The archaeology of mining, and quarrying, for Salt and the Evaporites (Gypsum, Anhydrite, Potash and Celestine)

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Rock salt, or halite ($NaCl$- sodium chloride), has been mined since the late 17th century, having been discovered during exploratory shaft sinking for coal at Marbury near Northwich, Cheshire, in November 1670. Prior to that the brine springs of Cheshire and those at Droitwich in Worcestershire were the source of salt produced by evaporation, along with production from a large number of coastal sites using seawater. Alabaster, fine grained gypsum ($CaSO_4 . 2H_2O$ - hydrated calcium sulphate), has however been quarried in the East Midlands for use in sculpture since at least the 14th century (Cheetham 1984, 11-13) and the use of gypsum for making plaster dates from about the same period.

Consumption

The expansion of mining and quarrying for salt and the other evaporites came in the 19th century with the development of the chemical industry. Salt (sodium chloride) was a feedstock for the production of the chlorine used in many chemical processes and in the production of caustic soda (sodium hydroxide) and soda ash (sodium carbonate). Anhydrite (anhydrous calcium sulphate) was used in the production of sulphuric acid. Salt or halite (rock salt) was first mined at Winsford in Cheshire (the site of the only remaining active rock salt mine in England) in 1844. Production expanded in the late 19th century to feed the chemical industry in north Cheshire (together with increasing brine production from the Northwich salt fields). The Lancashire salt deposits, on the Wyre estuary at Fleetwood and Preesall, not discovered until 1872 whilst boring in search of haematite (Landless 1979, 38), were a key to the development of the chemical industry in that area. Anhydrite mining was generally a much later development in west Cumberland and on Teesside where it again fed a developing chemical industry.

Potash (a generic term for a number of potassium bearing minerals but, in this case, referring to sylvinite, a mixture of potassium and sodium chlorides) was discovered at depths of 800 to 1300 metres below the east coast of Yorkshire in 1939 whilst drilling for oil but was not worked until the early 1970s at the Boulby Mine, where shaft sinking began in 1968. Another mine is currently proposed to work south and east of the Boulby Mine. The vast proportion of output, peaking at in excess of 600,000 tons per annum in the late 1990s to 2003, is used in the production of fertilisers. At the other end of the scale is celestite or celestine ($SrSO_4$ - strontium sulphate), a replacement deposit found in gypsum formations, in particular at Yate in South Gloucestershire. This was worked from the late 19th century through to 1994 by shallow quarrying (only a few metres below surface), initially for use in sugar refining but it subsequent found a multitude of other uses, including as a colorant in fireworks (SGMRG nd).

Geology

The salt and other evaporite deposits in England are of Permian, Triassic, and to a lesser extent, Jurassic age, resulting from the evaporation of seawater in large inland seas and, in some cases, its re-deposition by wind action (Morrison 2005). The deposits often show a repeated sequence of minerals, indicating cyclic conditions with a mineralogy determined by solubility. The sequence in which the most important minerals precipitate as evaporation proceeds starts with carbonate minerals (aragonite and Mg carbonates) and continues through gypsum and anhydrite, halite, polyhalite and potassium salts such as sylvite. (Encyclopaedia Britannica).

Calcite (calcium carbonate) occurs as an evaporite in many parts of the world but in England the only deposits which have been worked commercially are of hydrothermal origin and are therefore considered in the assessment for gangue minerals. Gypsum (hydrated calcium sulphate) and anhydrite (anhydrous calcium sulphate) are found as beds or nodular deposits in rocks from Cumbria, through the Midlands, in Sussex and in the South-West of England. In the Eden valley in eastern Cumbria and in a narrow band running south through Yorkshire, to the west of York, it is in Permian marls and Permo-Triassic sandstone. At St Bees, in east Cumbria, and in a wide band from Teeside, running south to the east of York, through the East Midlands and into Somerset gypsum and anhydrite are found at two horizons, the Tutbury, a single bed up to 3.5m thick, and the Newark, multiple beds of variable thickness over 15 -18m in total, in the Triassic Mercia Mudstone Group. In the Trent valley to the south of Derby, and a few other locations in Yorkshire and Staffordshire, the Tutbury Gypsum is of fine grain quality and found in nodules particularly suitable for extraction as alabaster for sculpture. At Yate, in south Gloucestershire, and further south in Somerset, at the horizon of the Newark Gypsum there are beds of celestine (strontium sulphate), the chief source of strontium in England, but little in the way of gypsum itself. In the south of England, from East Sussex across to Dorset, the gypsum is found in strata of Jurassic age (BGS 2006, 4-5; Firman 1984; Sherlock et al 1938, 10-24).

The halite (sodium chloride) or rock salt found in the Triassic Mercia Mudstone Group in the Cheshire Basin, extending into north Shropshire, is the most important salt resource in the country. Salt deposits of the same age are also found in Lancashire, under the Wyre estuary, in Worcestershire, Staffordshire, on Walney Island in Cumbria, and in Somerset; it is also known to underlie Dorset but has not been worked in that area. On Teesside, under much of east Yorkshire and into north Lincolnshire there are salt-bearing strata of Permian age (BGS 2006, 4-5). Polyhalite, a hydrated sulphate of potassium, calcium and magnesium, is found as a component of the Permian halite beds in east Yorkshire where exploration work is underway with a view to exploiting it as a source for fertiliser production (Sirius Minerals nd; Rowley 2012).

Sylvite (potassium chloride) is found in association with halite in the sylvinite or potash beds in east Yorkshire. The principal bed, the Boulby which is on average 7m in thickness, overlies a halite bed with a total thickness of around 40m. A second sylvinite bed, the Sneaton, overlies the Boulby but that is currently not considered of economic value. (BGS 2011, 3-4).

Historical context

Sodium chloride salt has always been in constant demand in England for preserving food and there has been continuity in production from Roman times through the medieval period to the present day. All the coastal counties of England had salt works or "wiches" designed to capture seawater at exceptional high tides. The resulting salt-rich sands were then washed to extract brine which was evaporated in pans, using wood or peat as fuel, to recover the salt.[1] In addition to the coastal resources there were two areas of England where salt was obtained from natural brine springs derived from salt-bearing rocks through the action of dissolution by surface fresh water of the exposed salt beds or "Wet Rock Head". These were in Cheshire, around the town of Northwich, and in Worcestershire, at Droitwich. Unlike coastal salt works, which were an intermittent operation governed by exceptionally high tides, the inland salt producers could continue throughout the year. The brine springs and evaporation pans at Droitwich were referred to in documents from the 7^{th} to 10^{th} centuries, as were the routes by which the salt was traded to a wide area of the west and south-west of England and, judged on the revenues itemised in the Domesday survey, were the major source in the 11^{th} century. Upwich, one of the principal brine springs at Droitwich, has provided archaeological evidence for continued production from at least the Roman period through to the late medieval. Many inland manors had rights to salt works on the coast as had manors remote from the inland salt-producing areas. Such was the importance of salt to the economy of the period that rights around Droitwich, with five springs supporting over 300 *salinae* or saltworks, included not only manors within the immediate area but some as far afield as south Gloucestershire and Buckinghamshire. The construction of salt boiling / evaporation pans was a significant usage of lead, and they were sometimes referred to as *plumbi* (Claughton 2011).

The inland brine springs were evidently enlarged into sizeable pits and continued to be exploited through and beyond the post-medieval period. It was not until the late 17^{th} century that deep shafts were sunk to directly exploit the salt-bearing strata. A sequence of rocks subsequently referred to as the "Top Rock" or upper halite was found by chance in November 1670 at Marbury near Northwich, in north Cheshire, during exploration for coal and was worked until 1781. Those workings were, however, unstable as the percolation of ground water dissolved the salt and led to collapses in the ground above with consequent flooding of the workings. A lower bed the "Bottom Rock" was discovered at Lawton, near Sandbach, in 1779 and, in 1781, at Marston, Northwich. By working the lower bed it was possible to reduce the inflow of ground water as the deeper workings were below intervening mudstones and under the "Dry Rock Head". Until the mid-19th century the mining of rock salt was confined to the area around Northwich where working continued until March 1928 before finally ceasing when the Adelaide Mine collapsed and flooded. In 1844 mining was begun at Winsford, continuing on a small scale until 1892. It was also discovered and worked on a small scale at Middlewich using shafts from about 1888. After the collapse of the Adelaide Mine in 1928 the Meadowbank Mine at Winsford was reopened and is currently the only operational salt mine in England (Rochester nd - Rock Salt; Sherlock 1921, 55-58). 'Bastard brine' was also pumped from abandoned and collapsed mines, and also from brine wells sunk specifically to exploit 'natural brine' in un-mined areas across the Cheshire saltfield (Wharmby 1987, 30-31). Pumping in this manner did however lead to severe subsidence and ground collapse problems until the technique of 'controlled pumping' (below)

[1] Coastal salt production is outside the remit of this assessment. For further details on the archaeology of coastal salt-making see the work of David Cranstone, particularly Cranstone 2012.

was introduced into Cheshire in the early 20th century. Controlled pumping was carried out as far northwest as Agden near Lymm, north of the Warburton fault (Lymm.com 2012).

Rock salt was also discovered at Stoke Prior, Worcestershire, in 1828, at Middlesborough in 1863, at Preesall, Lancashire, in 1872, at Walney Island, now in Cumbria, by the 1890s and at Puriton, Somerset, in 1910. Only in the case of Preesall was the salt mined. In Worcestershire, Somerset and at Walney Island it was exploited by means of wells and extracted as brine. At Preesall although access to the salt was by means of shafts it was recovered as brine which was allowed to flow to pumps in the main shaft. From 1892 a new technique was introduced, referred to as 'controlled pumping', where water is pumped down a pipe within a borehole to dissolve the salt below a head of compressed air and the resulting brine allowed to flow to surface. Once the cavity formed has reached an optimum size, extraction was moved to a new site about 180m distant and, by this means, stable cavities were created which did not result in surface subsidence. Under later management by Imperial Chemical Industries (ICI) the technique was transferred to Cheshire (Morrison 2005; Landless 1979).

Surface subsidence above the salt deposits in Cheshire had been a long standing problem since mining commenced in the 17th century. It was reduced by mining the lower salt bed but once mines had flooded it was possible to continue extracting brine by pumping. As the brine was replaced by fresh water from surface there was rapid dissolution of the surviving salt pillars in the abandoned mines, resulting in instability and the collapse of large areas of the surface including urban areas particularly in Northwich (Rochester 1985; Ward 1900; Calvert 1915).

Gypsum, particularly in the form of alabaster, was the only other evaporite which was worked to any extent prior to the 19th century. In fact the quarrying of alabaster commenced in at least the 12th century for, although its use in the sculpture of ecclesiastical images dates from around a century later, it was used in construction of the west door to the priory church at Tutbury, Staffordshire, in about 1160 (Cheetham 1984, 12). Although all the documentary evidence for alabaster sculpture is largely confined to material originating in the East Midlands (around Tutbury and Chellaston) it is very likely that it was also quarried in other areas of England. Fine grained gypsum suitable for use as alabaster is found near Kingston-upon-Soar (Nottinghamshire), in small deposits in Purbeck (Dorset), at Ledsham (Yorkshire) and perhaps near York itself, where there are references to men employed in the alabaster trade in the 15th century (Cheetham 1984, 12-13) although, in the latter case, its status and position on a navigable river meant that high grade material might have been imported coastwise from the Midlands. Firman (1984) provides a useful critical account of the sources of alabaster for sculptural purposes in the medieval and post medieval periods.

Buttercrambe, near York, was one of the sites documented as producing gypsum in the medieval period for calcining in the preparation of 'Plaster of Paris', used in York Minster. Other sites, including Purbeck, are known to have been exploited for plaster from at least the 14th century (Salzman 1923, 100). By the 19th century, wherever gypsum of suitable quality was found it would have been quarried and calcined for plaster and, later, the manufacture of plasterboard. It was also used in the manufacture of Portland Cement. In 1938 the Geological Survey listed over 45 mines and quarries in Cumberland, Derbyshire, Leicestershire, Nottinghamshire, Somerset, Sussex, Westmorland and Yorkshire, all working gypsum in some form (Sherlock et al 1938). In 2006 there were five mines and one quarry still working for gypsum (BGS 2005).

The mining of anhydrite, the anhydrous form of calcium sulphate, is a relatively recent 20th century development. It was rejected by miners working for gypsum as being unsuitable for plaster production and it was not until a use was found in inorganic chemical processes that it was extracted in any quantity. Even as late as 1938 there was only limited exploitation, primarily in Co. Durham (at Billingham and, earlier, from 1924 to 1930 at the Warren Mine at Hartlepool) as a feedstock for the production of ammonium sulphate and in the manufacture of sulphuric acid, with small amounts being used in recent developments in plaster production (Sherlock et al 1938, 8-9). The rise in anhydrite mining came after the Second World War. With increased demand for sulphuric acid a new mine was opened up in Cumbria at Sandwith near Whitehaven. The Long Meg Mine in the Eden valley, which had produced small quantities of anhydrite in the 1920s, was brought back into production (Tyler 2000) and the Billingham Mine continued in operation until 1971.

Potash mining in England is very much a post-war industry. The only mine in operation, at Boulby in what is now Cleveland, was not opened up until 1968. Prior to that date the source of potash along with other components in fertilisers came from that mined on the continent or from 'natural resources'- primarily guano - whilst potash for use in soap production was produced by burning wood and other organic material. With the Boulby Mine in full operation from the early 1970s, England has become a major producer of potash for use as fertiliser and a new mine is proposed to work the undersea polyhalite deposits to the south and east of Boulby (Sirius Minerals nd). The Boulby Mine drives its underground roadways in the halite beds below the potash. It is therefore producing rock salt, which general goes for highway de-icing, as a co-product (BGS 2011, 5; Rowley 2012).

Although strontianite ($SrCO_3$ - strontium carbonate) is found as a gangue mineral in a number of lead mines in the north Pennine it has never been worked commercially and is not an evaporitic mineral. Celestine has, however, been quarried in the Triassic Mercia Mudstone Group of Gloucestershire and Somerset. A large number of shallow pits were worked in the area around, and to the north of Yate, in South Gloucestershire, from the late 19th century through to 1994 (SGMRG nd). The location of those pits was mapped by the Geological Survey in the inter-war period when they were operated by the Bristol Mineral and Land Company (Sherlock et al 1938, 84). Working in Somerset appears to have been confined to an area west of Regilbury Court, near Winford, where disused pits of unknown date were recorded and at Leigh Court, at Abbots Leigh to the west of Bristol, where operations were large enough to justify a tramway to the River Avon before working ceased around 1912 (Sherlock 1938, 87-88).

Techniques and Technology

Early mining of salt and the quarrying of alabaster relied to a great extent on manual labour but from the 19th century onwards as the extraction of salt and the other evaporites expanded there was widespread mechanisation. Extensive use has been made of wheeled / trackless vehicles underground in the working of gypsum, anhydrite and potash. Continuous mining machines are currently used underground in the extraction of gypsum and potash. The late development of large scale underground extraction meant that most mines utilised drainage by electric pumps, although some of the earlier salt mines used steam powered pumps from 1788 onwards for both drainage and brine pumping (Rochester nd - Rock Salt, 2).

Solution mining techniques as first used in salt extraction caused extensive surface instability but that was overcome by the use of 'controlled brine pumping' developed at Preesall in Lancashire and transferred to other salt fields under ICI management (Morrison 2005; Landless 1979). Solution mining using controlled pumping was also tried on an experimental basis by ICI for the extraction of potash at Upgang and Aislaby, now in North Yorkshire, in the 1950s and 60s, and documents relating to the installation of pipelines can be found in the National Archives (TNA:PRO BT 356/10262 and 10263).

It was in the processing of salt that techniques unique to the industry were developed. From the Roman period onwards lead pans were used for the evaporation of salt. These were replaced by larger iron pans, heated by coal rather than wood fires, in the post medieval period and they continued to be used on a large scale right through into the 20th century. Large 'salt works' were established close to the point of extraction, producing a range of salt for various uses. Some rock salt was also sent to salt refiners on Merseyside and, from the early 19th century onwards, as a feed stock for new processes, such as the production of alkali by the LeBlanc process, on Merseyside, Tyneside and Clydeside (Rochester nd - Growth).

The real advance in the evaporation of brine to produce salt came in the 1890s with the application of vacuum evaporators to salt production. Considerable savings in fuel over the open pan method was the driving force behind the adoption of vacuum evaporation which is still used today. Large plants were constructed at Winsford and at Runcorn, in north Cheshire, fed by brine pipelines (Morrison nd). Some 'salt works', such as the Lion Salt Works at Marston, Northwich, continued to use the open pan methods right up until closure in 1986 (Fielding 2005).

Processing of gypsum for cement, as mineral white or for the plaster trade also required specialist plant that was generally located close to the point of extraction. Gypsum rock, crushed and ground using French buhrstones or Derbyshire millstones before going for use in plaster, was calcined in what were referred to as 'kettles' or 'boiled' in 'pans'. Sherlock et al (1938, 27) illustrate a flow sheet for the Cocklakes Mine which provides a useful explanation of the processes at that period and the grinding processes themselves are reviewed by Fitzgerald (2011, 136-38)

Transport and infrastructure

Pack horse routes linked the inland salt producing areas to their markets in the medieval and later periods (see, for example, Houghton 1932). There was a similar reliance, at least in part, for the transport of alabaster, worked and unworked, in the late medieval period. River and coastal shipping was, however, the most economic method of moving bulky cargoes of salt and alabaster and this was facilitated by the close proximity of extraction points to the river system in England. The alabaster quarries in the East Midlands were located close to the River Trent. In Cheshire the transport of rock salt was improved when the River Weaver was made navigable (Rochester nd - Rock Salt, 2). The Weaver Navigation Bill was passed in 1721, but the actual Weaver Navigation canalised river was opened in 1732 with the transportation of approximately 5,200tons of salt being increased to 18,600tons by 1760 (Wallwork 1959). Completion of the Trent and Mersey canal, in 1777, right through the salt field of the Cheshire basin, provided further improvements in transport and the erection of the Anderton boat lift near Northwich in 1875 to link the canal with the River Weaver was a result of increased traffic in salt.

The opening of the Trent and Mersey Canal also provided transport opportunities for the alabaster / gypsum quarries in Derbyshire. The canal was used by quarries at Aston-on-Trent from the late 18th century and a tramway linking them to the wharf was in use from 1812 until the early 20th century (Heath 1977).

The construction of the mainline railway network in the second half of the 19th century not only advanced the movement of salt but provided a basis for transport of the other evaporites, particularly gypsum and anhydrite, with many mines and quarries having direct links to either branch lines or the mainline itself (Sherlock et al 1938, 25-55). Within many of the mines and quarries, narrow gauge tramways, with locomotives, were in use. Even when operations still relied on river or coastal shipping, as with the celestine quarries at Abbots Leigh near Bristol (Sherlock et al 1938, 88), transport to the shipping point relied on tramways.

Aerial ropeways were also employed to link a number of mines at Kirby Thore in Cumbria to the processing mill in the 1930s (Tyler 2000, 254) and many operations later moved to the use of long conveyor belt systems for the same purpose. Pipelines were, and still are, used for long distance movement of brine and one is planned for the transport of polyhalite in suspension at the proposed York Potash operation in east Yorkshire. At Walney Island the brine was pumped to a holding reservoir, from where a pipeline led to the salt pans.

Settlements in the salt fields of Worcestershire and the Cheshire basin developed around the brine springs from the Roman period onwards. In the latter case, as production expanded those settlements grew and the salt works moved to the outskirts of the towns. As the industry expanded further, particularly with the advent of rock salt mining, some employers provided dedicated housing for their workers. In 1775 the Barons Croft Salt Works at Northwich had provided workers housing and by the early 19th century there were other similar terraces around Northwich. Brunner Mond and other companies provided housing up until the 1920s when the task passed to local authorities. Even then the large companies encouraged the building of housing by providing land to local authorities for the purpose and, with the expansion of social housing after the Second World War, council houses were specifically allocated to workers in the salt industry (Squire nd). At Walney Island a substantial settlement was planned but only a few cottages were built and these still survive (Brian Cubborn pers comm)

Outside the salt industry there is little evidence of dedicated housing although some operations, particularly gypsum / anhydrite mining, in rural areas would probably have justified at least a small number of dedicated workers' cottages.

The archaeology of salt and the other evaporites

Archaeological investigation of salt and the other evaporites has focussed almost exclusively on the processing of the product once extracted, and this is dominated by work on salt works, largely the earlier Roman to medieval sites (Fielding & Fielding 2006). It has to be noted, however, that investigation of rock salt mining in Cheshire is severely hampered by the subsidence and flooding that attended abandonment of the mines. For example, the Adelaide Mine opposite the Lion Salt Works, and the last to work in the Northwich area, is now represented by an extensive area of water infilling the surface subsidence area.. The emphasis has been on the history and archaeology of brine processing, be it from brine springs, brine pumping or as the result of rock salt extraction. Such a site at Upwich in Worcestershire, a multi-period site from Roman through to medieval, was investigated in detail in the late 1990s (Hurst 1997). Similar work has been carried out in Cheshire where two medieval 'salt houses' were investigated at Nantwich (McNeil nd).

Although no salt mines are listed in the National Record of the Historic Environment (NRHE) there has been extensive research carried out to identify the location of all known workings in Cheshire. The 'survey of abandoned salt mine workings and brine shafts in Cheshire' (Wharmby 1987) was driven by the need to identify all abandoned workings with a view to mitigating the associated subsidence risks. Since that date there has been extensive remedial work, particularly in urban areas, and access to abandoned underground working for archaeological purposes is highly unlikely. The survey does, however, provide a useful gazetteer of sites should the opportunity for surface investigation arise.

Archaeological interest in alabaster arises primarily from its use in ecclesiastical sculpture from the 14th century onwards. The product and its distribution have been researched at length by a number of scholars, more recently by Cheetham (1984, 2001 & 2003). Attempts have been made to link sculptures to particular geological sources of alabaster but with only limited success (Cheetham 1984, 13, citing Beasley 1978). Finds of tools and other evidence for the early extraction of alabaster from quarries in the Chellaston area of Derbyshire and at Tutbury in Staffordshire have attracted comment from time to time (Cheetham 1984, 12) but with little, if any, archaeological follow up. Similarly, stabilisation work on abandoned gypsum mine workings in advance of the construction of the Derby southern by-pass does not appear to have been accompanied by any archaeological investigation (Cooper & Saunders 2002). A number of gypsum mines in Cumbria, East Sussex and the East Midlands were listed in the Monument Protection Plan (MPP) Step 3 report for Lime and Plaster. At least one site, Brickyard Plantation, Aston upon Trent, has been the subject of archaeological assessment (Elliott et al 1995) and the Acorn Bank Gypsum Works at Temple Sowerby in Cumbria has been surveyed and is listed in the National Trust HER (National Trust ENA1387) but it is not clear if that survey included the extraction site itself (Maxwell 1997). There are currently eight gypsum mines listed in the National Record of the Historic Environment (NRHE). The extraction of potash and salt were included in the Historic Seascape Characterisation for parts of Co. Durham, Teesside and east Yorkshire (Baker et al 2007, 83-85).

Tyler (2000) provides a comprehensive social history of gypsum and anhydite mining in Cumbria, albeit unreferenced, and includes some sketch plans for sites which can be interpreted in the future. Otherwise there has not been much interest in recording and interpreting the remains of the industries in Cumbria. Further south, in the East Midlands, there has been interest over a long period. Evidence for gypsum working in Derbyshire was examined by Sarjeant in the 1960s (1962 and 1963), and Firman (1984) has documented and attempted to interpret a number of alabaster working sites in the East Midlands from a geological perspective. The work of the latter provides an insight into the archaeological potential for the quarrying of alabaster and, along with Barnes, the mining of gypsum in Nottinghamshire (Barnes & Firman 1991). The Fauld Mine in Staffordshire has also attracted interest if only for the fact that it was partially destroyed in the largest explosion on British soil whilst being used as storage for high explosives during the Second World War (McCamley 2004, 77-139). The surviving features of the Hawton Gypsum Mill, near Newark in Nottinghamshire, were surveyed for Nottinghamshire County Council archaeology service by Structural Perspectives Ltd in 2000 and provided the basis for a detailed assessment of the grinding processes used on that site (Fitzgerald 2011).

Overall, there has been little archaeological investigation of the extractive processes for salt and the other evaporites.

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