A Vanished Industry: Coprolite Mining

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Abstract: Phosphatic nodules, generally known as coprolites, occur mainly in the Cretaceous clay formations which outcrop in a SW-NE belt from Norfolk to Oxfordshire with outlying patches in Yorkshire and Kent and in the early Pleistocene of Suffolk. They were exploited commercially in Victorian times as source of phosphate for what was then called "chemical manure". Working this resource of fertilizer made a substantial contribution to British agriculture in the 19th century.

The early 19th century saw the recognition that the application of fertilizers, particularly those rich in bone meal, to agricultural land led to a significant improvement in crop yields. About 1827 the German explorer Humboldt returned from South America to Europe and his report led to Europeans discovering the beneficial effects of "huano", better known as guano, as fertilizer. Guano consists of phosphate-rich bird droppings with fish bones and other remains which formed an accumulation on the Chincha Islands off the coast of Peru. Large quantities were shipped to European ports such as Liverpool. Analytical chemists soon showed that the particular benefits as fertilizer came from phosphate, and a search was begun for cheaper and less distant sources. One deposit was already being exploited – the Red Crag of Suffolk and Essex, though the nature of its phosphatic content was not fully appreciated at first and the material was regarded as fossil bone-meal. Other sources of bone-meal were occasionally exploited including mummified cats from Egyptian tombs, the shavings from bone-handled knives in Sheffield, the wealth of bones on European battlefields such as Waterloo, and Italian catacombs. With the growing urban population in England's cities there was increasing demand for food and thus for fertilizer.

William Buckland

The term coprolite was introduced about 1829 by William Buckland, the first professor of Geology and Mineralogy at Oxford University, with reference to phosphatic nodules he had found in the Lower Jurassic rocks of Dorset and Gloucestershire. It was derived from the Greek *kopros* (= dung) and *lithos* (= stone). Coprolites had been collected earlier on the continent but were mistakenly regarded as some sort of fossil fir cone. In 1823, Buckland investigated the small Kirkdale Cave in north Yorkshire where he deduced that the bones of such animals as rhinoceros had been brought in by hyenas (both animals were extinct in Britain) and that they were not relics of Noah's Flood as previously supposed (Buckland, 1824, 1829, 1836; Duffin, 2006). He also noted that there were white ball-like objects in the cave and that these were probably hyena faeces. He was struck by the resemblance of these objects to *Album graecum*, a substance used by apothecaries for medical purposes. *Cara alba* was an equivalent material derived from dog excrement and used for heart conditions! In spite of his recognition of the excremental nature of the objects, it was not until several years later that Buckland coined the term coprolite when he collected specimens from the Rhaetic Bone Bed; he called these *Nigrum Graecum* from their black colour (Duffin, 2006). Buckland also obtained faeces from a hyena in a local menagerie for comparison. He spent several of his holidays at Lyme Regis on the Dorset coast where he met Mary Anning, then actively excavating ichthyosaur remains from the Lias for sale to the growing number of museums and other academic collectors. He noted that some associated nodules (locally called bezoar stones) had spiral markings and pointed ends and realized that they could be excreta, comparable to the objects he had found in the Rhaetic Bone Bed. Some were even found inside the pelvic regions of fossil ichthyosaurs, fossilized before evacuation! He realized that some of the excreted nodules contained the indigestible remains of ichthyosaur's prey, chiefly comminuted fish bones, scales and teeth as well as juvenile ichthyosaurs and cephalopod hooks. Thus Buckland founded the coprolitic branch of palaeontology. At his home in Oxford, Buckland was also noted for serving visitors with meals made from unusual animals such as crocodiles, and had a coprolite side-table made to amuse his guests: it comprised polished sections through both coprolites and septarian nodules set in a "cement" matrix and a wooden frame (Fig. 3): it is now in the Philpot Museum at Lyme Regis. The source of the septarian nodules is unknown but they might

***Figure 1**. Coprolites from the Red Crag (photo: Sedgwick Museum).*

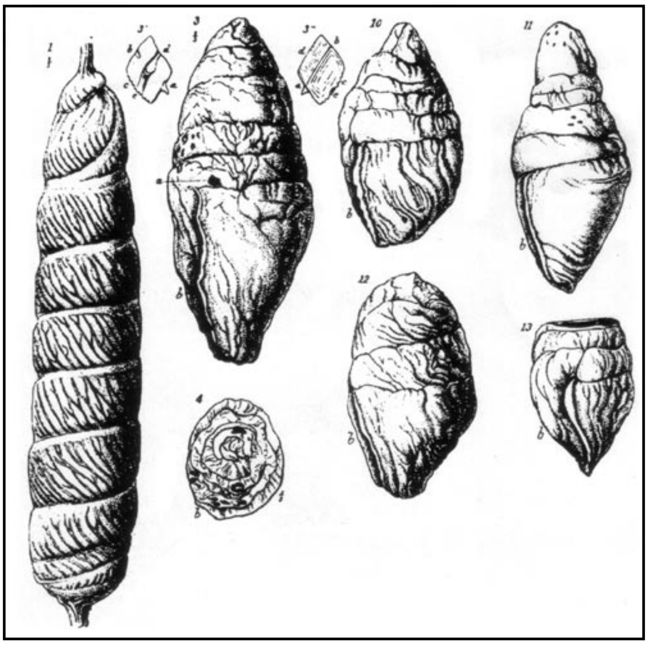

Figure 2. Drawings of coprolites (from Buckland, 1836).

have come from the Carboniferous Wardie Shales (Oil Shales Group) near Edinburgh: however, it is not known who made the table or when (Sharpe, 2004). A pair of coprolite ear-rings are said to have been made for his wife but it is not known if they survive today.

Coprolitology led to the appearance of several scurrilous cartoons, including one by Henry De La Beche (first Director of the Geological Survey) entitled "A Coprolitic Vision", which showed a figure in academic gown and mortar board, presumably Buckland, in a cave with large coprolite-shaped stalagmites and several animals in the act of making more coprolites (Fig. 4). Even the academic has a dark shadow on the ground between his legs!

Thus, thanks to Buckland, coprolites were confirmed as including the fossilized remains of animals' excreta. Later they were often referred to as dinosaur dung, though only a few bear the appropriate reptilian spiral shape with pointed ends, and the nature of dinosaurs

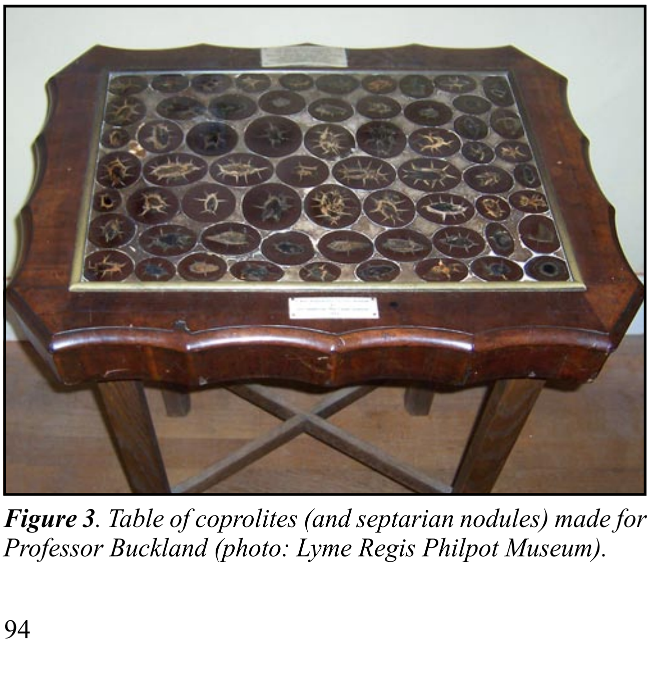

Figure 3. Table of coprolites (and septarian nodules) made for Professor Buckland (photo: Lyme Regis Philpot Museum).

was not recognized until Richard Owen coined the name more than ten years later. Some nodules are just irregular lumps of phosphatic material. Purists might wish to use terms such as pseudo-coprolites or false coprolites for any nodules which cannot be shown to be excretions, but the term coprolite has long been used commercially to embrace any phosphatic nodules, whether excreta or not. Scientifically it is probably best if they are all referred to as phosphatic nodules, though coprolite is normally taken as a colloquial or commercial equivalent term.

The Origin of Coprolites

It seems likely that most coprolites came from the larger marine reptiles or fish, which fed on their smaller brethren and concentrated phosphate in their faeces. Though most of the beds with coprolitic nodules were marine, remains of terrestrial reptiles preserved in the phosphatic nodules can represent carcasses washed in from rivers draining nearby land areas and scavenged by both marine reptiles and fish. Nodules were also recycled by erosion from earlier strata such as the Kimmeridge Clay of late Jurassic age, re-deposited in Cretaceous sediments.

Phosphatic nodules are not uncommon in most of the thick mudstone formations of the British Mesozoic and Cenozoic, ranging from the Lias to the London Clay; however, they are usually too widely dispersed to form an economic resource. The nodules appear to have formed at or just below the sea-bed during early diagenesis. Soon after their formation, winnowing out of the surrounding clay particles by strong currents and tides during periods of slight uplift above wave-base served to concentrate the nodules in lag gravels, many of which therefore mark non-sequences or disconformities. These lag gravels form the commercially exploitable coprolite beds. Repeated winnowings at successive horizons occasionally led to several nodule bands lying sufficiently close together to be exploited as single units. Regrettably, due to the commercial exploitation, there are few sections through the relevant strata available today meaning that a complete sedimentary and palaeontological analysis would be difficult.

Figure 4. The cartoon by Henry De La Beche.

In Mesozoic coprolite beds, the fossilized marine reptiles recorded include ichthyosaurs, plesiosaurs and pliosaurs. Amongst the terrestrial reptile genera recorded are *Craterosaurus, Dinotosaurus, Megalosaurus* and *Iguanodon*. The scattered records include both Jurassic and Cretaceous reptiles. Mesozoic crocodiles, turtles, sharks, and a variety of shells, particularly ammonites, belemnites and other molluscs have also been found. It is likely that the calcareous shells were replaced by phosphate after death and burial (McKerrow, 1978).

Professor John Henslow (Charles Darwin's mentor), his assistant Seeley and their students visited the active mid 19th century coprolite diggings around Cambridge and amassed a collection now housed in the Sedgwick Museum, Downing Street, Cambridge. A small selection is on display. A thorough search of Victorian geological literature and of museum records could extend the list of genera found though some identifications are probably rather loose and the locality records were often rather vague at that time, as the Victorian palaeontologists wished to keep their sources secret.

In addition to Cretaceous coprolites, numerous bones of Pleistocene mammals were recovered from the overburden on some of the coprolite pits and were added to the mixture. Neither coprolite diggers nor palaeontologists made much attempt to differentiate Cretaceous from Pleistocene finds. Though they were still bone and less soluble, they contributed to fertilizing properties over a longer period. The Pleistocene mammals included mammoth, rhinoceros, hippopotamus, deer, pig, hyena, oxen and horse. In Suffolk there were scattered finds of early Pleistocene mammal bones as well as teeth from the sharks *Carcharadon* and *Lamna* and there were occasional records of whale ear bones.

The early Pleistocene Crags of Suffolk and Essex were an important source of coprolites, mainly mammal bones concentrated at the base of the Red Crag. In 1866 Woodward noted a large accumulation at Sutton, amounting to some 220 tons, collected over the area north of Felixstowe. Gravelly lag deposits with local concentrations of phosphatic nodules marking winnowing events have been found in Tertiary clays of the southern North Sea (Balson, 1987).

P_2O_5	26.75	25.29	27.01
CaO	43.21	45.39	46.60
Insoluble siliceous matter	8.64	6.22	6.04
Al_2O_3	1.36	2.57	1.41
Fe_2O_3	2.46	1.87	2.08
MgO	1.12	0.48	1.06
Na_2O	0.50	0.73	n.d.
K_2O	0.32	0.84	n.d.
Moisture & organic matter	4.63	4.01	3.52
CO_2	6.66	5.13	5.49
SO_3	0.76	1.06	n.d.
F and loss	4.96	4.95	6.79

Analyses (%) of three nodules (from Voelcker, 1860).

Composition

The coprolite nodules are black, grey, brown or yellow lumps of impure calcium phosphate with the largest weighing over a kilogram. The mineral composition was investigated in the 19th century and is mainly carbonate-apatite ($Ca_5(PO_4,CO_3)_3F$), in which the carbonate ion replaces at least some of the fluorine ions present in apatite. This is sometimes known as phosphorite, though that term is better restricted for any commercial material containing phosphorus. The fossil bones were originally phosphate in the form of hydroxyl-apatite. The enclosing concretionary material, mainly calcium carbonate, was derived by nucleation from the surrounding sea-water.

The variation between nodules is attributable to the varied amounts of indigestible remains of fish etc. Commercial analyses usually express the phosphate content as a percentage of P_2O_5 which is generally around 25% in the nodules. Analytical records of various alleged phosphate minerals have included dahllite, francolite and floridite, all of which are now discredited as definable minerals (see also Dana, 1898).

Phosphate rocks have been produced at several localities in the Lower Palaeozoic rocks in Wales but none of these appears to be coprolite and of course the large reptiles had not appeared then. A comprehensive survey and list of analyses of both British and foreign phosphate deposits was prepared by Notholt & Highley (1979). Analyses of coprolites from the Speeton Clay of east Yorkshire were provided by Scott et al. (1987). Comparable analyses of a large dinosaur coprolite from the Cretaceous of Saskatchewan, Canada, have been given by Chin et al. (1998). Phosphate is sometimes associated with uranium in other contexts but no reference to uraniferous coprolites has been located.

Sources

Though bony fossils and nodules found at the base of the Red Crag in the cliffs at Felixstowe were ground up and used as fertilizer in Suffolk and Essex in the late 1820s, the chemical manure industry did not blossom until Lawes' patent in 1846. John Bennett Lawes apparently bought his patent from Sir John Murray who had introduced chemical manure in Belfast (later Dublin) in 1817 by treating bone meal with sulphuric acid and he took out a Scottish patent in 1842. Murray also gave lecture courses on the benefits of chemical manures in both Belfast and Dublin. Lawes bought Murray's patent in 1846 and established his first factory at Deptford in London but later moved to Neptune Quay in Ipswich, where much of the product was shipped out via the River Orwell. In 1843 Lawes inherited his father's estate at Rothamsted where he experimented with fertilizers and founded the Agricultural Research Institute which survives to this day.

Treatment of the phosphatic nodules with sulphuric acid produced what Lawes dubbed "superphosphate", effectively a mixture of calcium mono-, di-, or tri-

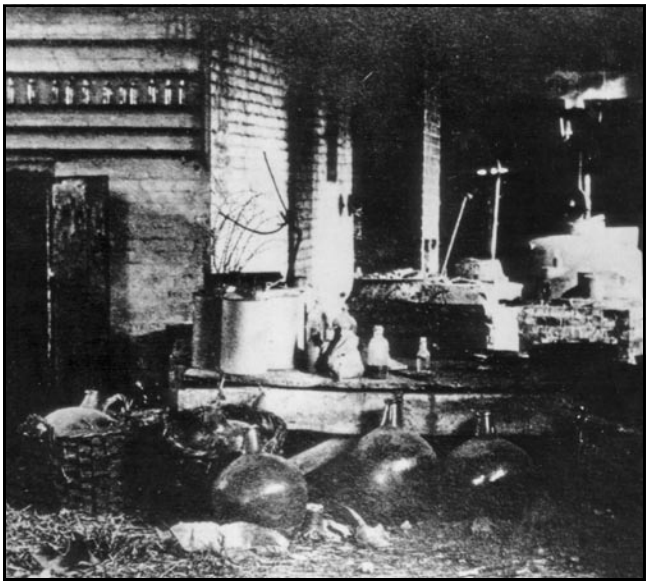

***Figure 5**. Inside the Lawes' Chemical Manure factory at Rothamsted, where superphosphate was first made (photo: Institute of Agricultural History and Museum of Rural Life, University of Reading).*

hydro-phosphate and calcium sulphate, much more soluble and thus more accessible to growing plants. A by-product was an awful smell, mostly hydrogen sulphide, which soon forced the removal of the works to a countryside locality on the River Orwell at Bramford outside Ipswich.

The German chemist Justus von Liebig is also credited with having discovered the fertilizing properties of phosphate rock treated with sulphuric acid about 1840; it is therefore a moot point as who should be credited with the first discovery, whether it was Murray, Lawes or Liebig..

Later the focus of the industry moved to Cambridgeshire following Professor Henslow's remarks to the British Association for the Advancement of Science when it met in Cambridge in 1846. He drew attention to the coprolite nodules in various Cretaceous strata near that town. The earliest recorded exploitation of coprolite beds in Cambridgeshire was in 1848 when John Ball opened pits at Burwell, near Newmarket; he used a windmill to grind the nodules. This was only two years after Henslow's report and within another year or so several other coprolite pits were opened near Cambridge. The coprolite diggers also put choice nodules with fossils on one side for lucrative sale to both professors and students at the Geology Department of the University of Cambridge, and some were offered for sale on market stalls. The nodule distribution was noted as being in a belt of country rarely more than 8 km wide along the foot of the Chalk escarpment from Cambridgeshire into Bedfordshire, Buckinghamshire and Oxfordshire, roughly the outcrop of the Gault and Greensand Formations. Though these are marine strata, they also contain fossils of terrestrial animals, which are thought to have been washed in by rivers draining the London land-mass.

Stratigraphic Distribution

The stratigraphic horizons with phosphatic nodules include the base of the Woburn Sands (Lower Cretaceous) around Great and Little Brickhill, Buckinghamshire, and around Ridgmont and Potton in Bedfordshire, where the Potton Nodule Bed was an important phosphate source. The so-called Junction Beds yielded coprolites at the base of the Gault near Leighton Buzzard, and the Shenley Hill Limestone was a calcite-cemented nodule bed overlying the equivalent Silver Sands near Leighton Buzzard. The base of the Upper Gault had coprolite beds at several localities between Towersay, near Thame, Oxfordshire, and Slapton, Buckinghamshire, and the basal Gault around Sandy, Bedfordshire, was an important horizon. Nodules have occasionally been worked at the base of the Gault near Folkestone, Kent, and Farnham, Surrey. The Cambridge Greensand, a sandy facies of the Upper Gault, which marked a non-sequence at the base of the Chalk Marl, was particularly rich in nodules and became an important horizon for exploitation.

These coprolite-bearing formations crop out along a tract 80 km long from Harlington, east Bedfordshire, to Soham, Burwell, Swaffham and Upware in Cambridgeshire (Fig. 6). Indeed some two dozen separate pits were opened around Cambridge. Coprolites were also obtained from equivalent strata near West Dereham and Crimplesham in Norfolk and from the Lower Cretaceous Speeton Clay on the

***Figure 6**. The main outcrops of the coprolite-bearing beds within the Lower Greensand, Gault and Red Crag series.*

Yorkshire coast, where winnowed horizons can be found on the foreshore; underground mining was attempted at Speeton without much success. A little underground mining was also tried at Bassingbourn in Cambridgeshire but flooding problems soon caused abandonment. A few nodules were obtained from the late Cretaceous Carstone of Norfolk and Lincolnshire. Phosphate rock at the base of the Spilsby Sandstone (Portlandian) in Lincolnshire was investigated during World War II but no production ensued. Some production was obtained from the Cambridge Greensand around Trumpington and Grantchester, Cambridge, during World War I and other localities at this horizon were investigated but were considered uneconomic.

"Hard grounds" representing brief emergence episodes in the Chalk show local concentrations of phosphate but none have proved profitable to any extent in England, in contrast with France and Belgium. Phosphatic Chalk was investigated near Taplow, Bucks., during both World Wars. Other Chalk localities investigated included Boxford and Winterbourne in Berkshire. The Glauconitic Marl of the Isle of Wight was also tested. Nodules have also been recorded in the Jurassic strata at Brora in northeast Scotland, and in the Upper Cretaceous Greensand of Morven in the western Highlands and in Antrim in Northern Ireland.

Most of the Cretaceous formations that contain the phosphates are fairly thin across the margins of the London land mass, and winnowing concentrated nodules in beds usually less than half a metre thick at or near the base of each unit. Occasionally nodules were concentrated in sea-bed hollows. Some winnowing of the underlying late Jurassic Kimmeridge Clay also occurred and thus Jurassic reptile bones were found in Cretaceous nodule beds.

Bones and fragments, mainly mammal, some enclosed in phosphatic nodules, are well-known in the early Pleistocene strata of east Suffolk, particularly the base of the Red Crag along the Deben and Orwell valleys and in the cliffs near Felixstowe. The nodule bed was worked at several localities on either side of these estuaries, particularly at Sutton, Butley and Waldringfield. There was even concern that the Red Crag might be totally removed as a geological formation (Charlesworth, 1868). Coprolite pits and works are scattered on the early Ordnance Survey maps but little can be seen today. In most of these occurrences the Red Crag lies on the Eocene London Clay and some of the fossils or nodules were winnowed out of the latter to be concentrated at the unconformity. Similar but small concentrations of nodules can be still found in the well-known exposures of the Red Crag at Bawdsey Cliff, north of Felixstowe, and at Walton-on-the-Naze, in Essex. Though the nodules are not common today they were sufficiently abundant in 1866 to yield a stockpile of 220 tons at Sutton. A similar lag gravel was also found at the base of the Coralline Crag at Sudbourn, near Orford, but this formation has only a limited extent and it seems that only one pit was worked there.

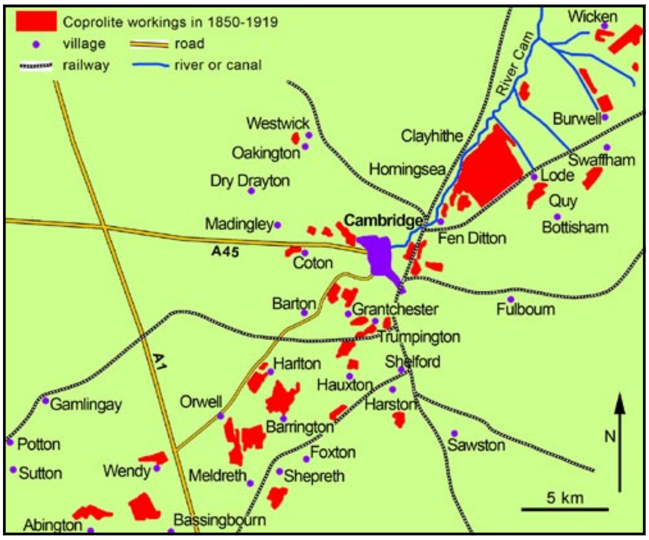

Figure 7*. Coprolite workings around Cambridge (after map by Sedgwick Museum).*

Phosphatic nodules occur on hard grounds in most of the Jurassic ironstones with phosphate content being around 1%. Mass production methods of ironstone working did not separate the nodules and the Northampton Sand, Marlstone, Frodingham and Cleveland Ironstones yielded iron and steel where the phosphorus content was undesirably high. Some of it was removed in basic slag, which was sometimes ground up and sold as fertilizer.

Though phosphatic nodules also occur in several other stratigraphic formations, such as the Lower Lias of Dorset and Gloucestershire, the Middle Lias of East Leicestershire, and the London Clay of Hertfordshire, there seems to have been no attempt to work them.

Extraction

Prospecting for phosphatic nodules was by observing the occasional sample thrown up by ploughing and in marl pits. Cliffs along the coast and rivers revealed more nodules. Sufficient nodules led to pits being excavated in appropriate fields. Later a hand-operated

Figure 8. *Coprolite diggings at Trumpington, Cambridge, during World War I, with an early dragline in the background (photo: Cambridgeshire Collections).*

Figure 9. *Digging for coprolites at Great Brickhill (photo: Buckinghamshire County Museum).*

corkscrew borer was used to test for the abundance of coprolites. Once located, coprolite production was by open-cast methods and whole fields were torn up. A few unsuccessful attempts were made to follow seams by underground mining. The removal of up to 8 metres or so of overburden uncovered coprolite nodule beds up to around half a metre thick. Up to 2000 tons per acre have been claimed, though around 250 tons per acre was usual, making the land much more profitable than agriculture. Up to 500 tons per annum were recorded at Speeton (Scott *et al*. 1987). Coprolite digging was a labour-intensive industry with thousands being employed and barracks to house workers were sometimes erected. During World War I extraction became mechanized and early draglines were used at Trumpington near Cambridge. Most of the works were operated by men but women were occasionally employed in washing procedures, e.g. at Potton. Coprolite-mining communities sprang up and became the focus of secondary trades with catering establishments, public houses and chapels being opened nearby. Ancillary trades such as carpenters, blacksmiths and engineers also developed around the workings.

Once raised, the nodules were processed to remove unwanted clay and sand by washing either in a trough or in a cylindrical wash-mill using water from wells or drawn from a nearby river. Surplus clay and sand were returned to worked-out diggings and fields; though very muddy the latter were returned to agriculture perhaps slightly lower in altitude. Nodules were usually carried to a processing plant at a nearby locality using carts (locally known as tumbrils). Temporary tram roads had trucks running on L-shaped rails drawn along by horses or, later, by steam engines (Fig. 10).

As output grew, barges on rivers and canals were used until railways reached the area in the 1860s onwards. Centralization grew with a few mills crushing and grinding the nodules in preparation for acid treatment. Some bulk transport went by sea and there is still a Coprolite Street by Neptune Quay at Ipswich. Nodules were also shipped to Barking for processing there. In the last years of the industry it became mechanized and early draglines and steam shovels were used to remove the overburden and both light railways and lorries were used for transport.

Figure 10. *An early steam railway used for transporting coprolites; Whaddon, near Meldreth, Cambridgeshire (photo: Mrs Coningsby, Whaddon).*

Figure 11. *Transporting coprolites by tumbril to Millbrook Station, Bedfordshire (from an old postcard).*

Utilization

Following the Industrial Revolution the need to feed the growing work-forces in the cities necessitated improvements in agricultural production in the early 19th century. Land-owners soon appreciated that the addition of bone meal improved crop yields and it was not long before it was realized that phosphate was the critical factor. However, bone meal only dissolves slowly in soil water and in 1842 John Bennett Lawes, a Hertfordshire landowner, discovered that ground-up phosphatic nodules from the Red Crag and other strata near Felixstowe were much more soluble if sulphuric acid was added. Suffolk manure merchants such as William Colchester, Edward Packard and Joseph Fison became interested and followed Lawes' lead in collecting nodules from the Red Crag. Lawes patented his discovery as "superphosphate" and works were set up in Ipswich and on his estate at Rothamsted; another superphosphate works was operated by Lawes on Thames-side docks at Barking. Colchester, Packard, Fison and the Prentice Brothers had fertilizer works in Ipswich but later moved to near Bramford and Stowmarket further up the Orwell valley. Transport was by lighters on the river. Joseph Fison later merged his company with the others and built up today's Fison's agricultural chemicals industry with a base at Levington, down river from Ipswich. There is still a short Coprolite Street in Ipswich: the site of the works was later used by Ransome's lawnmower factory but it is now occupied by an apartment block. Several coprolite mills were set up in and around Cambridge and some of that city's stylish Victorian buildings were built out of the profits.

Coprolite contractors paid landowners up to £200 per acre for the right to raise the nodules which they sold for up to £3.75 per ton. At a yield of 250 tons per acre this gave them a good profit margin particularly as labour costs were low. Statistics of coprolite production are incomplete, but a total of about 1.2 million tons was raised between 1874 and 1909. A reasonable estimate of the pre-1874 yield is around 737,000 tons, making an overall total of two million tons. Of this about 325,000 tons came from Suffolk, mainly from the Red Crag. Production expanded across the southeast Midlands counties in the 1850s and 1860s and peaked in the 1870s, when 258,150 tons of coprolites were recorded in 1876. Thereafter production fell rapidly to a maximum of 30,000 tons per annum in the 1880s. The last pit near Cambridge was at Burwell, worked intermittently until 1919. Only 4 tons were recorded in 1909 but there was a temporary resurgence of production at Trumpington, near Cambridge, during World War I when imports were restricted: prisoner of war and Irish republican labour were used. The decline was a result of exhaustion of the accessible nodule seams and increasing depth of overburden to be removed. The islands off Peru had largely been stripped of guano by the 1870s and there was increasing competition from imports of rock phosphate. At the same time, demand fell owing to cheap foodstuffs being imported from Argentina and Australia etc. Investigations of the possible utilization of phosphatic chalk during World War II came to nothing.

Much of the phosphate used in Britain today, over a million tonnes per annum, is imported from late Cretaceous to Eocene rock phosphate strata in north and west Africa, particularly Morocco and Senegal; lesser amounts come from Tunisia, Egypt, Jordan, Israel and Mauritania. Phosphatic guano deposits have been dug from several Pacific Islands, such as Nauru, leaving a bare karst landscape.

In spite of what must have been an intensive industry in Victorian times, with large tracts of land being torn up, there is little to show for it today, except for collections in the Sedgwick and other museums. There is little archaeological evidence to be found. A few flooded trenches can still be found near Quy Fen, east of Cambridge. Most pits have been back-filled and some have been built over. One cannot help wondering how many fossil species were lost to science by being ground up for use as fertilizer.

Figure 12. *Coprolite Street, Ipswich, today (photo: Chris Duffin).*

***Figure 13**. Lawes Chemical Manure works on the River Thames at Barking (photo: Valence House Museum).*

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Further Reading

Balson, P.S., 1987. Authigenic phosphorite concentrations in the Tertiary of the southern North Sea basin: event stratigraphy. *Meedelingen var de werkgroep voor Tertiaire en Kwartaire Geologie,* **24**(1-2), 79-94.

Bidwell, C., 1874. Coprolites. *Proceedings of the Institute of Surveyors,* April 27, 293-332.

Bishop, P., 1995. *The History of Ipswich.* Unicorn Press: London.

Buckland, W., 1824. *Reliquiae Diluvianae.* London. 2nd edition, 303pp.

Buckland, W., 1829. On the discovery of Coprolites, or fossil faeces, in the Lias of Lyme Regis and in other formations. *Transactions of the Geological Society of London,* Ser. 2, **iii**, 223-238.

Buckland, W., 1836. *Geology and Mineralogy considered with reference to Natural Theology.* (Bridgwater Treatise) 2 vols., Pickering: London.

Charlesworth, E., 1868. On the prospective annihilation of the Suffolk Red Crag as a geological formation, with a few remarks about the Red Crag phosphatic stones. *Geological Magazine,* **5**, 577-580.

Chin, K., Tokaryk, T., Erickson, G.M. & Calk, L. C., 1998. A king-size theropod coprolite. *Nature,* **393**, 680-682.

Dana, R.D. 1898. *System of Mineralogy.* 6th edition, New York.

Duffin, C. J., 2006. Coprolites. *History of Geology Group Newsletter,* 27, 7.

Duffin, C. J., 2006. William Buckland 1784-1856. *Geology Today,* **22**, 104-108.

Duffin, C. J., 2009. "Records of warfare ... embalmed in the everlasting hills": a history of early coprolite research. *Mercian Geologist,* **17**, xx-xx.

Edmonds, E.A. & Dinham, C.H., 1965. *Geology of the Country around Huntingdon and Biggleswade.* Mem. Geological Survey.

Fisher, O., 1871. The coprolite pits of Cambridgeshire. *Geological Magazine,* **8**, 65-71.

Ford, T.D. & O'Connor, B., 2002. Coprolite mining in England. *Geology Today,* **18,** 178-181; also **19**, 198 (2003).

Grove, R., 1974. *The Cambridge Coprolite Mining Rush.* Oleander Press: Cambridge, 51pp.

Grove, R., 1974. Coprolite mining in Cambridgeshire. *Agricultural History Review,* **24**, 36-43.

Henslow, J.S., 1846. On nodules, apparently coprolitic, from the Red Crag, London Clay and Greensand. *Report of the British Association,* 51-52.

Hughes, T. McK., 1884. Excursion to Cambridge. *Proceedings of the Geologists Association,* **8**, 399-404.

Judd, J.W., 1868. On the Speeton Clay. *Quarterly Journal of the Geological Society,* **24**, 218-252.

Jukes-Brown A.J. & Hill, W., 1900 & 1903. *The Cretaceous Rocks of Britain.* Memoir of the Geological Survey.

Lamplugh, G.W., 1889. On the subdivisions of the Speeton Clay. *Quarterly Journal of the Geological Society,* **45**, 575-618.

McKerrow, W.S., 1978. *The Ecology of Fossils.* Duckworth: London.

Malster, R., 1978. *A History of Ipswich.* Phillimore: Chichester.

Notholt, A.J.G. & Highley, D.E., 1979. *Dossier on Phosphate.* Report for the Commission of the European Communities by Institute of Geological Sciences.

Oakley, K.P., 1941. *British Phosphates.* Geological Survey Wartime Pamphlet, 8, pt. 3.

O'Connor, B., 1993. The origins and development of Britain's coprolite industry. *Subterranica Britannica,* 290, 21-31.

O'Connor, B., 2001. The origins and development of the British coprolite industry. *Mining History,* **4**(5), 46-57.

Packard, W.G.T., 1952. The history of the fertilizer industry in Britain. *Proceedings of the Fertiliser Society,* **19**, 5-42.

Scott, P.W., Kimgongust, N. & Middleton, R., 1987. The mineralogy and petrology of the coprolite phosphate deposit (Lower Cretaceous) at Speeton, Yorkshire. *Proceedings of the Yorkshire Geological Society,* **46**, 123-131.

Sharpe, T., 2004. (Buckland's Coprolite Table). *Geology Today,* **20**(4), 129-130.

Strahan, A., 1917. *Phosphate of Lime.* Geological Survey Special Report on Mineral Resources, **5**, 15-24.

Teall, J., 1875. *The Potton and Wicken Phosphatic Deposits.* Deighton & Bell: Cambridge.

Tye, W., 1930. The birth of the fertilizer industry, *Fisons Journal,* 4.

Voelcker, A., 1860. On the chemical composition and commercial value of Norwegian apatite, Spanish phosphorite, coprolites and other phosphatic materials used in England for agricultural purposes. *Journal of the Royal Agricultural Society,* Series 1, **21**, 350-381.

Walker, J.F., 1867. On some new coprolite diggings in the Fens. *Geological Magazine,* **4**, 309-310.

Woodward, H., 1866. An excursion to the Crag District. *Intelligent Observer,* **8**, 37-39.

Worssam, B.C. & Taylor, J.H., 1969. *Geology of the country around Cambridge.* Memoir of the Geological Survey, 159 pp.

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