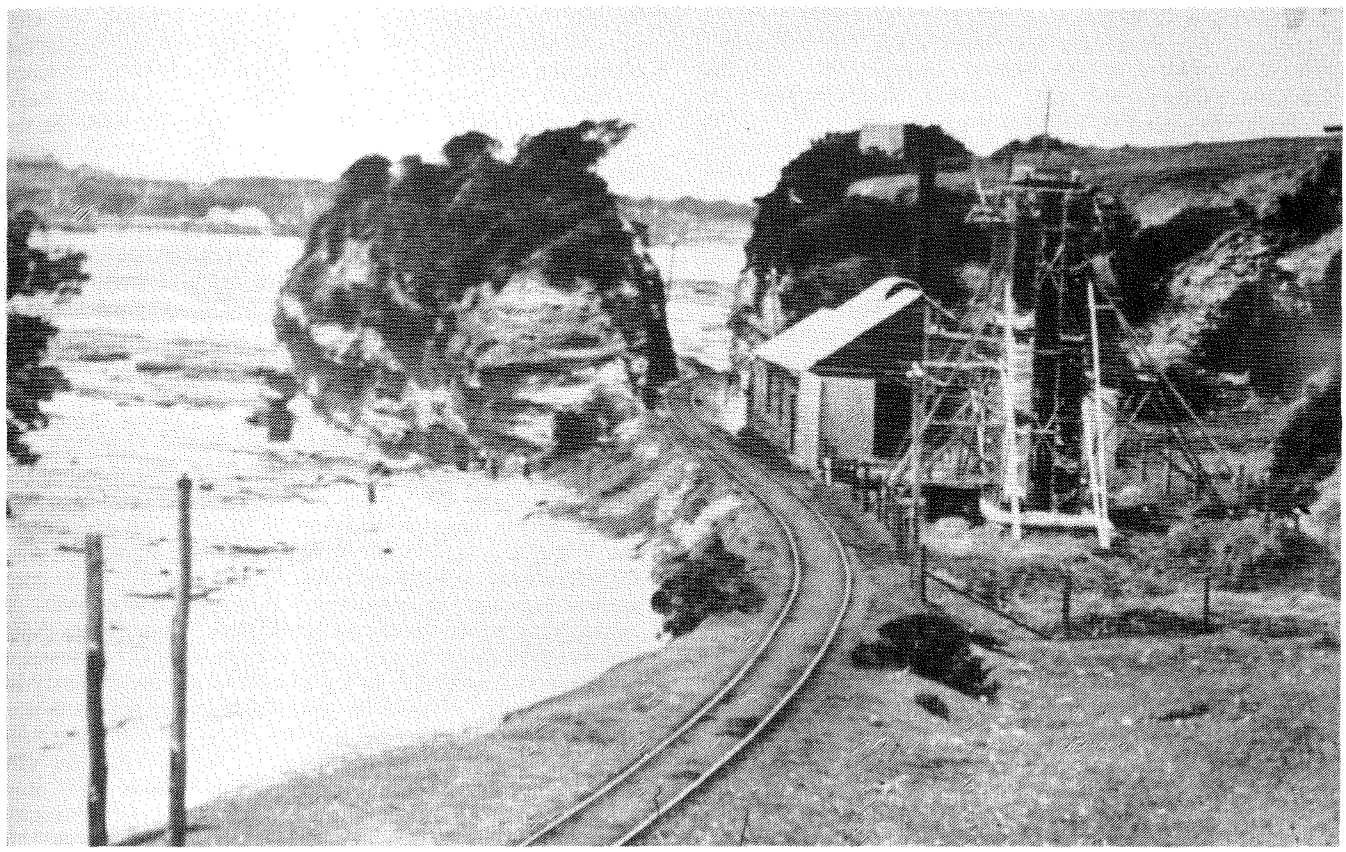
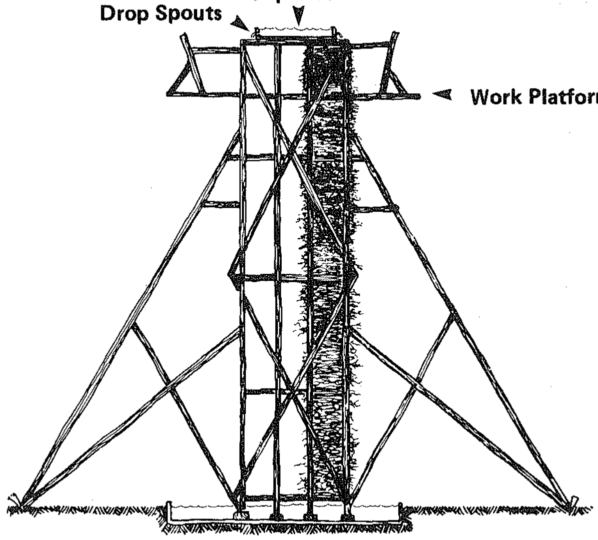


Fig. 8: Puckey's graduation works and salt-boiling house near Wollongong harbour (Fig. 7c, Puckey (a)). This is the only photographic record of the Australian graduation structures discussed in this paper. (Photograph: Wollongong Reference Library).

Fig. 9: This cross-section of Puckey's graduation works has been drawn to show more clearly the operational elements of the structure seen in Fig. 8. Although of the most basic design, the structure nevertheless contained the essential functional elements discussed in the earlier part of this paper.



In the absence of reliable climatological data, and of any knowledge of the relative effectiveness of blackthorn and tea-tree faggots, the capacity of the Sydney Salt Company's works can be very roughly estimated by applying the evaporation rates observed at Schönebeck (1128kg/m^2/day) and Moutiers (635kg/m^2/day) to its 446m^2 of surface. If the plant was operated for 280 days in a year, it would on the basis of these rates evaporate between 79,000 and 141,000 tonnes of water annually (or, if operated 300 days, 85,000 – 150,000 tonnes).[43] These quantities fall well short of the required evaporation, shown in Table 2, even at low concentrations and high recovery rates.

The extent of this shortfall suggests the need for a second graduation unit of at least similar dimensions. As the collection tank below the graduation structure was 300 feet

Table 2: Quantities of sea-water required to yield 5080 tonnes (5000 tons) of salt, and water to be evaporated to bring brine to several strengths.

Rate of recovery of salt from brine %	Tonnes of sea-water required to yield 5080 tonnes of salt	Tonnes of water to be evaporated to bring salt concentration to: 10%	12.5%	15%	17.5%
50	406,400	304,800	325,120	338,666	348,343
60	338,666	254,000	270,933	282,222	290,285
70	290,285	217,715	222,228	241,905	248,816

One ton = 1.016 tonnes

(91.4m) long, and the building itself was only half this length, it appears that provision had been made for additional graduation walls. It is likely that the company deferred the expenditure on a second stage, pending a flow of funds from successful operation of the first stage.

Duplication of the graduation house would have placed the estimated potentials for evaporation between 158,000 and 282,000 tonnes of water in a 280 day year (170,000 – 300,000 tonnes in a 300 day year). Although they must be treated with a great deal of caution, these figures suggest that given very favourable conditions, the extended structure may have been able to meet the needs of its owners.

Guided by the results of the Bulli experiments, Lycett certainly would have planned his graduation works with appropriate capacity, while the Company's shareholders would have sought to minimise any potential for loss by restricting investment in an unproven process. This would account for the size of the collecting cistern, and the apparent deficiency in graduation surface.

Puckey's Experimental Works: In 1895, soon after he had purchased a chemist's shop in Wollongong, Courtney Puckey began to experiment with salt-making, having previously conducted such experiments on Point Frederick, Gosford, between 1892 and 1894. Neither Puckey nor his operation were given attention in the local press, but in the 1960s his daughter recalled that in 1895 her father:

> '. . . had a tea-tree framework 30ft high erected to the top of which he pumped sea water, which was then allowed to slowly percolate through to large wooden tanks, and generally dried by heat from a furnace.
>
> He later bought 44½ acres of land across Fairy Creek . . . in . . . 1905. Here he set up his framework with a windmill to pump the sea water, and with the help of one labourer, experimented here for years.'[44]

The first site was at the southern end of Wollongong's North Beach, and the second a few hundred metres to the north. Puckey's experimental and commercially inconsequential operation is of disproportionate significance to this survey, because his 'tea-tree framework' is the only Australian example of a graduation works presently known to be recorded pictorially (Figs 8 & 9). The structure was a readily identifiable example of a two-walled graduation works, with the functional features clearly discernible. This gives some clue to the kind of structures employed at the Illawarra sites already discussed, for Puckey would have had opportunity to view the works of both the Sydney Salt Company and the Illawarra Salt Company. Two interesting features are the extent to which the two brushwood walls are separated, and the vertical faces on those walls.

CONCLUSION

The adaptation of graduation technology to salt-making in eastern Australia produced structures which had only basic similarities to each other, and to the European structures on which they were modelled. All were small by European standards, the largest being a mere 46m long, and apparently they were less substantially constructed than those on which they were modelled. They would almost certainly have lacked such refinements as *Geschwindstellung*, as their size would not have required much labour to alter the brine-flow manually. Another problem arising from their restricted size was that, with the possible exception of the works at Bulli and the two at Austinmer, there was little scope for dividing the walls so as to separate out the individual falls, along the lines in Figure 6. For reasons not made clear, two of the works had a quite atypical arrangement of the brushwood, that at Stockton having the sticks arranged vertically and that on Russell Island apparently having the layers separated by gaps of 1.2m.[45] Introduction of graduation technology to Australia required that a substitute for traditional blackthorn faggots be found, and the ubiquitous coastal tea tree (*Leptospermum* sp.) was used in the majority (if not all) the structures. The efficacy of this material is unknown, but since it lacked the angularity of blackthorn it may not have produced the same evaporation surface. In addition, the tea tree would tend to pack more closely, and therefore it may not have permitted air to circulate so freely as did the blackthorn faggots.

It is possible to explain the small scale of the works, their lack of refinement, and their relatively fragile construction, as a reflection on the one hand of the restricted markets available for salt, and on the other of a parsimonious approach by entrepreneurs to outlaying scarce capital funds on specialised plant for an essentially untried manufacturing process.

To some extent each of the three regional groups of graduation houses represented an innovation. On the one hand thorn graduation was not associated with concentrating sea-water in Europe, and some entrepreneurial vision was needed to see the possibilities in this use. On the other hand the three groups of sites at Newcastle, Moreton Bay and Illawarra were so separated in time and space that the later entrepreneurs would almost certainly have been unaware of the attempted innovations made elsewhere. That these innovations were not successful in producing profits cannot be attributed necessarily to a lack of technical efficiency in the graduation process, for the salt-works at which it was employed were in general neither more nor less successful than those which operated without it. Of all the salt enterprises which operated in eastern Australia to 1900, only John Blaxland's Newington establishment enjoyed continuity of operation over an extended period (from about 1807 to 1880), and Scott's works were operational for only a decade. Apart from these, few salt-works were active for more than two or three years. The explanation of this is almost certainly to be found in the market place rather than in technology. In part it may well have been the inability of salt manufacturers to overcome the general prejudice against colonial manufactures, and the more particular belief in the superiority of 'Liverpool salt'. In the 1890s the rapid expansion in South Australian salt manufacture and the import of cheap salt from that colony to New South Wales completely undermined any viability the Illawarra salt-works may have had. The price of this salt was so low that it could substantially displace English salt from the market. This is not to deny that there may have been problems with the graduation process. It is quite conceivable, for example, that the brushwood walls were so small as to deny their operators any economies of scale, so that costs associated with graduation eroded the savings on fuel for boiling, or that tea tree was no real substitute for blackthorn. There is also a large question concerning the evaporative power of the atmosphere in the coastal locations of these graduation works, as compared to the inland sites in Europe. In the absence of specific data, further speculation along these lines would be unprofitable.

It is unlikely that the major sites discussed in this paper would yield significant data to archaeological investigation. The Stockton site has been obliterated, the two at Austinmer have been built over, and according to long term residents of Bulli, the area about Bulli Point was considerably disturbed in the 1950s. On the other hand there are apparently still some remains of the Moreton Bay works, and the two sites used by Puckey could conceivably yield some information concerning dimensions, as the ground appears relatively undisturbed.

NOTES

1. For a brief overview of salt-making in N.S.W. to 1900 see Rogers 1983.
2. *Historical records of New South Wales* 6: 310.
3. This list is tentative. So little is known of the processes

used at a number of salt-works that it is not presently possible to determine whether thorn graduation or other pre-concentration process was employed.

4. Paul 1878: 240; Berthier 1810.
5. Sometimes the terms 'drop graduation' or 'faggot graduation' are used.
6. Musspratt 1860. The following figures would be representative of the range of brine strengths:

	% NaCl		% NaCl
Salzhausen	0.94	Dürrenberg	6.6
Moutiers	1.06	Schönebeck	9.6
Nauheim	2.36		

7. Multhauf 1978: 54–5, 79; Swedenborg [c.1728]: 70. Carlé 1965b notes that evidence of a much more ancient form of graduation has been found at Schwäbisch Hall (Germany). Brine was run into troughs, and elongated pieces of porous (baked) clay were added; these absorbed water, which then transferred by capillary action to the exposed portions of the clay, from whence it evaporated.
8. Multhauf 1978: 78–9.
9. Hunt 1878: Vol. III, 744–55.
10. There are some differences in the literature in English concerning the relationship of graduation works to the direction of the prevailing wind, some publications asserting that the two should be aligned, others stating that the length of the buildings should be exposed to the prevailing winds. Common sense, as well as the first-hand experience of Bakewell (1823) and Berthier (1810), supports acceptance of their view, that the structures should be built across the usual direction of the wind.
11. Richardson & Watts 1863: 174–5.
12. Calculated from Muspratt 1860: 903. The figure for Schönebeck is given as 3.7 cubic feet/24 hours and that for Moutiers as 13 gallons/24 hours. Fremy 1883: 392 gives evaporation figures ranging from 5.6m³ to 11.4m³ per square metre but these are quite inconsistent with other estimates. Almost certainly the error has resulted from the decimal point being misplaced one place to the right.
13. Fremy 1883: 391.
14. Berthier 1810.
15. From the size of graduation works at some salines can be gained some appreciation of the possibilities for this mode of operation. Salza had 1773m of thorn wall, Dürrenberg 838m, Kissingen 2000m. At Moutiers four graduation houses contained a total of 920m of actual graduation wall, the overall structures being considerably longer. Numbers 1 and 2 graduation houses (Fig. 4e), each approximately 350m long, operated in parallel to reduce the volume of brine by one half, bringing it to a strength of 3 per cent. This change was usually effected in two falls, each house being divided into two sections for the purpose. The brine from Numbers 1 and 2 graduation houses then entered Number 3 graduation house, where it was brought up to a concentration of 10–12 per cent salt. This third structure, roofed to prevent dilution of the brine by rain, had seven divisions in its 340m of 8m-high thorn walls. The length of each division, reflecting the relative volume of brine to be dealt with, was 60, 60, 55, 48, 42, 36, 35m. The brine passed from the seventh stage of this building to Number 4 works, which had only 55m of thorn walls, which were 10m high. Normally a single raising on this structure sufficed to bring the brine to a suitable strength, mostly about 18 per cent, but as high as 22 per cent in very favourable conditions, or as low as 14 per cent in winter. (Berthier 1810)
16. Diagram reproduced by kind permission from Carlé 1961: 86.
17. Tomlinson 1868: 554.
18. Fremy 1883: 391.
19. ibid.: 392.
20. *Historical records of Australia*, Series 1, Vol. 14: 3–5; Jervis 1935.
21. Turner 1980: 27.
22. *Maitland Mercury* 6/7/1844, quoted in Turner 1980: 25.
23. The general limit imposed on the height of graduation structures in Europe was 16m. The requirements of construction and servicing were the main factors determining this limit. (Fremy 1883: 387)
24. Leichhardt 1968: Vol. 2, 525.
25. Mease 1812: Vol. 2, 342.
26. *Sydney Morning Herald* 10/1/1843, 27/2/1844. Jervis 1935 states the works were in operation in 1839 and that the graduation house collapsed in 1848. Turner 1980: 27.
27. The author is grateful to Ian Sanker, Curator of Industrial Technology, Queensland Museum, for drawing his attention to the Moreton Bay Salt-works, and for providing a good deal of the information on which this section is based. [See also Sanker 1984, published since this paper was written. (Editor)]
28. Welsby 1977: 54. Sanker notes that Welsby was acquainted with Campbell's three sons and presumably obtained his information from them.
29. Hurd 1917.
30. ibid.
31. In a personal communication Ian Sanker states that a works on Russell Island was operated by J.W.S. Willes. Hurd, on the other hand, notes that a Mr Willes supplied Hervey and himself with firewood. It is possible that Willes took over the operation of the plant when it was abandoned by Hurd and Hervey, but it is also possible that the oral reports of Willes' role in the operation have been distorted through repetition.
32. *Illawarra Mercury* 4/4/1893, 6/4/1893.
33. *Illawarra Mercury* 6/4/1893 stated that the Bulli Coke Company was to 'test a process which is described by Dr Eures, of Germany, in his *Chemistry as Applied to the Arts and Manufactures*'. Searches both in Australia and overseas failed to locate a work of this title by a 'Dr Eures', and it seems certain that the work referred to was *Ure's dictionary of arts, manufactures and mines* (Hunt 1860).
34. *Illawarra Mercury* 31/8/1893, 22/9/1893, 28/9/1893.
35. *Illawarra Mercury* 4/8/1894.
36. The only data relating to this firm comes from the *Illawarra Mercury*, 1892 to 1897. Most of the references are small.
37. *Illawarra Mercury* 30/1/1894.
38. Evidence: 1: Lycett lived in Illawarra district from 1892. 2: Bulli Coke Company was reported to be making use of an 'analytical chemist': Lycett's family believes that he was university-trained as 'an industrial or analytical chemist' (personal communication from Mrs R. Taylor). 3: Following the failure of the Bulli Coke Company, Lycett worked with the ex-Manager of that company to conduct salt-making experiments elsewhere in Illawarra prior to the formation of the Sydney Salt Company. 4: The graduation house built by the Sydney Salt Company was similar in dimensions to that of the Bulli Company, and may possibly have been built to the same plan.
39. *Wollongong Argus* 30/3/1895.
40. *Wollongong Argus* 15/6/1895; *Illawarra Mercury* 18/1/1896, 6/8/1896, 28/8/1897.
41. In 1890 South Australia produced a mere 5600 tons of salt and in 1894 the output was 7600. In 1895 production rose sharply to 17,700 tons, and in the following years it continued to increase to 36,000 tons in 1899. During this period South Australia's contribution to N.S.W. salt imports rose from 12 per cent in 1890 to 61 per cent in 1900, while imports from Great Britain fell from 83 per cent in 1890 to 25 per cent in 1900.
42. The tabulation shows a range of concentrations which would balance salt-loss from continued graduation against increased fuel costs for evaporating weaker brines. The fuel used here was slack coal from local pits which was dumped in large quantities at the mines, the coke industry not having developed to any extent near Austinmer mines.

43. These estimates of the working year allow for Sundays and holidays, rain-days, and equipment failure. The estimate of 280 days is probably the most realistic.

44. Notes by C. Puckey's daughter, Dr Mary Puckey, quoted in *Circular of the Illawarra Nautral History Society*, August, 1967: 29, (see Walsh 1967).

45. Hurd 1917 refers to the works having three layers of brushwood 4 feet (1.2m) apart. It may be that he was referring to the laths or racks which supported the branches, an arrangement which would produce a single uniform graduation surface similar to that used in Europe, but it seems that the interpretation used in this paper is the more likely.

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