Johann Christian Wiegleb and the first published chemical analyses of archaeological bronzes

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ABSTRACT: This paper focusses attention on what is currently believed to be the earliest published chemical analysis of archaeological bronze artefacts, attributable to Johann Christian Wiegleb in 1777. Not only is this publication 13 years earlier than the previously-identified 'earliest' publication, it is extremely early in the history of gravimetric analysis (wet chemistry, or 'analysis by the humid method') and is therefore significant in the history of analytical chemistry. As well as pushing the history of analytical chemistry applied to archaeological materials back to the beginning of quantitative analytical chemistry itself, the opportunity is taken to update the list of such publications between 1790 to 1869 (Pollard 2015a) from 118 to 305, and the number from which data have been digitized from 30 to 49, thereby reporting 2825 analyses from this period. Both the list of publications and the digitized data are available at http://flame.arch.ox.ac.uk/public-resources/.

Archaeometallurgical chemistry up to 1869

Building on previous work on the early history of archaeometallurgical chemistry (Bleck 1966-1971; Brandt and Riederer 1978; Caley 1948; 1949a; 1949b; Forbes 1940-1950; Riederer 1982), Pollard (2015a) compiled a list of all of the papers known to him at that time dating to before 1869 containing the chemical analyses of archaeological copper alloys. This list contained 118 publications, although not all reported chemical analyses. The date of 1869 was chosen as the cut-off since that was the year that Dr Ernst Freiherr von Bibra (1806-1878) published the first major corpus of such data, comprising 1250 analyses, of which 600 were his own, and the other 650 were taken from earlier work by at least 90 different analysts. Continuing work has shown that this list is a substantial underestimate of the number of relevant papers in this period, although the total number of new chemical analyses revealed is not large. A fully updated and consolidated list of these publications, currently numbering 305, is now available on the University of Oxford's School of Archaeology FLAME project website (http://flame.arch.ox.ac.uk/public-resources/historical-metal-data/Historical-Papers-1790-1869.docx).

Part of the interest in compiling this list was to identify the first chemist to publish quantitative analyses of archaeological metal objects, in order to contextualize such analyses within the history of analytical chemistry. For many years, this distinction has been conferred upon Martin Heinrich Klaproth (1743-1817), largely as a result of the work of Caley (1949a). Although Klaproth was undoubtedly one of the most significant early archaeological chemists, as well as being the 'father' of mineralogical chemistry, his famous publication dated 1792/3 (but actually read 9th July 1795), in which he reported the chemical analyses of six Greek and nine Roman coins, was not the first to do so. Pollard (2013; 2015a) identified Michel Jean Jérome Dizé (1764-1852) as the earliest author to publish such quantitative data. His paper reported the tin content of five Roman, one Greek and two Gallic copper alloy coins (Dizé 1790). Significantly, however, Pollard (2015a) also showed that earlier chemical analyses of archaeological metals must have been carried out, and were occasionally referred to, but were not actually published in full so it is not possible to know how they were done, and whether they were quantitative. For example, there is a reference to the 'accurate assay' of a 'sword … found in a bog at Cullen, in the County of Tipperary, in Ireland' in a paper read by Governor Pownall at the Society of Antiquaries (London) on 10 February 1774 (Pownall 1775). Two swords are illustrated, but it is not clear which one was analysed. The analysis of is attributed to 'Mr. Alchorn, his Majestie's assay-maker', who is presumably Stanesby Alchorne (1733-1800), assistant to Joseph Harris, Mint-Master, from 1757, and the King's assay-master from 1789. Alchorne reports:

> 'It appears to be chiefly copper, interspersed with particles of iron, and perhaps some zinck, but without containing either gold or silver: it seems probable, that the metal was cast in its present state, and afterwards reduced to its proper figure by filing. The iron might either have been obtained with the copper from the ore, or added afterwards in the fusion, to give the necessary rigidity of a weapon. But I confess myself unable to determine any thing with certainty.' (Pownall 1775, 355-356).

Mr Alchorne was a naturalist and plant collector at Chelsea Physic Garden before he joined the Mint. He appears to have published little of his metallurgical activities in his own name (exceptions being the analysis of ores in Fordyce and Alchorne (1779) and some experiments on the effect of tin on gold in Alchorne (1784)), but his work is occasionally referred to by others, as in Pownall (1775) above. Another example, showing that he produced quantitative data, is Mills (1800, 467), in which he reports two analyses of native Irish gold.

The interest in this early work lies not only in documenting the early history of the chemical analyses of archaeological metals, but also in recovering the data themselves. There has been an increasing interest in the use of 'legacy' data in the interpretation of archaeological copper alloys (*eg* Pollard *et al* 2018) – partially because most of it is now unrepeatable, and partly because, as the work reported here shows, there is a large amount of it, even when compared with modern analytical campaigns. Clearly, in the early stages of analytical chemistry, it is highly unlikely that the analyses are particularly reliable. Many are very partial – sometimes only tin is reported, or at best copper and tin together. However, by the end of the period under consideration here (*ie* up to 1869), most analysts are reporting up to 10 elements, with (mostly) a high degree of accuracy. Another motivation for compiling the data from these publications, therefore, was to 'rescue' the analytical data for posterity. The Excel database on the FLAME website (http://flame.arch.ox.ac.uk//public-resources/historical-metal-data/data_historical-metallurgy-1790-1869_08012019.xlsx) contains some of the larger analytical data sets published up to 1869, cross-referenced where possible to the earliest known publication of the individual analyses. When first posted, this database contained data from 30 publications, but the current version lists 49 papers, and more may be added as they come to light. Table 1 lists the publications from which these data have been abstracted, with the post-2015 additions and amendments to it starred. The total number of analyses listed is 2825, but this includes considerable duplication. The largest individual contributions are von Bibra (*c*600) and von Fellenberg (205).

The contribution of Johann Christian Wiegleb

It is in this context that we must consider the publication of Johann Christian Wiegleb (1732-1800), entitled *Chemisch Untersuchung einiger künstlichen Metallarten, woraus verschiedene aus dem Altertum herrührende Instrumente versertiget gewesen, welche im vorigen Jahre in einer benachbarten Gegend gefunden worden find*, which was read to the Kurmainzische Akademie Nutzlicher Wissenschaften, Mainz, on 2 April 1777 (Wiegleb 1777a). This paper was referred to in volume 3 of Partington's *History of Chemistry* (Partington 1962, 567-9), but its full contextual significance was not commented upon. From the title (Chemical examination of some artificial types of metal, from which various instruments originating from antiquity were made, which were found in a neighboring area in the previous year) it is clear that this paper represents the earliest currently known full publication of such work. Wiegleb was an apothecary who was born on 21 December 1732 in Langensalza, Electorate of Saxony (now Bad Langensalza, Germany). Between 1748 and 1754 he became an apprentice-apothecary in Dresden, and from 1754 to 1755 he was appointed assistant to an apothecary in Quedlinburg. He returned to Langensalza and in 1759 he established his own apothecary, which he directed until 1796. He died at the age of 67 on 16 January 1800 in Langensalza. As well as running an apothecary, he was also recognized as a distinguished chemist, being appointed to the Kurmainzische Akademie Nutzlicher Wissenschaften (Electoral Mainz Academy of Useful Sciences) and the Leopoldina (Deutsche Akademie der Naturforscher Leopoldina – Nationale Akademie der Wissenschaften).

His broader publications in chemistry were prolific

Table 1: Publications up to 1869 which contain multiple quantitative chemical analyses of archaeological copper alloy objects.

Date	Reference	No of analyses
1790	Dizé M J J 1790, 'Analyse du cuivre, avec lequel les Anciens fabriquoient leurs médailles, les instruments tranchans', *Observations sur la Physique, sur l'Histoire Naturelle et sur les Arts* 36, 272-276. [also listed as *Journal de Physique*, April 1790]	8
1792-3*	Klaproth M H 1792 and 1793, 'Mémoire de numismatique docimastique', *Mémoires de l'Academie Royale des Sciences et Belles-Lettres depuis l'avénement de Fréderic Guillaume II au Trône. (Classe de Philosophie Expérimentale)*, 97-113. [published Berlin 1798]	15
1796	Pearson G 1796, 'Observations on some metallic arms and utensils; with experiments to determine their composition', *Philosophical Transactions of the Royal Society of London* 86, 395-451.	7
1799	Dizé M J J 1799, 'Mémoire sur la séparation, par la voie humide, du zinc uni a cuivre, alliage connu sous la dénomination de cuivre jaune, de laiton et de similor; suivi d'une analyse de cinq espèces de monnoies de cuivre, grecques et romaines', *Journal de Physique, de Chimie, d'Histoire Naturelle et des Arts* 48, 173-183.	5
1804	Mongez A 1804, 'Mémoire sur le bronze des anciens et sur une épée antique', *Mémoires de l'Institut National, Classe de littérature et beaux-arts* 5, 187-228.	10
1804	Mongez A 1804, 'Second mémoire sur le bronze antique, sur des épées et un anneau élastique des anciens', *Mémoires de l'Institut National, Classe de littérature et beaux-arts* 5, 496-516.	5
1808*	Klaproth M H, 'Analyses de plusiers alliages antiques d'airain et de deux substances minerales', *Journal des Mines* 23, 161-176 (1808).	9
1815	Klaproth M H 1815, *Chemische Abhandlungen Gemischten Inhalts* (Nicholaischen Buchhandlung, Berlin and Stettin) [Vol 6 of *Beiträge zur Chemischen Kenntniss der Mineralkörper*].	40
1823*	Gill T 1823, *The Technical Repository, containing practical information on subjects connected with the discovery and improvements in the useful arts* (Cadell, London).	28
1826*	Parkes S 1826, 'An account of the analyses of some Roman coins selected from the several Series denominated Large, Middle and Small brass', *Quarterly Journal of Science, Literature and the Arts* 21, 301-319.	22
1827	Hünefeld L and Picht F 1827, *Rügens metallische Denkmäler der Vorzeit, vorzugsweise chemisch bearbeitet, und als Beitrag zur vaterlandischen Alterthumskunde herausgegeben* (Leopold Voss, Leipzig).	10
1836-7	Berzelius J 1836-7, 'Undersökning af metallmassen i några fornlemningar', *Annaler for Nordisk Oldkyndighed*, 104-108.	10
1839*	Schubarth E L 1839, *Handbuch der technischen Chemie: zum Gebrauch beim Unterricht im Königl. Gewerbinstitut und den Provinzial-Gewerbschulen des preuß. Staats; 1* (Rücker and Püschler, Berlin).	13
1842	Göbel F 1842, *Ueber den Einfluss der Chemie auf die Ermittelung der Völker der Vorzeit oder Resultate der chemischen Untersuchung metallischer Alterthümer insbesondere der in den Ostseegouvernements vorkommenden, Behuss der Ermittelung der Völker, van welchen sie abstammen* (Ferdinand Enke, Erlangen).	119
1842*	Kruse F 1842, *Necrolivonica, oder Alterthümer Liv-, Esth- und Curlands bis zur Einführung der Christlichen Religion in den Kaiserlich Russischen Ostsee-Gouvernements* (Voss, Leipzig).	84
1842*	Schreiber H 1842, *Die eheren Streitkeile zumal in Deutschland. Eine historisch-archäologische Monographie* (Gebrüder Groos, Freiburg).	29
1844*	von Santen H L 1844, *Chemische Analysen antiker Metalle aus heidnischen Gräbern Mecklenburgs, mit antiquarischen Einleitungen und Forschungen begleitet von G. C. F. LISCH* (Schwerin).	38
1845	Moëssard A 1845, 'Analyse de divers coins de bronze antiques, trouvés dans le department de l'Oise', *Comptes rendus hebdomadaires des séances de l'Académie de Sciences* 21, 1177-1179.	7
1847	Erdmann O L 1847, 'Zusammensetzung einiger altgriechischen bronzemünzen', *Journal für praktische Chemie* 40, 371-374.	8
1848*	Onnen H 1848, 'Untersuchung einiger sorten von chinesischen kupfer', *Journal für Praktische Chemie* 44, 242-244.	9
1849*	Mallet J W 1849, 'Report on the chemical examination of antiquities from the Museum of the Royal Irish Academy', *Transactions of the Royal Irish Academy* 22, 313-342.	18
1850*	Sabatier J and Sabatier L 1850, *Production de l'or, de l'argent et du cuivre chez les anciens et hôtels monétaires des Empires Romain et Byzantin* (Bellizard, Saint-Péterbourg).	33
1851	Wilson D 1851, *The archaeology and prehistoric annals of Scotland* (Sutherland and Knox, Edinburgh).	8
1852	Berlin N J 1852, 'Några materialier för bedömandet af sammanhanget mellan de antika bronsernas sammansättning och ålder', *Annaler for Nordisk Oldkyndighed og Historie*, 254-271.	25
1852	Berlin N J, 'Om några nordiska metall-legeringars sammansättning', *Annaler for Nordisk Oldkyndighed og Historie*, 249-254.	193

Table 1 continued

Date	Reference	No of analyses
1852*	Bobierre A 1852, 'Untersuchungen über die dauerhaftigkeit der bronze als schiffsbeschlag', *Dingler's Polytechnische Journal*, 187-191.	11
1852	Girardin J 1852, 'Analyse de plusieurs produits d'art d'une haute antiquité', *Mémoires présenté par divers savants à l'Academie des inscriptions et belles-lettres de l'Institut de France* (series 1) 2, 86-104.	4
1852	Phillips J A 1852, 'A chemical examination of the metals and alloys known to the ancients', *The Quarterly Journal of the Chemical Society of London* 4, 252-300.	37
1853*	Girardin J 1853, 'Analyse sehr alter kunstprodukte', *Journal für praktische Chemie* 60, 89-94.	18
1853*	Hawranek J 1853, 'Chemische zusammensetzung eines mergels und eines hippuritenkalkes aus der Gosau, so wie einiger antiker bronzen', *Journal für praktische Chemie* 60, 443-444.	4
1854*	Wocel J E 1854, *Archäologische Parallelen* (Kaiserlich-Königlichen Hof- und Staatsdruckerei, Wien).	26
1855*	Wocel J 1855, 'Archäologische parallelen', *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften. Philosophisch-Historische Classe (Wien)* 16, 169-227.	131
1855*	Uvarov A S 1855, *Recherches sur les antiquités de la Russie méridionale et des Côtes de la mer Noire* (Ouvaroff , St Pétersbourg).	9
1855*	Otto F J 1855, *Graham Otto's Ausführliches Lehrbuch der Chemie dritte umgearbeitete auflage. Zwitter band in drei abtheilungen. Anorganische Chemie von Dr. Fr. Jul. Otto,* 3rd edn (Vieweg und Sohn, Braunschweig).	55
1856*	Napier J 1856, *The ancient workers and artificers in metal, from references in the Old Testament and other ancient writings* (Simpkin, Marshall and Co, London).	34
1857*	Erdmann O L 1857, 'Vermischte mittheilungen. 6: Antike bronzen aus Oldenber', *Journal für praktische Chemie* 71, 193-215.	4
1857*	Phillips J A and Darlington J 1857, *Records of mining and metallurgy: or facts and memoranda for the use of the mine agent and smelter* (E and F N Spon, London).	12
1858*	Genth F A 1858, 'Contributions to metallurgy, No. 1', *Journal of the Franklin Institute* 36, 261-266.	19
1860	von Fellenberg L R 1860, 'Analysen von antiken bronzen', *Mittheilungen der Naturforschenden Gesellschaft in Bern* Nr 444-446, 43-56; Nr 448-449, 65-79; Nr 459-460, 153-162.	60
1861	von Fellenberg L R 1861, 'Analysen von antiken bronzen', *Mittheilungen der Naturforschenden Gesellschaft in Bern* Nr 474-475, 41-55; Nr 490-491, 173-187.	40
1861	Roux B 1861, 'Observations sur des canons chinois et cochinchinois', *Comptes Rendues Hebdomadaires des Séances de l'Académie des Sciences* 52, 1046-1050.	4
1862	von Fellenberg L R 1862, 'Analysen von antiken bronzen (Fünfte Fortsetzung Von Nr 101 bis 120 inclusive)', *Mittheilungen der Naturforschenden Gesellschaft in Bern* Nr 497-498, 1-14.	20
1862*	Wilson D 1862, *Prehistoric Man. Researches into the origin of civilisation in the Old and the New World,* Vol 1 (Macmillan, Cambridge)	48
1863*	Commaille A 1863, 'Mémoire sur la composition des monnaies et médailles romaines antiques' *Journal de Pharmacie et de Chimie* 44, 5-13.	41
1863	von Fellenberg L R 1863, 'Analysen von antiken bronzen', *Mittheilungen der Naturforschenden Gesellschaft in Bern* Nr 531-532, 43-54; Nr 548, 135-142.	40
1864	von Fellenberg L R 1864, 'Analysen von antiken bronzen', *Mittheilungen der Naturforschenden Gesellschaft in Bern* Nr 566-567, 122-134.	20
1865*	Bischoff E 1865, *Das Kupfer und seine Legirungen* (Julius Springer, Berlin).	106
1865	Church A H 1865, 'Analyses of some bronzes found in Great Britain', *The Journal of the Chemical Society of London* 18, 215-217.	4
1865	von Fellenberg L R 1865, 'Analysen von antiken bronzen', *Mittheilungen der Naturforschenden Gesellschaft in Bern* Nr 580-581, 1-20.	21
1865*	Wibel F 1865, *Die Cultur der Bronze-Zeit Nord- und Mittel-Europas* (Akademische Buchhandlung, Kiel).	25
1866*	von Fellenberg L R 1866, 'Nachtag zu den analysen antiker bronzen', *Mittheilungen der Naturforschenden Gesellschaft in Bern* Nr 613, 261-264.	4
1866*	Struve H 1866, 'Analyse verschneidener antiker Bronzen und Eisen aus der Abakan- und Jenissei-Steppe in Siberien', *Bulletin de l'Académie impériale des Sciences de St-Petersbourg* 9, 282-290.	12
1867*	Stolba F 1867, 'Analyse alterthümlicher bronzeobjecte aus der sammlung des böhmischen museums', *Journal für praktische Chemie* 101, 139-145.	24

Table 1 continued

Date	Reference	No of analyses
1868*	von Sacken E 1868, *Das Grabfeld von Hallstatt in Oberösterreich und dessen Alterthümer* (Braumüller, Wien).	21
1869	von Bibra E F 1869, *Die Bronzen und Kupferlegirung der alten und ältesten Völker, mit Rücksichtnahme aur jene der Neuzeit* (Ferdinand Enke, Erlangen).	1249

Notes: Pollard (2015a, Table 1) contains most entries but those starred are additions or have been amended.
The analytical data can be found at:
http://flame.arch.ox.ac.uk//public-resources/historical-metal-data/data_historical-metallurgy-1790-1869_08012019.xlsx

and influential. Perhaps best-known is his two volume Handbuch der allgemeinen Chemie, published in several editions in Berlin from 1781. It was nominally translated into English by Charles Rivington Hopson (1744-1796) as A general system of chemistry, theoretical and practical. Digested and Arranged, with a Particular View to its Application to the Arts. Taken chiefly from the German of M. Wiegleb (1789), but this version contains a considerable amount from other sources. Wiegleb's other works include Historisch-kritische Untersuchung der Alchemie oder der eingebildeten Goldmacherkunst, von ihrem Ursprunge sowohl als Fortgange, und was nun von ihr zu halten sey (1777b), which is a highly critical review of the concept of the alchemical production of gold. In this he said that alchemy was akin to witchcraft, and saw its continued existence as a threat to the growth of the enlightenment (Principe 2013, 90).

The details Wiegleb gives in his 1777 paper on the analyses of archaeological metal are reasonably clear. Moreover, he gives a description of the process used, and the weights yielded at each step. He discusses four analyses from three objects – 'the handle of a great metal dagger or knife' (§ 2), a 'thin tortuous stalk, from a tomback-coloured brittle metal that was markedly different from the former' (§ 9), 'a wedge-shaped instrument' (§ 13) and 'the ridges of the wedge-shaped instrument' (§ 16).

The process he describes for the first sample involved dissolving 1 drachm of metal (in the apothecaries units of weights and measures, a drachm was one eighth of an ounce, or approximately 3.89g) in nitric acid ('purified saltpetre spirit'), resulting in a blue solution and a white precipitate. After filtration, the solution was dried and weighed, giving 2 grains of precipitate (1 grain = 64.8mg). Somewhat confusingly, he also describes adding iron to the copper solution, which precipitates copper, but does not give the weight. He then extracts the white precipitate in ammonia solution, which extracts further copper, and repeats this until no blue is seen in the extract. He dries and weighs the precipitate, giving 4 grains (approx 260mg). He is clear that this precipitate must be a 'tin-scale', since he notes that it was not gold, and that the other metals (silver, lead, iron, zinc and bismuth) would have dissolved into the copper solution. He tried unsuccessfully to reduce this 'tin-scale' to metal, but noted that by heating with salt of tartar and lead, taking up the residue in 1 drachm of lead, and cupellation of the mass, it yielded a grain of silver. He also carried out a direct cupellation for silver, by heating 1 drachm of the original metal with 16 drachm of lead, and produced 1 grain of silver. The first two of the other three samples are analysed in a similar manner, with the exception that the grain of silver from the second object also contained some gold. The fourth object was only cupelled for silver.

He concludes that all four objects are made from nothing other than copper and tin, and are therefore similar to the 'bronzes of the ancients'. The silver is seen to be unintentional. He gives the following as the composition of three of the four objects, and concludes that the differences in colour are related to the different ratios of copper to tin in the alloy:

§ 2: 18 to 20 parts of copper to 1 part tin (*c*4.8-5.3% Sn)

§ 9: 7 to 8 parts of copper and 1 part tin (*c*11.1-12.5% Sn)

§ 13: 30 parts of copper and 1 part tin (*c*3.2% Sn).

Finally, in common with many 18th and 19th century authors, he compares these analyses with the information given on the manufacture of bronze statues by Pliny:

> 'The proper blend for making statues is as follows, and the same for tablets: at the outset the ore is melted, and then there is added to the melted metal a third part of scrap copper, that is copper or bronze that has been bought up after use. This contains a peculiar seasoned quality of brilliance that has been subdued by friction and so to speak tamed by habitual use. Silver-lead is also mixed with it in the proportion of twelve and a half pounds to every hundred pounds of the fused metal. There is also in addition what is called the mould-blend of bronze of a very delicate consistency,

because a tenth part of black lead is added and a twentieth of silver-lead; and this is the best way to give it the colour called Græcanic 'after the Greek.' The last kind is that called pot-bronze, taking its name from the vessels made of it; it is a blend of three or four pounds of silver-lead with every hundred pounds of copper. The addition of lead to Cyprus copper produces the purple colour seen in the bordered robes of statues.' (Rackham 1952, Book 34, p199).

The term used by Pliny and translated by Rackham as 'silver-lead' is *plumbum argentorium,* which Rackham states is 'Spanish silver lead', consisting of equal amounts of tin and lead. If mixed with the copper in the proportion of twelve and a half pounds to every hundred pounds of the fused metal, then, neglecting losses, this would give an alloy of 87.5% Cu, 6.25% Sn and 6.25% Pb. Other authors, however (*eg* Thomson 1830, 57), have asserted that *plumbum argentorium* is actually tin (citing the analyses of Klaproth, and also the fact that, according to Rackham's translation, Pliny himself refers to tin as 'white lead' and lead as 'black lead' (Rackham 1952, Book 34, p241). This interpretation would make Wiegleb's second analysis (§ 9) consistent with Pliny. Similarly, Pliny's 'pot bronze' ('three or four pounds of silver-lead with every hundred pounds of copper') would be very similar to Wiegleb's third analysis (§ 13). More recently, Craddock (1988) has suggested that *plumbum argentorium*, should be translated as 'lead from the Spanish silver mines', whereas he interprets *argentorium* as 50:50 tin:lead. If *plumbum argentorium* were purely lead then there is no explanation for the tin content, apart from the scrap 'copper or bronze', so it seems most likely that 'silver lead' is either pure tin or 50:50 tin and lead.

Conclusion

Irrespective of the quality and interpretation of these analyses, the significance of this paper in the history of archaeo-metallurgical chemistry should not be underestimated. Its date places it at the very beginning of 'analytical chemistry by the humid method', analysis by quantitative precipitation from solutions, or 'wet chemistry'. Following the experimental work carried out by Johan Andreas Cramer (1710-1777) at the University of Leiden in the mid-18th century on the properties of aqueous solutions, several eminent scientists, including Robert Boyle in England, Étienne François Geoffroy in France, and others, carried out systematic studies of aqueous chemical reactions and precipitations. This, combined with the growing accuracy of the laboratory balance, led to the publication of a protocol for the aqueous gravimetric analysis of gemstones in 1777 by Torbern Bergman (1735-1784) at the University of Uppsala, Sweden. This was followed by more detailed protocols by Nicolas-Louis Vauquelin (1763-1829) in Paris (1799) and Martin Heinrich Klaproth (1743-1817) in Berlin (1792/3). The analytical protocols of Torbern, Vauquelin and Klaproth have been re-published and compared by Oldroyd (1973).

Wiegleb is rarely referred to as a pioneer of analytical chemistry, let alone of archaeological chemistry, although his best-known work (*Handbuch der allgemeinen Chemie*) contains significant sections on the application of chemistry to the 'useful arts', including glass, metals and ceramics. For example, he provides some very interesting insights into the first production of European hard paste porcelain by Bottger in 1709 (Pollard 2015b), linking it to Bottger's alchemical work, in which he needed to produce crucibles which could withstand high temperatures. This early contribution by Wiegleb is therefore contemporary with some of the earliest work in analytical chemistry, and currently represents the earliest known published application of analytical chemistry to archaeological metals.

Acknowledgements

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