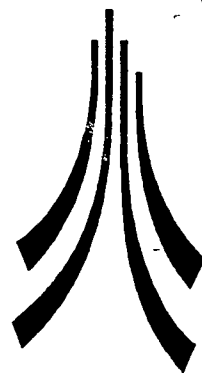


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March 1996

MONUMENTS PROTECTION PROGRAMME

THE LIME, CEMENT, AND PLASTER INDUSTRIES

Step 1 Report

Commissioned and funded by

English Heritage

MONUMENTS PROTECTION PROGRAMME

The Lime, Cement, and Plaster Industries

Step 1 Report

Checked by Project Manager	
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2 INTRODUCTION

2.1 Scope

In line with other MPP Step 1 projects, the aim in producing this report has been to set out current understanding of the industry as a basis for selecting sites as candidates for statutory protection according to their historical and archaeological importance. The report has been prepared in accordance with the Draft Specification for Industrial MPP (unpublished report by LUAU for use of English Heritage, submitted November 1995).

The report specifically deals with three classes of site: lime works - that is sites concerned with the production of lime by burning and slaking, cement works - sites concerned with the production of cement, and plaster works - sites concerned with the production of gypsum plaster. Limestone extraction has been considered as part of the Stone Industry (Ashbee 1995). The production of mortar and concrete is normally performed at the construction site rather than at the lime or cement works and is therefore outside the scope of this report, although reference is made to it.

The basic material required for producing lime is chalk or limestone. Some deposits of these rocks (for example Chalk marls, liassic limestone) contain impurities of silica and alumina (clays) which result in a naturally 'hydraulic' lime (essentially one that sets under water). Cements are inherently hydraulic, their difference from hydraulic lime being a higher percentage of clayey material. Gypsum plaster is produced from the grinding and burning or roasting of Rock Gypsum.

2.2 Lime and Cement Definitions

Figures 1 and 2 (from Davey 1961, 109) give a useful summary of the various groupings of lime, cement and gypsum plaster. Calcium carbonate (CaCO_3) occurs naturally in the form of limestone or chalk. By heating these rocks to temperatures of the order of 900-1200°C, carbon dioxide (CO_2) is driven off from the stone to leave 'lumps' or 'cobs' of 'quicklime', a white caustic alkaline earth, chemically referred to as calcium oxide (CaO) (see Ashurst 1988, Bick 1984, 91-3, Searle 1935, 404). Quicklime is unstable and will combine with water to produce 'slaked lime' or calcium hydroxide, Ca(OH)_2 , in a strong reaction that releases heat and reduces the lumps of lime to a stable powder form. The term 'lime' tends to be used generically to cover both these materials.

Lime for agricultural use was normally transported to the fields as quicklime, and could be spread slaked or unslaked. Lime mortars set by the gradual conversion of the slaked lime back to calcium carbonate, by reaction with atmospheric carbon dioxide - there is no chemical reaction with the sand or other filler in the mortar.

The purity of lime depends on the composition of raw materials used to produce it. If silica and alumina are present, then calcining the stone causes them to combine to form insoluble compounds that give the lime hydraulic properties, that is the lime has increased strength and will set under water. The hydraulic property of lime is important in relation to the building industry, where the need for good quality mortars drove much of the technical advancement in lime and cement production in the industrial era. Four broad groups of lime may be defined (see Davey 1961).

- Non-hydraulic lime - high calcium or 'fat' lime, derived from a pure limestone such as white chalk, Oolitic limestone or Carboniferous (massive rather than shaley) limestone
- Semi-hydraulic lime - from grey chalk, siliceous limestone or argillaceous limestone (ie containing matter of various mixes of alumina and silica)
- Hydraulic lime - from chalk marl and Liassic limestone
- Magnesian lime - from Magnesian limestone (with up to 40% magnesium carbonate - over 40% is technically a 'dolomitic' lime - the magnesium is inert and the stone produces a non-hydraulic lime)

A cement is essentially a mixture (natural or, more commonly, artificial) of calcium carbonate and clayey material (silica/alumina). The distinction from hydraulic lime is by a higher percentage of clayey material and in the method of production - the mixture is calcined to the point of vitrification and the resulting clinker ground to a dry powder (Davey 1961)

The chemistry of cement production is complex, depending in detail on the precise composition of the mix and the firing temperature. In outline, the kiln chemistry consists of a reaction of lime with silica (SiO_2) and/or alumina (Al_2O_3), to form various calcium silicates and aluminosilicates, which are then ground to a powder. In the setting reaction, the powder reacts with water to form calcium silicate hydrate and related minerals, which form a network of hard insoluble crystals.

Cements may be grouped according to the specific mix of raw materials and the temperature of calcination. The main groups are natural cements (naturally occurring limestone and clay mixes), artificial cements (separately mined and then mixed combinations of limestone and clay), 'Puzzolanic' cements (limestone mixed either with naturally occurring volcanic earths, such as Italian 'pozzolana' or Dutch 'trass', or with manufactured materials such as ground tile and pot), and slag cement (limestone and blast furnace slag). Of the artificial cements, 'Roman cement' (as produced in the eighteenth century) is produced from calcining at a temperature equivalent to the burning of lime ($900-1200^\circ\text{C}$), whereas 'Portland cement' is calcined at a higher temperature ($1300-1450^\circ\text{C}$).

2.3 Gypsum Plaster Definitions

Calcium sulphate (CaSO_4) occurs naturally in the form of Rock Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, or Alabaster in its pure form) and Mineral Anhydrite (CaSO_4). Heating gypsum to $130-170^\circ\text{C}$ drives off most of the water to form hemihydrate plaster ($\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$), or Plaster of Paris. Burning to 400°C removes all the water leaving anhydrous calcium sulphate (CaSO_4). Grinding mineral anhydrite also produces the latter without calcination. Adding water to these plasters produces set gypsum plaster (CaSO_4). Pure Plaster of Paris sets very quickly. To be more usable, retarders may be added, for example keratin (cooked from animal hair, horns and hoof in caustic soda solution) and other glue-like materials (see Ashurst 1988, 29; Davey 1961).

Other terms to be aware of in any study of limes, cements and plaster are as follows (see for example Davey 1961, Ashurst 1988, 28-9)

- Concrete - cementitious material (lime, cement) mixed with aggregate (ie solid materials). The distinction from mortar is one of adopted definition. Davey quotes a figure for the boundary of aggregate size as $3/16"$
- Gesso - a term for Plaster of Paris mixed with glue

- Mortar - a term for material used for bedding, jointing, and rendering of brickwork and stonework. The term may cover a variety of mixtures of materials, including mud, clay, gypsum mortar, lime mortar, and cement mortar. In the latter cases lime or cement is mixed with sand to act as a dilutant (reducing cost) and giving a pozzolanic effect.
- Selenitic Lime or Cement - hydrated lime plus 5% Plaster of Paris, which gives quicker setting and a stronger lime.
- Scagliola - coloured gypsum plaster that is intended to imitate marble.

Terms such as Sgraffitto, Stucco and Pargetting refer to forms of application of lime, gypsum and cement and are not relevant to this study.

2.4 The Uses of Lime, Cement and Plaster

Documentary and archaeological records show that lime has had an important role in a wide range of industrial processes and activities (see Searle 1935 211-66, Dix 1979, Neve 1726, Singer 1958 447-50, 519, 538-9, Samuel 1977 5, 6-7, annual summaries of work in Britannia, Medieval Archaeology, Post-Medieval Archaeology). The history of these uses is beyond the scope of this report. However it is felt useful to list them. The two major and well known uses are as an agricultural fertilizer and in the building trade, as the main ingredient in lime washes and lime mortars, plasters and concretes. From the early nineteenth century, a wider range of uses for lime was developed, for example in the emerging gas industry (note that from the 1840s lime was occasionally used as the flux in blast furnaces rather than limestone, Van Laun pers comm, also Searle 1935, 629-31). A list of 26 uses of lime given by Searle (1935, 531) illustrates its wide application in the early twentieth century (see table).

Table of Uses of Lime in early twentieth century, based on Searle (1935, 531)

- Abrasives and Polishing industry
- Agriculture and horticulture - as fertilizer, animal feed additive, as disinfectant (eg sheep dips)
- Building industry - for lime mortar cement and concrete, limewash and lime-sand bricks
- Road and pavement construction - especially in USA
- Chemical industries - widely used (see following entries)
- Distilling industries - wood, coal, shale, alcohol, ammonia
- Coke and gas manufacture - absorbs gas and moisture
- Explosives and allied industries
- Food industries - eg sugar refining, starch manufacture, malting
- Fuel - oil and gas production
- Furnace construction and refractory materials
- Glass making
- Glue size, gelatine manufacture - acts as hydrolysing agent
- Leather manufacture - used to soften hides
- Medicines and Pharmacy
- Metallurgy - in blast, open hearth and puddling furnaces, in melting iron and wire drawing, in the recovery of mercury and gold and in smelting of lead, copper, zinc, tin, aluminium moulding
- Refining non-edible oils and lubricants
- Paint, distemper and allied industry
- Paper and cellulose industries
- Refining petroleum
- Pottery, glaze and enamel industry
- Rubber and resin industry
- Sanitation
- Soap and allied industries
- Textile industry
- Softening and Purification of water
- Other

Cement and gypsum plaster were developed specifically for the building trade. Cement mortar gradually (in the nineteenth and twentieth centuries) replaced lime mortar for bedding, jointing and rendering of brick and stonework. Concrete has had a very important role in structural work, for foundations and for the main structure, in the Roman period and again in the early to mid-nineteenth century, when its use was linked to the use of Roman and Portland cements. Gypsum plaster has been used for rendering and for decorative work at least from the thirteenth century but on a large scale only from the late nineteenth century.

3. GEOLOGY AND RAW MATERIALS

The essential raw material for the production of lime (calcium oxide) is limestone or chalk (calcium carbonate). In the period in which lime has been produced in England (from the Roman occupation onwards), this stone has been extracted from a range of geological deposits. Limestones of varying thicknesses and purity occur in almost every county of England and in rocks of almost every geological period. Almost all of these have been used for lime or cement production to some degree. In particular, the acid soils and difficult transport of many upland areas have encouraged the use of even thin and impure limestones for local lime production. However, certain deposits have been more important for lime production. These may be summarised in terms of a categorization of the resultant lime based on the degree of its hydraulicity (see Technical Outline).

Table of geological deposits in England, historically used for lime burning (derived from Davey 1961, 99)

Geological Period	Rock	Distribution	Type of Lime produced
CRETACEOUS	Upper Chalk	Wolds of North Yorkshire, Humberside, Lincolnshire, East Anglian Heights of Norfolk, Suffolk, Cambridgeshire, South-east England - Herts, Bucks, Oxfordshire (Chiltemps), Surrey, Kent (North Downs), East and West Sussex (South Downs), Hampshire (Downs), Berkshire Downs, the Thames basin - Essex, Greater London, Kent and Wiltshire (Salisbury Plain and Marlborough Downs), Dorset (Downs), Devon	Non-hydraulic
	Lower Chalk	Thames basin (Essex, Kent, Greater London) and the Dorking, Merstham, Guildford area of Surrey	Semi-hydraulic
	Chalk Marls	Cambridgeshire	Hydraulic
JURASSIC	Oolitic limestone	Dorset (Portland), Somerset, Wiltshire, Avon (Bath), Gloucestershire, Oxfordshire, Buckinghamshire, Northamptonshire, Cambridgeshire, Lincolnshire, Humberside, North Yorkshire (North York Moors) and Cleveland	Non-hydraulic
	Liassic limestone	Devon, Dorset (Lyme Regis), Somerset, Avon (Keynsham), Gloucestershire (Shipton), Hereford and Worcester, Warwickshire (Rugby), Northamptonshire, Leicestershire (Barrow-on-Soar), Nons, Lines, Humberside, N Yorkshire, Cleveland	Hydraulic
PERMIAN	Magnesian limestone	Derbyshire, Nons, South Yorkshire, West Yorkshire, North Yorkshire, Durham and Tyne & Wear	Magnesian (non-hydraulic)
CARBONIFEROUS	Carboniferous limestone	Derbyshire, Peaks, Forest of Dean, Mendips (Somerset, Avon), Also North England - Lancashire, Cumbria, North Yorkshire, Durham, Northumberland	Non-hydraulic
DEVONIAN	Devonian limestone	S-W England (Devon, Cornwall)	Non-hydraulic
SILURIAN	Silurian limestone	Shropshire (Wenlock Edge and Ludlow) and N-W Herefordshire, small outcrops in Black Country and Coniston area in Lake District	Non-hydraulic

Cement production makes use of the same deposits. However, of particular importance are those under the semi-hydraulic and hydraulic headings. Also important are separate clay deposits, particularly those of the Thames basin. In addition, deposits of septaria or cement stone (nodules of argillaceous limestone)

were the raw material of Roman cements. These are found in the Thames estuary, the Essex coast, the South coast (Isle of Wight, Hampshire and Dorset), the North Yorkshire coast (in the Alum shale deposits), Derbyshire, the West Midlands (Wolverhampton) and Somerset (Bridgewater area)

Gypsum is the base ingredient in the production of gypsum plaster. Deposits in England include those in Dorset (around Purbeck) and, more extensively, in the Keuper Marl belt of the Triassic period in Nottinghamshire (near Newark and Nottingham), Staffordshire (Fauld) and Derbyshire (Chellaston), the Permo-Triassic Beds in Cumbria (Whitehaven and vale of Eden); and the Purbeck Beds (Upper Jurassic) around Robertsbridge near Battle in Sussex (see Davey 1961, 94-5, Ure 1843). There are also deposits in Somerset and Avon (Ashbee 1995, 14) and in Teesside, where it is in the form of anhydrite and is mined for the chemical industry (Raistrick 1973, 60, Trinder 1992, 27, 749).

The fuel used in burning lime, cement and gypsum plaster has included wood, peat, coal, oil and gas. For coal distribution, see the MPP step 1 report for Coal (Gould & Cranstone 1992, Figs 1 & 2).

4 TECHNICAL OUTLINE

4.1 LIME WORKS

4.1.1 Introduction

The Lime Works class covers a range of sites from isolated field kilns through to large works within quarries and along transport routes. Broadly, raw materials must be prepared and brought to a kiln for burning. Both fuel and stone may have been transported by hand or cart on a roadway, or by tramway, canal or railway over varying distances. The main preparation of the stone is that it needs to be broken to an appropriate size. This may be done in the quarry or at the kiln depot, by hand or in a crushing mill.

Lime burning is by direct heating in a lime kiln (see below for types and process). The resultant quicklime may be stored on site ready for slaking or be transported in that form. Agricultural lump lime could be transported directly to where it was required and then slaked in the field. Lime for industrial use meant a distinct slaking process, possibly at the lime works (although quicklime was transported, as testified by occasional reports of it setting fire to the cart/barge/boat). Production of mortar normally also occurred on the site.

4.1.1 Lime Burning

In burning lime several problems had to be overcome for the operation to be a success (Searle 1935 267-9, 404-14). Although all types of limestone were potential sources of lime, in practice variations in the properties of the stone affect its usefulness. Essentially the stone had to be hard enough to resist being crushed under the weight of the full charge of a limekiln and of sufficient purity for the use to which the final product was going to be put. The size of individual stones was also important. If they were too large an unburned core might be left, and if too small overburning could vitrify the outer part of the stone, although these effects could also result from a failure to maintain heat to a sufficient temperature, length or evenness. Impurities also came from the fuel used to fire the kiln. For example where coal was mixed in alternate layers with the stone, this would leave a certain level of ash. As the lime was removed in solid lumps this contamination was minimal. Nevertheless a purer lime could be obtained by using a fumace kiln, where the fuel was separate. Peat, furze, wood, coke and coal were all used before the eighteenth century (and continued in use afterwards), but it was essentially the wider availability of coal from this period that allowed bigger, more efficient kilns to be built. More recently gas and oil have become important fuels.

The maintenance of a strong draught through the kiln was crucial on several counts. In the first place it supplied oxygen to fuel the fire and to allow the chemical change into lime to take place. In a continuous kiln where a 'burning' zone was maintained (either moving as in the Hoffman or stationary as in the draw kiln) this draught also cooled the burnt lime prior to its extraction and pre-heated the stone and fuel charge before it entered the burning zone. Equally essentially the draught drove off the carbon dioxide, which is heavier than air, released in the burning process. If carbon dioxide was allowed to build up, re-calcination of the lime could occur wasting both fuel and labour. It was therefore essential that the stone and fuel were packed in the kiln in such a way that air could pass through. Steam could also be used to drive off the carbon dioxide and

is the reason behind the occasional practice of wetting stones before putting them into the kiln. Some late designs of lime kiln injected steam into the kiln, although the practice was viewed as wasteful of heat and fuel (Searle 1935 409)

In broad terms then, the process of lime burning required a suitable limestone or chalk, hard enough to resist crushing in the kiln and of a purity that satisfied the intended use of the lime, combined with a suitable fuel which when heated to about 900-1200 °C for a sufficient length of time, converted all the stone to lime without causing vitrification. In addition a strong draught through the kiln had to be maintained to allow the fuel to combust, to provide oxygen for the conversion process and to remove carbon dioxide

4.1.2 Lime Kiln Types

Lime has been produced in Britain by 'burning' limestone or chalk in kilns of various designs. Several distinctive types of kiln are identifiable from documents and from the archaeological record. These types broadly represent an evolution in technology although there appears to be some uncertainty over the exact progress of that evolution (see Historical Outline). Variation in terminology is also apparent in the literature. In common with other MPP work, a simplified terminology has been adopted for the purposes of the study. Known variations are specified where relevant. Two particular properties of kilns are also highlighted here as being of significance in understanding their technological development. First there is the distinction between 'intermittent' kilns, where a kiln is loaded, the load burned and the lime removed, as opposed to 'continuous' kilns where a kiln is loaded and burning established and maintained, with periodical drawing of burnt lime and adding of raw materials (that is 'continuous' and 'intermittent' refer to the nature of the burn rather than the nature of the way lime is taken from the kiln). Secondly there is a distinction between kilns where the fuel and stone are kept separate and kilns where the two are mixed. The lime kiln types described here are summarised in the table below. These technological variations have been used as the basis for the typology used in the Components section and is intended as a model that which will be subject to modification in steps 2 and 3. It should be noted that there is often surprisingly little difference in form between kilns using some of these technologies. In particular, flare kilns and draw kilns can be very similar, especially if the pot and interior of the drawing arch are not exposed (as is often the case), and considerable difficulty is anticipated in reliably distinguishing all of these types in the field.

It is perhaps worth emphasising that for small kilns there is a possibility of misidentification of surviving remains. There may for example be confusion between lime kilns and ore-roasting (calcining) kilns, coke ovens, elling hearths (burning bracken for potash eg in Cumbria), chopwood kilns and white coal kilns (drying wood for ore-hearth lead smelting, best known in Derbys), and kelp ovens (seaweed for soda production).

Table Summary of Lime Kiln Types

Kiln type	sub type
Clamp	<ul style="list-style-type: none"> • Sow • Pye • Horseshoe
Flare	<ul style="list-style-type: none"> • similar to draw kiln • domed stoke hole • flue/stoke hole • domed tops
Draw	
Vertical mixed-feed	<ul style="list-style-type: none"> • 1-shaft • 2-shaft
Vertical furnace-fired	<ul style="list-style-type: none"> • wood-fired • coal-fired • oil-fired • gas-fired
Horizontal	<ul style="list-style-type: none"> • ring - eg Hoffman, De Wit • tunnel
Rotary or inclined	

4.1.3 Clamp Kilns

In this report, the term 'clamp kiln' is used to mean a kiln without permanent superstructure. Specifically this is an intermittent mixed-feed kiln formed as an excavated bowl or pit, within which was placed a base of kindling and a mound of alternating layers of limestone and fuel (coal or wood or other). The sides may have been built up slightly with earth and/or rough stone walling, and the load was covered with sods of earth. A flue was incorporated in the base of the mound and when ready the whole mass was set alight and left to burn itself out over a period of days. The kiln was then dismantled and the lime removed.

Two subtypes of this kiln type may be identified from contemporary accounts and from fieldwork, a small circular form (*Sow*) and a larger rectangular form (*Pye*).

Sow or 'Sod' kilns are described by several early writers (eg Rees 1819/20, Ure 1828) as being small and round. Examples broadly matching these descriptions have been excavated, including an example in Northumberland (Jobey 1968), an early nineteenth-century kiln in the Gower peninsula (Ward 1983), and a seventeenth-century kiln near Peterborough (Dakin 1968). Several Roman features interpreted as clamp kilns have also been excavated (Dix 1982).

Pye kilns were used in Derbyshire from at least the late eighteenth century and are known from contemporary accounts (Farey 1811-17) and surveyed examples (Leach 1995, Raistrick 1967 75-6). They were larger than *sow* kilns and rectangular in plan (in Derbyshire recorded examples are 4-19m long by 2-10m wide with a surviving depth of 0.5-1.8m). Again they incorporated flues in the base and were built up as alternating layers of fuel and stone, generally built into a bank, sometimes with a front of rough stone, covered with sods of earth and burnt through before dismantling and removal of the lime.

A Medieval treatise by Walter de Henley describes a kiln for producing agricultural lime as a 'ploughed ridge' seven yards wide with alternate layers of fuel and stone covered with sods and clay or marl and incorporating 'flues in all directions' (Williams 1982 117-18). Although the reference to a ridge is confusing this would appear to be describing a clamp kiln. The relatively small number of recorded examples and limited geographical distribution of both of these subtypes are probably due to their ephemeral nature and difficulty of identification. From their basic technological nature one might expect a wider use both geographically and chronologically.

Archaeological data and documentary evidence show that other shapes of kilns of an essentially 'clamp' nature (what might be termed 'developed clamp kilns') were also used for industrial production as well as local agricultural use. For example Ordnance Survey maps and British Geological Survey archive photographs show examples of 'horseshoe-shaped' kilns within large quarry complexes in the early twentieth century (see Stanier 1995). Further research into clamp kilns might well reveal a broader range of form and size.

4.1.4 Flare Kilns

In the published literature, this term is broadly applied to a permanent stone structure that was operated as an intermittent kiln with fuel and stone kept separate, and this is the definition adopted here. Terms used by other writers include 'flame', 'pot' and 'field' kiln (technical reports of various dates sometimes refer to furnace-fired kilns as a 'continuous flare' kiln, but this has been avoided as potentially confusing terminology). The form also varies - four distinct subtypes are defined for the purposes of this report.

Flare kiln similar to draw kiln - A draw kiln of the form described below could equally be operated as a flare kiln.

Flare kiln with domed stoke hole - Broadly this type of kiln would be set into a pre-excavated pit or dug into a hillside slope, was stone-built, oval in plan, square in section and incorporating a narrow ledge near the base of the kiln 'pot'. There would also be at least one flue perhaps running to a raking out pit. In preparation for firing, a loose stone dome would be built springing from the ledge (possibly over a wooden framework). Above the dome a top-loaded charge of limestone would be placed. The volume below it formed a stoke pit. When the fire was lit any wooden arch was burned away and the stones settled into a supporting dome. This kiln type was described by Cato in c 150 BC (Dix 1979). Post medieval and industrial era writers also describe this form of flare kiln, although with varying design. George Owen's 1603 description broadly fits Cato's description, although without reference to a ledge. Neve's 1726 'lime' entry describes a Sussex kiln that includes a dome-supporting ledge. Similarly, Searle (1935, 271-2) refers to a form of flare kiln with a pot as 'two truncated cones placed base on base' and considers a 'modern' arrangement where a dome of stone is built over a stoking area to support the stone to be burnt above.

Flare kiln with separate flue/stoke holes - Rees (1819/20) describes a 'flame' kiln from Wellingborough, Northants fuelled by furze/peat with a rectangular kiln block incorporating three arched flues underneath, in which fuel is placed and burned. Searle (1935, 271-2) also describes this form of flare kiln.

Bottle-shaped or domed flare kiln - Stanier (1995, 30-31) reproduces several early twentieth-century British Geological Survey photographs showing banks of flare kilns with domed tops in Surrey chalk- and lime-works. Williams (1989, 23)

reproduces an 1823 drawing of bottle kilns at Dorking, Surrey), and Bowie (1980) describes a bank of kilns with bottle-shaped tops at Twyford Waterworks dating from 1905. Other writers base this term on the shape of the pot profile.

Broadly, excavated and surveyed examples suggest a use of flare kilns in Britain from the Roman period on. For the Roman period, there is no evidence to suggest that kiln types other than the flare and clamp were used in manufacturing lime. Many of the excavated Medieval kilns may also have operated as flare kilns, although there is evidence to suggest some at least were operated as draw kilns. Distinguishing between these two types is in fact not necessarily straightforward, as pointed out by Murphy and Sambrook (1994) in their survey of South East Dyfed Minerals. Nevertheless, many of the eighteenth- and nineteenth-century 'field' kilns, built to produce agricultural lime and scattered over much of the British landscape, are thought to be of this type, although published accounts rarely give a clear picture of the interior form of these kilns (Crossley 1990, 210).

4.1.5 Draw Kiln

The draw kiln is generally taken to be a continuous, mixed-feed kiln (although a kiln built and charged as a 'draw kiln' could be operated on an intermittent basis). In this report only stone or brick built kilns are referred to as draw kilns, to distinguish them from steel-clad versions of the vertical shaft kilns that operated in the same way. Its advantages over the flare kiln were higher output, greater efficiency and longer life. Rees (1819/20) gives a detailed account of how a draw kiln was constructed and operated from a period when their use for industrial-scale lime burning was supreme. Williams (1989, 15-23) has summarised the kiln components, from documentary and field evidence.

The main superstructure of a draw kiln is the *kiln block*, which may be of stone or brick construction, square or circular in plan, and usually built against a natural or artificial bank or cliff for charging access. This block provided structural strength and insulation for one of more *pots* or bowls contained within it. Pots generally had a profile as an inverted cone or truncated, inverted egg and were usually lined with hard stone or firebrick. Sometimes *inspection doors* were incorporated midway up the kiln pot to allow checking of the firing process. At the base of the kiln pot, one or more apertures (*draw-holes* or kiln 'eyes') allowed air into the kiln and allowed lime to be drawn out (using tools such as a drag and shovel). These openings were accessed through *draw-hole recesses* (with exterior arch or supporting lintel) of which there could be from 1-4 for each pot, with connecting access tunnels where required. They were generally large enough to allow a man to stand, and could be very large to allow cart or rail-tub access.

One of several mechanisms were used to allow extraction of the lime through the kiln eyes (see Rees 1819/20). These included a raised wedge (a 'horse') to force lime into the apertures, possibly via chutes, an iron bar or bars fixed into the base, or an adjustable iron grate through which burnt cobs of lime fell (possibly onto a lower ash grate, see Clarke 1987, 19). Lifting mechanisms were sometimes located adjacent to the draw-hole, and a *poking hole* was sometimes located immediately above.

There was great variety of form to draw holes, probably to a certain extent according to local building tradition. However Moore-Colyer and Hughes have pointed out the importance of these openings in controlling the draught through the kiln. For example the Upper Swansea canalside kilns, where high grade anthracite was available and would burn well, have draw holes which narrow towards the kiln exterior to restrict draught. In comparison, kilns of the

Cardiganshire and Pembrokeshire coast, where low grade 'culm' needed a strong draught to achieve required temperatures, have draw holes that splay outwards (and could incorporate baffles to deal with excessive winds, see Hughes 1981, 101-2, Moore-Colyer 1992, 24-5)

The number and arrangement of draw holes also varies widely and includes single, twin (side-by-side, serving one or more eyes, or on opposite sides), three and four holes. Again this may reflect control of draught as well as drawing capacity. For example in clmd kilns many draw holes might be included to allow alternating use according to prevailing wind direction during firing (Hughes 1988, 68). Where more than one pot is built into a kiln block, the same variation occurs and may incorporate connecting tunnels (see for example Skinner 1975, 227).

A draw kiln was operated by charging it with alternating layers of fuel and stone, lighting at the base of the kiln, and establishing a burning zone in the middle of the kiln bowl. Hence burnt lime could be drawn off at the base and more material added at the top as required.

The origin of this important kiln type is uncertain. Draw kilns are well documented from the eighteenth century (for example, Robert Maxwell's 1757 *The Practical Husbandman* includes instructions on how to build a draw kiln, see Skinner 1975) and surviving structures can be dated from that period, so that it has frequently been stated or implied that the draw kiln originated in the mid-eighteenth century as a response to increased demand (for example Williams 1989, 15). However, whilst there certainly was a major uptake of this technology at this time, Ellison et al (1993) have suggested that lime kilns may have been operated on the draw principle in the Medieval period (from the fourteenth century or earlier). This is based on field evidence of two forms: first that several kilns have been excavated with two, three or four 'draw holes' and, it is argued, this implies very careful control of draught, and secondly an estimate for the final firing period of 51 days for one of the kilns excavated at the Swirle, Newcastle (based on an evaluation of the remagnetisation of sand surrounding the kiln). Although it could be argued that a flare kiln might employ several draw holes simply to take advantage of varying wind directions, the long firing time for the Newcastle kiln (even assuming a large degree of error in the estimate) would seem to imply a mning kiln.

Many variations and improvements on the basic design of the draw kiln were put forward in the late eighteenth and early nineteenth centuries, some effectively precursors of shaft kilns, for example designs by Rumford in 1800, Jameson in 1800, Dirom in 1801 and Monieth in 1837 (Rees 1819/20, Skinner 1975 226). Nevertheless the basic design of the draw kiln as described above was very successful and continued to be the major lime kiln design for large scale production into the mid-nineteenth century.

4.1.6 Nineteenth and Twentieth Century Kilns

There is no standard work that plots developments beyond the draw kiln, although there are many nineteenth- and twentieth-century contemporary technical works which closely detail the operation of the industry through this period (eg Pasley 1838, Ure 1843, Gilmore 1870, Reid 1877, Doncaster 1916, Eckel 1928, Searle 1935, Marks 1971). Searle describes three main types of continuous kiln in use for lime burning in the 1930s: 'vertical shaft kilns', 'horizontal kilns' and 'rotating kilns' (Searle 1935 273). All were adapted for lime burning after being successfully employed for cement manufacture. Shaft kilns appear to have been a development of the draw kiln, originating in Germany. The Hoffman kiln was the

major type of the horizontal family and was originally developed for brick-making, again in Germany. The rotating kiln was patented in England in the 1850s in relation to the alkali industry (Francis 1977, 231) and was also used in the arsenic industry (Cranstone 1993, 5).

4.1.7 Vertical Mixed-feed Kilns *7 of 5*

A wide variety of vertical mixed-feed kilns are described by Searle, Eckel and others. Common features are as follows. Earlier examples were of brick or stone construction, but most later kilns had casings of sheet steel (from 1914 the cost of masonry increased dramatically and it became much cheaper to build kilns of steel). The kilns were circular or oval in plan and draught was created by the tallness of the kiln or by a short kiln surmounted by a chimney. The vertical profile of the kiln shaft varied. A shaft with straight sides was cheap to build, a slight taper to the top reduced sticking, tapering to the bottom was sometimes used on the basis that burnt lime occupied a smaller volume than the equivalent stone. In all cases the burning zone was often restricted. The lowest 8' of the kiln was generally an inverted cone (with 60° - 70° angle). The kiln top was open for loading stone and fuel. At the base was one or more openings to draw lime, together with inspection holes to watch burning, and poke holes to dislodge 'stuck' material.

Designs fall into two main groups: two-shaft kilns which were good for soft stone; and single shaft kilns. In both cases stone was fed in at the top. Fuel could also be fed from the top, but more often was passed, through small angled shafts, direct to the burning zone.

An example of the two-shaft type is the Dietzsch kiln, first used in cement manufacture in 1884 and later adapted for lime burning (Eckel 1928, 414-5). An example is still standing on a site in Betchworth, Surrey (Cossons 1987 158; Sowen pers comm). The two shafts were set back to back, each with 'a cooling chamber at the base, a fire chamber or "creuset", and a pre-heating chamber' - stone was loaded from the top, and fuel fed directly into the fire chamber.

There appear to have been numerous designs for kilns based around a single shaft. The Aalborg or Schofer kiln was introduced following the success of the Dietzsch kiln (Eckel 1928, 414, Searle 1935, 296). Other makes named by Searle include the Brockham (mainly for chalk, patented by Arthur Bishop at Brockham Surrey in 1889 - see Williams 1989, 24), Smidth, Spencer, Ryan, Hauenschild, Comet, Candlot, Campbell, Sterger, Duchez, Polysius, and Chaudiere kilns (with a central tube to remove excess cooling air below the burning zone). According to Searle the Aalborg, Smidth (a variation on the Aalborg design) and Spencer kilns were 'well known and widely used' in 1935 (ibid 285).

4.1.8 Vertical furnace-fired Kilns

This design is essentially like the vertical mixed-feed kiln but with several furnaces located outside the main shaft at the level of the burning zone. Again there is a variety of designs that were fired by wood, coal, oil, or gas.

The origins of this kiln type appear to be the c1800 design of Count Rumford - a brick built kiln with a narrow tapering shaft and fire-places opening into the burning zone on one side (see Rees 1819-20). Ure (1843, 771-4) describes what is effectively a furnace lime kiln in use in Rudersdorf, near Berlin. Built of stone and brick, limestone was fed into the central 'shaft' from the open top. Burning

was commenced by lighting a wood fire in the draw holes and heating an initial small load of stone. Once going, the shaft was fully loaded with stone, and burning then maintained (using turf or coal) via a series of furnaces located just below the burning zone. Lime was drawn off every 12 hours through separate draw holes. Gillmore (1870 132-5) describes a similar design by one C D Page of Rochester, NY and in use at that time in much of New York state, apparently stone or brick built, using wood or coal, and used for both lime and cement production.

Searle (1935) describes a large number of steel clad variants to this design. He claims those with wood-fired furnaces as being of the earliest type, generally employing four large furnaces in opposed pairs about 12' off the ground. Coal-, oil- and gas-fired versions were similar with two or more furnaces. Named types of coal-fired kilns include Broomel, Keystone, Arnold (USA design), Doherty-Eldred and Priest kilns. Oil-fired examples included Gillette kilns. Gas-fired examples included Schatolla, Fahnehjelm, Priest, Dowson & Mason, Ashmore Benson Peas & Co, Crosland, Mount, Paretti & Funck, Gilbert & Whitaker, Smith & Co, Duchez, Lengersdorff, Isserlin, Meiser & Meiser and others. Marks (1971, 91-2) describes a 'modern' vertical gas-fired kiln operating in essentially the same way.

4.1.9 Horizontal Ring Kilns

The Hoffman kiln was the first horizontal ring kiln. In this kiln type, stone was stacked within an annular or ring-shaped tunnel. Coal was fed into the stone stacks from the top of the kiln, through a multitude of feeder holes, and draught was created via the tunnel entrances and a series of flues feeding from the tunnel to a central flue and chimney. These features were used to control the kiln such that a burning zone was established and advanced continuously around the tunnel, with new stone manually loaded ahead of the burn and burnt lime unloaded behind it (see Searle 1935, 368, Tmeman 1992).

The Hoffman kiln was developed for brick making, and Hoffman's design was apparently inspired by the Siemens regenerative furnace, patented in 1856 (Hammond 1977 181). In 1857 the first Hoffman kiln was operated industrially and in 1858 Friedrich Hoffman took out the patent. Humphrey Chamberlain obtained the patent in Britain and one of the first Hoffmans to be built in England was in 1868 at the Nottingham Patent Brick Company's Mapperley Rice works (demolished in 1971). In the latter half of the nineteenth century a great many patented improvements were made to the design of the Hoffman kiln. It was presumably in this atmosphere of experimentation that its usefulness for lime burning was recognised. Hoffman himself in 1870, patented a rectangular version that became the more usual design. Searle describes the length of tunnel required in a Hoffman as being not less than 168 ft and preferably 240 ft (Searle 1935, 369). The Scheduled Hoffman kiln at Langcliffe, near Settle, has a tunnel just under 800 ft long.

Many variations to the basic Hoffman design were devised. These include the forms given below. Examples in England include the 'De Wit' kiln at Amberley Chalk Pits which was built with a series of partitioned chambers, with fuel and draught fed from above and a series of flues running under and around the kiln to a chimney at one end (that is a 'chambered' Hoffman design). A horizontal ring kiln at Llanyrnnech is another variation patented by George Warren in 1894. Other patents were taken out by William Sercombe of Dorset in 1891 and 1894 and James Osnan of Devon in 1895 (kilns of the latter type were built at Fulwell, Cleveland and Rochester, Kent) (Tim Smith pers comm).

Hoffman kiln variations specified by Searle (1935, 371)

- Belgian Kilns - fuel and stone kept separate by burning fuel in troughs or grates across the tunnel
- Kiln with drop arches - where these project below the tunnel arch to prevent hot gases flowing over the top of the load (ie forcing it through the load)
- Chambered kilns - using partitions and sub-floor flues to cause an up and down movement of the hot gases (eg De Wit kilns)
- Buhner's zig-zag design - to increase tunnel length in a square plan, giving fast fire, low fuel consumption and efficient heat use
- Gas-fired versions - rare as use more fuel than coal
- Archless kilns - using a double layer of brick and ash in place of a tunnel arch, allowing the use of a crane for loading and unloading (but creating a problem of greater heat loss)
- Bock's sunken kiln - tunnel constructed by excavation (tends to be affected by moisture) Used in continental Europe

4.1.10 Horizontal Tunnel Kilns

In this form of kiln the material to be fired was carried on tracks or plates through a stationary fire contained in a circular or straight tunnel (Searle 1935 368). A tunnel kiln was first built for ceramic production in 1839 in Denmark although it appears not to have been patented until 1877 (Singer 1958 667). In 1935, Searle describes their use for lime as experimental and unlikely to be used extensively. Reid (1877, 255-6) describes the tunnel kiln as devised by M Bock, based on a design of the 1850s by M P Bome of Paris.

4.1.11 Horizontal Rotary or Inclined Kilns

This consists of a long steel cylinder (20-260' long, 2-12' diameter), lined with firebricks and mounted on trunnions at a slight angle to the horizontal. In operation it is rotated at 5-6 revolutions per minute with stone fed in at the upper end, and gas or powdered coal blown in at the lower. The latter heats the stone and exits to a chimney. The stone is broken up as it is rotated and burned, and the lime emerges at the lower end into a second, cooling cylinder.

A rotary kiln was patented in 1853 for use in the alkali industry and was used from the 1870s (devised by Hocking and Ockland) in the arsenic industry (see Francis 1977, 231, Cranstone 1993, 5, 7, 14, 32). An adaptation for cement production was patented in 1877 by T R Crampton and this was subsequently improved by Ransome in 1885 and Stokes in 1888 (see Davey 1961, 108, Francis 1977, 231). Its use for lime burning dates from 1885 (in Britain, 1906 in USA), its first commercial success in Britain being at the Beckton works of the 'Gas, Light and Coke Co' from 1893. Subsequently it was widely employed (Searle 1935, 375).

4.1.12 Kiln Loading

A variety of means of loading kilns have been used. Broadly, early kilns (and many later), were built into a bank allowing material to be barrowed or carted to the top. Otherwise inclines were used with lifting mechanisms provided by horse-gin, water-power or steam-power. Other mechanisms used have included ropeways, conveyors and cranes (see Williams 1989, 27-31).

4.1.13 Lime Slaking

In the nineteenth and twentieth centuries, a range of lime products have been developed and marketed (see Searle 1935, 531-2). Broadly these involve the grinding and slaking of burned lime by various means. Such a range is not documented for earlier periods when, as already described, the use of lime was dominated by agriculture and the building trade. Until the twentieth century, slaking was carried out by hand. According to Searle (1935, 488-93), the essence of the process is the addition of water to burned lime in an appropriate amount to produce either a dry powder (dry slaking) or a paste (wet slaking). Both methods may also have involved grinding, sorting and sieving of the lime prior to slaking, to control purity. The slaking process seems to have commonly been done at the site of use, but it was also carried out at the limeworks, and hence is included within the scope of the report.

In the dry slaking process Searle describes two methods. In the first, lime was spread out on the ground and sprinkled with water, before being mixed into a heap and left for a day. In the second, lumps of lime were placed in a basket, immersed briefly in water, and then placed in heaps or silos to complete the process. In the wet process lime was put, with 3 to 4 times its weight of water into a trough or tub and then stirred with a wooden rake. When slaking was complete, the mixture was run off into another pit.

Broadly speaking, agricultural lime was often taken to the field in lump form and allowed to 'air slake' (effectively a form of dry slaking). Building lime was prepared using the wet process in a slaking pit. Lump lime could not be stored for long because of the tendency to air slake. Slaked lime keeps longer, and could be transported in barrels or sacks.

These processes appear to have been understood and applied in the Roman period. Vitruvius describes a test of the thoroughness of the slaking process by chopping at the lime in its pit, and a scene on Trajan's column has been interpreted as depicting this operation (Davey 1961, pl 14). Vitruvius also refers to slaking as being best done well before the slaked lime was required, a view repeated by Pliny, who recommended carrying out slaking three years before the lime was required (Ling 1976). Furthermore, a feature interpreted as a Roman slaking trough has been recovered at Chelmsford (Davey 1961, pl 46), and a circular pit interpreted as for slaking has been recovered at St Albans (O'Neil 1945, 48), although an alternative interpretation is that they could have been for mixing mortar (see also Blake 1968, 314-15, Williams et al 1979, 118).

Mechanical slaking is apparently a twentieth-century practice, involving large hydrating plants. Lime is passed through a crusher to storage bins and from there to a hydrator, where water is mixed with the lime. From here the material may be passed through a grid or screen (to remove impurities), passed by conveyor to silos (for storage until slaking is complete), passed by conveyor to a disintegrator (to break down any lumps), and finally to a lime dresser (to remove any remaining impurities) (Searle 1935, 494-500).

4.2 CEMENT WORKS

4.2.1 Introduction

The essential materials to produce cement are calcium carbonate (limestone, chalk, calcareous mud) and clayey materials (clay, clay shale, clay mud). Natural cements were produced from calcareous and argillaceous materials that occurred together in the right proportions. Specifically 'Roman' cements were produced from nodules of argillaceous limestone called septaria or 'cement stone', at the turn of the eighteenth and nineteenth centuries. Artificial cements were made by mixing stone and clayey material in empirically determined proportions. Portland cement is the most famous form of artificial cement, where the appropriate mix is burned to the point of vitrification. The resulting clinker is ground to a powder or cement 'flour' (Singer et al 1958, 4 447-50).

In manufacturing 'Roman' cements, the following broad process appears to have been used (Francis 1977, 36). The stone was first broken to an appropriate size (about 2" across), by hand or with a mechanical crusher. It was then placed in the kiln and calcined, the resulting burnt stone ground in a crushing mill (which may have been driven by horse-gin, water-power, tide-power, wind-power or steam). The powder may then have been sifted prior to packing in barrels or casks.

Several processes were developed for the manufacture of artificial cements (Francis 1977, 131, 201). For softer materials, such as chalk, a 'wet process' was originally devised. For harder stone, initially a 'double kiln process' was used, but this was replaced by the 'dry process' in the mid nineteenth century.

In the wet process, stone and clay were placed into a washmill and broken into a slurry that was turned into reservoirs or 'backs' (or settling ponds). Over several weeks solid matter sank to the bottom, and water was drained off. The resulting deposit was then dug out in lumps and these were placed on drying floors, or flats (covered area with iron plates or tiles over ovens). Iron scuttles were used to convey the dried cement mix to kilns where it was burnt to form clinker. The clinker was then conveyed to a clinker grinding mill. The resulting powder was then placed in barrels ready for transport. Later storage was in silos and the cement was bagged for transport.

In the double kiln process, limestone was broken and burned in a lime kiln. The lime was then ground and mixed with shale/clay and water and this mixture was dried and burnt to form the clinker. In the dry process, shale or clay was dried on heated floors before being mixed with the stone. This mixture was then crushed by rollers or breakers and ground by millstones to produce a 'raw meal'. Water was added to the meal to make bricks which were dried and then burnt in a kiln.

In the late nineteenth century it was found that granulated blast furnace slag had hydraulic properties and could be added to Portland cement. The slag was granulated by quenching it rapidly in water. This material was then added to the cement clinker and the two ground together. Typical mixes would have 65-70% slag (Davey 1961, 110). High Alumina cement is produced by melting a mixture of limestone and bauxite. This cement hardens very rapidly and is useful in emergency work. It was first produced in France in 1908 (Davey 1961, 110).

4.2.2 Cement Kilns

The range of kilns used for cement production were essentially similar to those used for lime burning, excluding clamp kilns. A 'Dome' or 'bottle' version of the flare kiln was widely used in the early period for both Roman and Portland cements. Draw kilns were also used for both, with some modifications to suit the material, specifically a solid dome in the base of the kiln shaft to push clinker into draw holes, and possibly separate fire-holes above (see Pasley 1838, 282). Fumace kilns were also used from the mid nineteenth century, by now mainly for Portland cement (Gillmore 1870, 127). Numerous improvements and kiln designs were devised from the mid nineteenth century on. For example R O White took out a patent for a storage chamber for the slurry to be built into the upper part of a cement kiln. Within it the slurry was placed as moulded bricks, each with fuel incorporated, ready for the burning process (Francis 1977, 138). I C Johnson patented a kiln in 1872 which incorporated a slightly inclined trough, set over a series of arches between a kiln and a chimney. Cement slurry was carried down this trough and was dried by the kiln's exhaust. This design was apparently popular and spawned several variants (Francis 1977, 153, 162, 171, 225, Eckel 1928, 411-12). Hoffman kilns were also used for cement in Britain from the 1870s (although they were more widely used as such in Germany). Vertical shaft kilns were also used from the late nineteenth century, mainly for the dry process - Dietzsch and Schneider kilns being popular in Britain (Francis 1877, 236). A recorded shaft kiln at Beddingham, West Sussex, would appear to be a late, experimental example of this type where powdered raw materials fell under gravity and were heated by rising hot gases injected from fumaces located below a burning zone (Martin 1992 & 1994). Rotary kilns followed and, after a period of effectively competing with other kiln technologies in the first half of the twentieth century, became universally used for modern large-scale cement production (Marks 1971, 99).

4.3 GYPSUM PLASTER WORKS

In the production of gypsum plaster, raw material (in the form of rock gypsum or alabaster scrap) was transported to plaster mills where it was crushed and ground to powder before being placed in the kiln. Diderot (c1760) illustrates a Gypsum kiln in the form of a walled structure incorporating flues, over which are placed a large number of pans or kettles containing the ground gypsum. Heating the powder to about 150°C drives off three quarters of the water content leaving Plaster of Paris in powder form. Retarders may be added to this to produce general purpose building plasters. In modern works the powder is then bagged or used in the manufacture of plasterboard (see GPDA 1974 and 1977). Important properties of gypsum plaster in comparison with lime based plasters are that it sets faster and does so without shrinkage, in fact by expanding slightly.

4.4 PROCESS RESIDUES

Some waste may occur from the various stages in the production of lime, cement and gypsum, but the most significant is from the kiln. Although this material is probably limited as a source of technical information it may be important, in conjunction with the recorded form of a kiln, for example in identifying a kiln structure as having been for lime burning and it may help in distinguishing a flare from a draw kiln.

Specific waste from lime kilns would include waste raw materials from preparation areas. This material may be useful in identifying the fuel used in the

kiln, the stone type used and its geological source, and the size of pieces that were put into the kiln. Kiln waste in the form of fuel ash and lime ash may be scattered close by or well away from the kiln. This material may contain unburnt stone and overburnt stone and, in theory, could give an indication of the efficiency of the burning process, although this may be difficult in practice. Rejected or unsuccessfully-fired batches of material are occasionally dumped at the kiln site (R. White, pers. comm.), and may be a source of technological information. A remnant of the last kiln load may survive within the pot, and this material could also be useful in contributing information as described above. Finally, remanent geomagnetism retained by the kiln fabric has been used for dating purposes on lime kilns, and the remagnetisation profile of nearby material has been used to estimate the length of firing of a kiln's last burn.

5 HISTORICAL OUTLINE

5.1 Lime

Although there is currently no evidence for pre-Roman lime burning in Britain, it is clear that the Romans made extensive use of lime for building work and documented the process of lime burning. Cato, writing in c150 BC, gives a description of how to construct and operate a flare kiln. From the first century BC, a concrete mix based on lime and crushed pot and tile formed a major Roman building material. Hence Vitruvius describes how to mix pozzolana with sand and lime to produce a fire-resistant mortar that set under water (Granger 1931, 97). Evidence for the use of lime in Britain is clear from the numerous building remains, above and below ground, and from the excavated evidence of limekilns. Excavated examples of flare kilns have been reported at Helpston, near Peterborough (Challands 1976), Wellingborough, Northants (Foster et al 1977), Cardington, Bedford (White 1977), Hadrian's Wall (near Housesteads, see Dix 1982) and Weekley, Northants (Jackson et al 1973). The kiln at Weekley matches Cato's description and Williams (1989, 4, 11) claims a broad match of excavated examples with Cato's description (although Toft 1975, 76 cites the same reference to claim the opposite). Clamp kilns have been excavated at Richborough and it is possible that features excavated by Pitt-Rivers at Cranbourne Chase were clamp kilns (Dix 1982).

There is no direct evidence of Anglo-Saxon lime kilns, but the use of lime mortar is again clear from surviving Saxon structures and from excavated mortar mixers at Northampton and Jarrow (see Williams et al 1979, 21 & Williams 1985, 118).

In the Medieval period, there are numerous documentary references to the use of lime mortar, from the thirteenth century on. These indicate the use of wood and coal for fuel. For example, between the thirteenth and seventeenth centuries, building accounts include many purchases of sea or pit coal for lime burning and in the thirteenth and fourteenth centuries there were complaints about the use of coal in London (Salzman 1923, 4, 6, 100-101).

Kilns were built for specific construction projects such as castles, town works and monasteries (Salzman 1923, 100-101, Raistrick 1967 69). Salzman also suggests that some kilns were built and run as commercial kilns, citing a sixteenth-century account of 8 large kilns (probably in Calais). In relation to agriculture, Walter de Henley, writing in the thirteenth century, describes the construction and operation of a clamp kiln and advises on the use of lime on arable and grass land (Williams 1982, 117-18, Davis 1815, 145). Excavations of over 50 kilns of the period have recently been reviewed by Ellison et al (1993) in relation to the excavation of a bank of kilns at the Swirle, Newcastle-upon-Tyne. This evidence confirms the picture of kilns constructed for specific building works and reveals a variety of kiln form (see Technical Outline) with tentative evidence for the emergence of draw kiln technology.

In the Post Medieval period, the sixteenth and seventeenth-centuries saw an expansion of the lime industry in relation to agricultural improvements. Contemporary writers such as Fitzherbert (1547), Merrick (1578), Norden (1607), Gabriel Platten in 1639 and Gervase Markham in 1639 document this expansion. The practice of erecting kilns for building work also continued, and pozzolanic materials appear to have been used again, specifically imports of the volcanic earth 'trass' from Holland (Davey 1961, 103). One writer, G. Owen (1603), describes a kiln in common use in the Gower peninsula of south-west Wales, with

a tapering bowl, two flues at its base and the limestone kept separate from the fuel - essentially a flare kiln (Raistrick 1967, 71, Williams 1982, 115). There is also some excavation evidence for both flare kilns (for example at Clementhorpe Nunnery, York see *Post-Medieval Archaeology* 11, 99-100.) and clamp kilns (at Peterborough, see Dakin 1968).

The eighteenth century saw a large increase in demand for lime due to urban development, agricultural improvements and industrial growth. Neither the primitive sod-kiln nor the flare kiln could provide the quantities required and it was in this century that large numbers of the continuously worked, massively-built 'draw kilns' began to appear. As already discussed, this technology may have emerged during the Medieval period, but the earliest contemporary accounts appear in the eighteenth century. Hence by 1757 Robert Maxwell, secretary of the Edinburgh Society of Improvers, was able to publish an account of the best means to erect a draw kiln, based on a kiln already working in Angus (erected by Robert Scot of Duninold and still surviving in 1975, see Skinner 1975, 226). By the end of the eighteenth century, draw kilns in commercial operations, often in relation to canals such as the Montgomeryshire built from 1794 (see Hughes 1988), were widespread throughout Britain and remained a major form of industrial kiln to the end of the nineteenth century.

The nineteenth to early twentieth century was a period of increasing industrialisation and large scale production, as well as a time when the lime industry was under strong economic and technological influence from the cement industry. Technologically, a variety of advanced kiln designs were introduced, generally as a cross-over from other industries. These included the Hoffman kiln, vertical shaft kilns, and rotary kilns (see Technical Outline).

5.2 Cement

The latter half of the eighteenth century saw a growing need for dependable hydraulic mortars. In the 1750s, in preparation for construction of the third Eddystone lighthouse, John Smeaton investigated the use of Italian pozzolana and Dutch trass in creating hydraulic mortars. He also experimented with different limes and established that it was specifically the mixing of limestone and clay materials that produced a lime with hydraulic properties. In the mass of experimentation that followed, a series of natural cements and then artificial cements were produced (Ashurst 1988, 9, Davey 1961, 103-10, Francis 1977, and Singer et al 1958, 4 447-50).

In 1796 James Parker of Northfleet, Kent patented what he called 'Roman' cement, made from septaria taken from the clay beds of the Thames estuary (initially the foreshore, later dredged from the river) and later from the Essex coast and further afield. Other similar products included Medina cement, using septaria from the River Medin in the Isle of Wight and other sources along the south coast, various named brands from the North Yorkshire coast around Whitby (eg Whitby, Mulgrave and Atkinsons cement), and products from works in Hull, Essex, Derbyshire, Wolverhampton and Somerset (see Regionality). Other cements were produced in Scotland, France and the USA.

Artificial cements sprang from the understanding gained by Smeaton, L J Vicat in France, Pasley and others (see Pasley 1838). In 1811 James Frost patented an hydraulic cement made by mixing limestone and clay in a wet mill. Frost eventually established that a higher temperature was required to drive off the CO₂ and took out a second patent in 1822 specifying this. His latter product was

widely used and in 1825 he built a cement works at Swanscombe, Kent (taken over in 1833 by J B White)

In 1824 Joseph Aspdin of Leeds took out his patent for 'Portland' cement (the name was a public relations exercise, begging comparison with Portland stone) In this form of artificial cement, the calcining temperature was high enough to cause vitrification of the raw materials, producing a clinker that was then ground to a powder Aspdin's first works was at Wakefield (1825) This was continued by his son William who, with various partners, also established works at Northfleet on the Thames (1843) and in Gateshead (1851)

I C Johnson established the first reliable production of Portland cement in 1845 at Swanscombe in Kent, and may have been the first to properly understand the nature of the process Johnson also set up works at Gateshead By 1850 the process of high temperature calcination to produce Portland cement was generally understood and practiced, this cement becoming the dominant product In the late nineteenth century a notable further development was the discovery that granulated blast furnace slag had hydraulic properties and could be mixed with Portland cement

The cement industry was initially focused on the Thames estuary This area remained of prime importance, but cement works were also established in other areas (see Regionality) The north-east ports were particularly important in the late nineteenth century In all these areas, increased competition from the 1870s was part of the reason for a tendency to build fewer but much larger works (Trinder 1982,240-3)

In terms of kiln technology early cement works (for Roman and Portland cements) used 'bottle' or 'dome' kilns, operated both as flare and as draw kilns Many patented improvements and kiln designs were made including Johnson's kiln, patented in 1872 Hoffman kilns were also used in the UK from the 1870s, and Vertical shaft kilns and Rotary kilns from the late nineteenth century (see Technical Outline)

5.3 Concrete

Roman use of concrete, based on a pozzolanic lime mortar using crushed pot and tile, is well documented This technology was subsequently lost and only rediscovered in the eighteenth century (see Francis 1977, 55), when it was boosted by the production of consistent cements For example, George Semple used 'roach' lime and gravel for his bridge over the river Liffey in Dublin, George Dance, John Soane and Sir Robert Smirke used lime-concrete foundations in various construction projects, Telford used concrete based on Parker's Roman cement in the Chirk viaduct (1796-1801), and Brunel used it in the Thames tunnel in 1825 Portland cement concrete was used extensively in the Victoria Docks, London in 1850-5 and in the construction of London's main drainage system in 1858-75 (the first really large-scale use) by Sir Joseph Bazalgette The first concrete road in England was built in 1865 (Singer et al 1958, 4 449, 539)

5.4 Gypsum

Gypsum plaster is known to have been used by the Egyptians and the technology was also known to the Romans, for example both Vitruvius and Pliny refer to the use of gypsum (see Ling 1976, 209) In Britain, at York and Malton, Roman coffins have been found which contain gypsum, although this could be explained

as the result of quicklime being chemically altered by sulphate-bearing waters (Davey 1961, 94)

The first clear documented use of Gypsum plaster in Britain dates to the mid thirteenth century, when it was imported from France. By the late thirteenth century gypsum for plaster was being mined at Nore Down, Purbeck. Other gypsum deposits were also worked for plaster at Knaresborough in Yorkshire and in the Trent valley. Waste from alabaster works was probably also used to make plaster, alabaster being mined at this time at Tetterhall, Turbury and Hanbury (Fauld mine) in Staffs. Chellaston, SE of Derby (which supplied Nottingham's famous alabaster carving industry), the Trent valley, Humberstone, east of Leicester, and in the Dorset/Somerset area (see Ashurst 1988, 27-9, Clifton-Taylor 1972, 190, 352, Firman 1964)

The working out of deposits in Chellaston in the sixteenth century led to the further development of the industry in Nottinghamshire. In the nineteenth century the focus of Nottinghamshire mining was around Gotham, south of Nottingham, where there were a series of water-powered plaster mills and kilns, slight remains of which survived in the 1960s (see Smith 1965, 143-4). In the Nottingham area, in the eighteenth and nineteenth centuries, the upper floors of many vernacular houses were formed by laying gypsum plaster on reeds over joists (Rees 1819/20, Plaster entry; Singer et al 1958, 450). By the twentieth century Nottinghamshire produced half the national total of gypsum.

From c1800, gypsum plaster was used for internal walls and ceilings in England, but to the twentieth century gypsum was relatively expensive, and this use was therefore restricted. Nevertheless, the nineteenth century saw great expansion in the industry and plaster works became large-scale, an example being the 'SubWealden Gypsum Company' of Robertsbridge, Sussex (see illustration). In the twentieth century, production of gypsum plaster increased dramatically, the biggest producers being in Nottinghamshire, Sussex and Cumbria. This reflected changes in the building industry. Specifically, in the 1920s the use of gypsum plaster for interior wall covering largely replaced the use of lime plaster. At the same time plasterboard became common: this was originally patented in 1890 in the USA, and introduced into England in 1917 (see Firman 1964, 200, GPDA 1974 and 1977).

A range of gypsum plasters have been manufactured during its history of usage. Three notable mixes marketed in the nineteenth century, and named 'cements' presumably to compete with Portland cement, were as below. These cements were subsequently manufactured and sold by various Portland cement firms (Ashurst 1988, 33, Francis 1977, 74, 130, 54).

Martin's Cement - patented by R F Martin in 1834 and made by mixing gypsum with pearl ash and sulphuric acid

Keene's Cement - patented by R Keene in 1838, plaster of Paris mixed with alum. or aluminium sulphate, and warm water, which is then dried and recalcified at 400-500 C and ground to powder

Parian Cement - patented by J Keating in 1846, plaster of Paris was mixed with borax and warm water. This was then dried, recalcified, ground to a powder and mixed with sand and water. It was popular throughout the nineteenth century.

6. REGIONALITY

6.1 Lime

The early date of lime production has ensured regional variety of kiln form, although the technology is essentially the same. The location of sites has been governed by location of raw materials, location of markets and available transport. Published regional studies of the lime industry exist but at present are too scattered geographically and divergent in approach for regions to be consistently defined by the real vernacular variation. This section is therefore structured largely by modern geographical regions and is intended to give a broad idea of the regional variation.

In North-West England, lime has been produced largely from Carboniferous limestone. In Cumbria there is a scatter of field kilns for local use, in Furness, and the east and north west of the county. On the north-west coast, commercial lime was transported on coastal vessels. On the Cumbria/Lancashire border, early kilns supplied local needs and building work in Kendal and Lancaster, and, after construction of the Lancaster-Kendal canal in 1819, this commercial industry grew. The second main area of Lancashire's lime industry is around Clitheroe and Chatburn, north of Pendle hill. Remains include seventeenth-century field kilns, and nineteenth-century industrial kilns for building and chemicals (see Ashmore 1982, 10, Bennet 1993, Davies-Shiel & Marshall 1969, 158).

North-East England contains large areas of Carboniferous limestone and includes the north end of the Magnesian belt. Across the uplands there is a scatter of small kilns, with circular/oval pots, employing coal from local thin deposits. These were probably operated commercially for local farmers, with transport by packhorse in the eighteenth and early nineteenth century. Coastal kilns operated from at least the eighteenth century, based on local stone and fuel and exporting the lime by boat (there are surviving examples on the Northumberland, Tyne & Wear and Durham coasts, for example at Seahouse and Beadnell). In the mid nineteenth century railway construction saw many large kilns built next to main lines (Atkinson 1974, 102, Ayriss & Linsley 1994, 42-3, Beamish pers comm, Linsley 1992, 96).

The extensive Carboniferous outcrops extend to the Yorkshire Dales, where again a long history of use for lime may be traced. Medieval clamp kilns were probably used for agriculture and occasional kilns for building work. Industrial expansion came in the eighteenth and nineteenth centuries and railway building such as the Settle-Carlisle line of the 1870s went hand in hand with development of large quarries and limeworks for distant markets (see Cleasby 1994 & 1995, Raistrick 1967, ch 5, Tmeman 1992, 127).

The Peak District includes a further extensive and historically important outcrop of Carboniferous limestone which supplied nineteenth-century industries (eg chemical, iron and steel) in emerging industrial conurbations as well as the construction industry that built those conurbations. Again, until the eighteenth century, lime burning would have been mainly for local agricultural use (whether produced commercially or by farmers). Stone built draw kilns and pye kilns were used in this phase, with fuel in the form of wood, peat, furze and (from the early seventeenth century) local coal. From the eighteenth century, turnpikes allowed the use of carts rather than the earlier packhorse and these were followed in turn by canal transport. These improvements in communication allowed the growth of commercial limeworks. For example, and of particular importance, the Peak

Forest canal and tramway was built in c1800 for an expanding limestone quarrying and lime burning industry around Buxton, and numerous lime kilns were built along the canal banks in the early nineteenth century. Other local centres were the Matlock/Wirksworth area, Stoney Middleton and Hope. Railway construction of the 1830s and 1860s allowed further expansion and the use of new kiln technology. The industry remains active to the present day (see Harris 1971, 60-74, Leach 1995, Nixon 1969, 79-83, Thompson undated).

The belts of Magnesian, Liassic and Oolitic limestone run north-south from the North York Moors through Nottinghamshire and Leicestershire into Warwickshire and Northamptonshire. There are also pockets of Carboniferous limestone in West Leicestershire (around Breedon, Ticknall and Calke). There are lime kilns of the pre-industrial and industrial eras along this broad band with early kilns on or near the limestone outcrops and later kilns along canals and railway. The pockets of Carboniferous limestone have been intensively worked (see LIHS 1983, Marshall et al 1992, Palmer & Neaverson 1986, 18, 34, 36, & 1992, 39-41, Smith 1965, Spratt & Harrison 1989, 166-7).

The West Midlands has fewer outcrops of limestone, but those that occur have been intensively worked. There is some Carboniferous limestone in Shropshire near Oswestry. Quarrying of these deposits include those at Llanymynech Hill that supplied large volumes of agricultural lime on the Montgomeryshire Canal (Hughes 1988). More extensive are the Silurian limestones of Wenlock Edge, the Dudley/Walsall area and the Malverns. Wenlock Edge has been quarried since at least the Medieval period and has extensive remains of lime burning landscapes and kilns (see Bick 1984, Brook 1977, Clark 1993, 75-81, Crompton 1991, 12, 34, Drury 1992, Goodbury 1992, McLeod et al 1987, Mills et al 1992, 44, 48, 50, Samuel 1977, 5-7, Sherlock 1976, 100, Stanier 1995, 53).

A broad band of chalk runs from the Chilterns through the Gog Magog hills of Cambridgeshire to the low chalklands of Suffolk and Norfolk, where it is mostly under agricultural land. Beyond the Wash this chalk rises to form the Wolds of Lincolnshire and Yorkshire. Much of the lime produced here has been for agricultural use. In Norfolk and Suffolk a distinct vernacular tradition is apparent amongst draw kilns dating mainly from 1810-50 (but including late eighteenth century examples at Costessey, Hillington and Purfleet). These kilns have a very distinctive form with the base of the kiln being surrounded by a circular chamber, into which feed a series of chutes for drawing the lime (see Alderton 1984, 12-15; Alderton & Booker 1980, 25, Johnson 1970, 19).

In South-east England, chalk forms the North Downs of Kent and Surrey and the South Downs of East and West Sussex and Hampshire. All have a long history of use for lime production. North Kent and Surrey have in addition provided important supplies to London. Notable sites include Brockham and Betchworth in Surrey, and the Amberley Chalk Pits in East Sussex (see Aldsworth 1979, Austen, Cox & Upton 1985, 17, 21, Crocker 1990, 17, 24, 39, Haselfoot 1978, Haveron 1993, 16-19, Stamer 1995, 30-1, Todd 1994, 33-5).

In southern England the area between Hampshire and Somerset and from Dorset to Gloucestershire includes a wide range of limestones - with the southern ends of the Liassic and Oolitic belts, small areas of Carboniferous limestone in the west (Bristol, the Mendips and around the Forest of Dean), as well as large areas of chalk forming Salisbury Plain, and the Hampshire, Marlborough, and Berkshire Downs. This is a rich area for limeburning with a long history of use and a wide range of surviving kilns (see Bowie 1980, Buchanan 1980, Buchanan & Cossons 1969, Day 1987, 30, 41, Hudson 1965, Minchinton 1984, Moore 1984, Stanier 1993).

In the South-West, Cornwall and Devon have limited limestone outcrops. There are narrow bands of Devonian limestone around Plymouth, Torquay and Brixham and near Combe Martin in North Devon. The majority of kilns are on or near the coast or near these bands. Coastal traffic has played an important part in the history of the industry here, so that for example kilns along the north coast used limestone from South Wales, and kilns on the south coast of Cornwall brought limestone from Plymouth (see Booker 1971 69-81, Minchinton 1984, Todd & Laws 1972).

6.2 Cement

The cement industry was essentially a product of the Industrial Revolution. With the improved communications of this period the technology of the industry was applied on a national level and the geographical location of the industry was based on geological and economical factors. Hence the Thames basin was of very high importance.

Roman cements were based on naturally occurring septaria and the industry inevitably was located around these deposits. Initial development was based on the Thames estuary material and the industry became based on London, although raw material also brought in from Essex coast (Harwich, Southend, Walton on the Naze), and later Yorkshire and Derby (Francis 1977, 28, 35, 37, 65).

Although London and the Thames remained the focus of the industry, cement works were established in other areas as new deposits of cement stone were found. On the North Yorkshire coast around Whitby, septaria were found in the alum shales of the Upper Liassic deposits. The first cement works in the area was established at Sandsend (Mulgrave works) in 1811. Others followed at Loftus, Grosmont, and Peak. When alum production ceased in the 1880s the cement works also closed, apart from that at Sandsend.

A cement works was also started at Hull, by 1821, using septaria brought from Yorkshire and, later, from Essex (Francis 1977, 71). In Derbyshire, cement stone was discovered in the 1830s and resulted in a small industry around Morledge. At the same time deposits were discovered near Wolverhampton and a cement industry developed around Coseley, Bilston and Tipton. In Somerset, in 1844, a lime works was opened at Bridgwater where a band of 'cement rock' was found and used to produce a Roman cement through the nineteenth century (Francis 1977, 72-3).

A particularly important product was Medina cement, produced and manufactured as a 'superior Roman cement' from the 1840s, based on septaria obtained from the south coast, including the River Medina in the Isle of Wight, Christchurch in Hampshire, Lyme Regis, Kimmeridge and Weymouth bay in Dorset (Francis 1977, 54).

The Portland cement industry was also focused in the south-east, particularly along the north Kent coast, making use of London clays and North Downs chalk, whilst bringing in coal by sea and taking cement to London on barges. Areas between Gravesend and Stone and the Lower Medway were major centres. For example by the 1890s, there were at least 16 cement works between Gravesend and Stone. These works were steadily amalgamated in the late nineteenth and early twentieth centuries, so that by the late 1920s there were two large works at Swanscombe and Northfleet. Swanscombe closing in 1990. In 1995 the Northfleet

works of Blue Circle was still operating, taking stone from Swanscombe and clay pumped under Thames from Essex (Stanier 1995, 27-32, Francis 1977)

In the mid-nineteenth century Portland Cement works were also established in the Gateshead area (by William Aspdin, I C Johnson and others) and by the late nineteenth century the north-east ports were an important area for cement production, including 2 works in Wallsend, 1 at Hebburn, 2 in Newcastle, 1 at Jarrow, 2 in Hartlepool and 1 in Sunderland. From the 1880s, slag cement was produced here. The industry declined sharply after 1910 (Francis 1977)

Other mid nineteenth-century works were established in Humberside (specifically Hull in the 1850s), Warwickshire (1860s) Leicestershire (c1869), Essex (1860s) and Suffolk (1860s). In the last quarter of century further works were established in Cambridgeshire (mainly in the south of the county), Bedfordshire (a minor industry compared to brick), Northamptonshire (1 works only), Staffordshire, Nottinghamshire (Vale of Belvoir), Lancashire (Clitheroe), and Merseyside (small and did not survive to the twentieth century)

6.3 Gypsum

Rock Gypsum has a more restricted distribution than limestone and chalk and the industry developed specifically around the deposits. There are references to gypsum plaster works in the following counties: Leicestershire (Humberstone), Nottinghamshire (in the north between Kneesall and Claborough, in the west around Gotham, and in the east between Newark and Cropwell Bishop), Staffordshire (around Fauld and Tutbury), Derbyshire (around Chellaston and Aston), Cumbria (near Whitehaven and in the Vale of Eden), Yorkshire (around Knaresborough), Dorset (Isle of Purbeck), and Sussex (near Robertsbridge).

7. ARCHITECTURAL IMPORTANCE

The structures of these industries can be very impressive in the local landscape, but they were generally functional in design. The existence of some vernacular tradition with respect to lime kilns has already been mentioned (see Regionality). Lime kilns show considerable regional variations in detailed form, and in many areas this forms an important aspect of the vernacular tradition, especially in demonstrating the adaptation of vernacular masonry traditions to the construction of complex three-dimensional industrial structures. In addition, there was at least occasional architectural pretension (for example an 1888 kiln at Great Tosson, Alnwick was designed with the involvement of an architect, see Linsley 1992, 96). Beyond the kilns, works buildings generally gave scope for further architectural expression, as indicated by contemporary illustrations (see illustrations).

Many limekilns have therefore been Listed for their architectural or historical importance, in accordance with normal Listing criteria.

8. COMPONENTS LIST

Surviving components are grouped within three classes: LIME WORKS, CEMENT WORKS and GYPSUM WORKS. Components common to all three are listed separately at the end. Components are listed alphabetically. Terms used are for MPP purposes, but have been chosen in an attempt to reflect terminology used in the industry. The general importance of each component in isolation is given; the importance of a particular example will depend on its date, condition and typological/regional variation.

Features of all three classes frequently occur in and adjacent to quarries. Where the QUARRY features are of importance in their own right, they will be separately assessed as part of the Quarrying Industry, but where they are of importance only for group value with the LIME, CEMENT, or GYPSUM WORKS, the appropriate terms from the Quarrying components list will be used within the LIME assessment.

8.1 LIME WORKS

<u>Hydrating plant</u>	Series of machines for mechanically slaking lime
Date Range	Twentieth century
Importance	An intact early example would be high
<u>Lime kiln - clamp</u>	A temporary mixed-feed kiln formed as an excavated pit and covered with sods of earth. May vary in form (from circular to rectangular) and size
Date Range	Medieval (possibly earlier) to twentieth century
Importance	Rare identification and ephemeral nature makes these generally high
<u>Lime kiln - draw</u>	A continuously run kiln consisting of a stone tower containing at least one pot and drawing arch. Fuel and stone were loaded in alternate layers and the base of the pot may incorporate one of several mechanisms to facilitate periodic drawing of lime mixed feed. This form of kiln could equally be operated as a flare kiln and firm identification in the field may be difficult
Date Range	Possibly Medieval to twentieth century
Importance	Medieval to early industrial era examples generally high. Later examples depends on typological variation and quality of survival
<u>Lime kiln - flare</u>	An intermittently run kiln in several distinct forms. A flare kiln with domed stoke hole consists of a stone tower containing at least one pot and drawing, the stone and fuel being kept separate. A flare kiln with separate flue stoke holes may be a rectangular block with a series of horizontal flues running beneath it. A 'bottle' or 'domed' flare kiln is a brick or stone structure with a bottle-shaped or domed upper part in which fuel and stone may be mixed or kept separate
Date Range	Roman to twentieth century
Importance	Medieval to early industrial era examples generally high. Later examples depends on typological variation and quality of survival

<u>Lime kiln - horizontal ring</u>	Specifically the Hoffman kiln and its variants, where the burning zone was moving continuously around a horizontal tunnel
Date Range	mid nineteenth century to twentieth century
Importance	Relatively rare in UK. therefore generally high
<u>Lime kiln - horizontal tunnel</u>	A kiln in which the stone to be burned was carried on trucks through a heated tunnel
Date Range	late nineteenth century
Importance	Any example would be high
<u>Lime kiln - rotary</u>	A kiln where stone is burnt as it falls through a heated and slightly inclined rotating steel tube
Date Range	late nineteenth century to twentieth century
Importance	Poor chance of survival of redundant examples due to nature of construction, therefore early surviving examples generally high Widely used today
<u>Lime kiln - vertical furnace</u>	A continuously run kiln with superstructure of brick or stone (early examples) or steel (later), and fired via furnaces located around the burning zone
Date Range	early nineteenth century to twentieth century
Importance	An important technology, but early examples appear to be rare and therefore have high importance The tendency to scrap steel kilns, makes surviving examples of these also generally of high importance
<u>Lime kiln - vertical mixed-feed</u>	Continuously run kiln with superstructure of brick or stone (early examples) or steel (later), and fired by injecting fuel into the burning through a series of narrow, angled shafts
Date Range	mid nineteenth century to twentieth century
Importance	An important technology, but early examples appear to be rare and therefore have high importance The tendency to scrap steel kilns, makes surviving examples of these also generally of high importance
<u>Lime shed</u>	A shelter of stone, brick or wood over kiln drawing arches, to protect lime from the elements
Date Range	Uncertain origin, certainly from eighteenth century
Importance	Survival appears to be rare, but importance depends on individual kilns
<u>Lime storage shed</u>	Area for storing lime
Date Range	Uncertain origin
Importance	Depends on individual kilns
<u>Slaking pit</u>	A pit (or trough) within which quicklime was slaked with water For earlier periods, normally located at point of use, probably rare at the kiln site May be more common on kiln sites from nineteenth century
Date Range	Uncertain, presumably from earliest dates of lime burning
Importance	Features largely unreported in published literature, therefore importance of individual examples uncertain at this stage