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An economic history of the post-Medieval world in 50 ingots: the British Museum collection of ingots from dated wrecks

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Summary This contribution describes the British Museum's collection of ingots from wrecks, and their composition. Selected pieces are used to illustrate the rise and fall of the European non-ferrous mining and smelting industry. From the sixteenth century until the late nineteenth century, European vessels circled the globe introducing and then dominating a worldwide maritime trading system; from the start metals played an important role in this traffic. Europe was well placed to supply base metals such as copper, tin and lead, but needed to import the precious metals, gold and silver. The latter were supplied mainly from the Americas, but also from Africa and East Asia. Precious metals were required to purchase the spices, textiles and a range of exotic products from Asia. Amongst the latter was zinc, which came from China and for which India provided the principal market. As a result, much of the trade in this period was conducted wholly outside Europe, but in European vessels.

Through the centuries European metal production expanded, especially as the Industrial Revolution took hold. By the nineteenth century European mines could no longer cope with the demand and an ever-increasing proportion of the ore required came from outside sources. Initially these ores came to Europe for processing, but inevitably smelting began in their countries of origin. This was much more efficient and brought about the decline of European base metal production, particularly in Britain. In the British Museum's collection, the copper 'melon' ingots transported in Portuguese vessels for sale to the East heralded the dawn of European dominance, while the bars of South American 'Chili cement' copper that came to Europe for refining in the mid-nineteenth century signalled its end.

INTRODUCTION

The European discovery of the sea routes to the Americas, India and the Far East had a profound effect on economies the world over. Necessarily, the trade in spices, textiles and other perishables has to be studied largely from surviving documentation as the majority of the materials concerned no longer exist, but this is not the case for metals. The latter played an indispensable part in international trade, from the gold and silver needed to purchase the exotic products of the East to the ballast cargoes of lead needed to ensure that vessels were sufficiently seaworthy to arrive at their destinations. These ingots bring immediacy to the study of economic history that, combined with their scientific examination, can add significantly to our knowledge of trade patterns generally. The British Museum possesses an important, and growing, collection of post-Medieval metal ingots from shipwrecks [1, 2].[1] In the majority of cases these are from identified wrecks where details of embarkation, destination and dates are known precisely, while for some of the other wrecks associated artefacts provide a reasonably secure date range. Only a minority are not associated with a wreck and for these the form, composition and often an inscription provide information on their origin and date.

Previous publications on these ingots have demonstrated the diverse range of information that the ingots can provide [1, 2]. This study lists and briefly describes the collection as it stands at present, but then concentrates on one particular aspect – the contribution that these surviving ingots can make to the study of economic history, both through the direct material evidence of a trade previously only known from documentation, as exemplified by the Namibia wreck described below [3], and by revealing hitherto unexpected trade penetrations. For example the use of Cornish copper (as indicated by its bismuth content) by the Inuit in some

TABLE 1. Gold and silver ingots

Quantity	Registration number	Type	Wreck	Provenance	Date	Weight (kg)
GOLD						
3	PE 1993,0516.2 PE 1993,0516.3 CM 1993,0730.1	Bars	'Tumbaga Wreck'	Bahamas Channel	1530s	0.356 0.519 –
1	CM 1986,0934,1	10 Tael bar	CFIO *Prince de Conty*	South China Sea	1746	0.364
1	CM 1988,0606.2	Half ring	CFIO *Prince de Conty*	South China Sea	1746	0.368
SILVER						
1	PE 1985,0704.1	Melon	*St Anthony*	Gunwalloe Cove, Cornwall	1527	8.00
1	PE 1993,0516.1	Bar	'Tumbaga Wreck'	Bahamas Channel	1530s	1.714
1	PE 1992,0706.1	Bar	*Maravillas*	Bahamas Channel	1656	1.736
2	PE 1989,0505.1 PE 1989,0505.2	Bars	VOC *Slot Ter Hooge*	Madeira	1724	1.908 1.930
2	PE 1987,0105.1 PE 1987,0105.2	Bars	VOC *Bredenhof*	Madagascar	1753	1.946 1.814

TABLE 2. Lead ingots

Quantity	Registration number	Type	Wreck	Provenance	Date	Weight (kg)
1	PE 1985,0704.7	Wedge	*San Bartolemé*	Scillies	1597	44.5
2	PE 1987,0608.1 PE 1987,0608.2	Long bars	VOC *Campen*	Isle of Wight	1627	72 62
1	PE 1988,1207.1	Square-ended bar	VOC *Hollandia*	Scillies	1743	76
1	PE 1993,1204.1	Long bar	EIC *Albion*	Off the east Kent coast	1765	79.5
1	PE 1993,0201.1	Long bar	EIC *Fanny*	Off Weymouth, Dorset	1792	83
1	PE 1993,0607.1	Long bar 'Blackett'	EIC *Henry Addington*	Off Weymouth, Dorset	1798	70
1	PE 1995,0203.1	Long bar 'Dee Bank Lead Co.'	EIC *Earl of Abergavenny*	Off Weymouth, Dorset	1805	72
1	PE 1995,0203.2	Long bar 'Bollihope'	EIC *Earl of Abergavenny*	Off Weymouth, Dorset	1805	75
1	PE 1998,0104.1	Long bar 'Queensberry' & 'WMCo'	No associated wreck	Off Seaford, Sussex	1849?	64.5
1	PE 1998,0105.1	Long bar 'F. El Sol'	The *Filomena*	Off Alderney	1867	55
1	PE 2012,8016.1	Long bar 'Walkers Parker & Co.'	SS *Lifeguard*	Off Flamborough Head, Yorkshire	1892	49

TABLE 3. Zinc and stibnite ingots

Quantity	Registration number	Type	Wreck	Provenance	Date	Weight (kg)
ZINC						
1	PE 1990,1204.1	Bun ingot	VOC *Witte Leeuw*	St Helena	1613	2.5
2	PE 1997,0202.1 PE 1997,0202.2	Rectangular plates	EIC *Diana*	Off Malacca, Malaysia	1816	5 4
STIBNITE						
1	PE 2008,8040.3	'Pudding basin'	Unknown	Off the north Kent coast	Seventeenth century	4

TABLE 4. Copper ingots

Quantity	Registration number	Type and mark, if any	Wreck	Provenance	Date	Weight (kg)
5	PE 1985,0704.2 PE 1985,0704.3 PE 1985,0704.4 PE 1985,0704.5 PE 1985,0704.6	Melons	*St Anthony*	Off Gunwalloe, Cornwall	1527	9.2 14.7 2.9 4.2 7.6
2	PE 2002,0503.1 PE 2002,0503.2	*Reißscheiben* with stamp of Paller family		Elbe, off Wittenberg	Late sixteenth century	7.75 5.0
1	PE 2003,0306.1	Bar ingot with scribed 'W' merchant mark and stamps		Elbe, off Wittenberg	Late sixteenth century	8.5
1	PE 2003,0306.2	Hammered plate with stamps of Paller and city arms of Neusohl		Elbe, off Wittenberg	Late sixteenth century	24.5
1	PE 2008, 8040.1	*Reißscheibe* with scribed crosses and stamps		Off the north Kent coast	Late sixteenth to early seventeenth century	19
1	PE 2008, 8040.2	*Reißscheibe*		Off the north Kent coast	Seventeenth century	7
6	PE 1995,1201.1 PE 1995,1201.2 PE 1995,1201.3 PE 1995,1201.4 PE 1995,1201.5 PE 1995,1201.6	Small bars	VOC *Waddingsveen*	Table Bay, Cape Town	1697	0.058 0.080 0.113 0.113 0.120 0.118
1	PE 1992,1204.2	Battery plate, MR (Mines Royal)	EIC *Albion*	Off the east Kent coast	1765	9.0
1	PE 1992,1204.3	Battery plate, marked with '+'	EIC *Albion*	Off the east Kent coast	1765	3.5
3	BMRL samples 296, 273 and 277	Granulated copper	EIC *Winterton*	Off Madagascar	1792	0.392 (total)
1	PE 1993,0607.2	Small bar	EIC *Henry Addington*	Off Isle of Wight	1798	0.202
1	PE 1985,0705.1	Small bar	EIC *Hindostan*	Goodwin Sands, off Ramsgate, Kent	1803	0.392
7	PE 1985,0705.2 PE 1993,0202.1 PE 1993,0202.2 PE 1993,0202.3 PE 1993,0202.4 PE 1993,0202.5 PE 1993,0202.6	Small bars	EIC *Earl of Abergavenny*	Off Weymouth, Dorset	1805	0.190 0.200 0.204 0.203 0.292 0.221 0.261
1	PE 1985,0704.8	Battery plate, marked with '❀' (Rose Copper Co.)	EIC *Admiral Gardner*	Goodwin Sands, off Ramsgate, Kent	1809	14.3
3	PE 1994,0405.1 PE 1994,0405.2 PE 1994,0405.3	Battery plate 14 lb Battery plate 28 lb Battery plate 56 lb	EIC *Carnbrae Castle*	Off Isle of Wight	1829	6.5 12.7 25.5
3	BM AF 1984 N43 A BM AF 1984 N43 B BM AF 1984 N43 C	Manillas	*Douro*	Scillies	1843	0.075 0.075 0.075
1	PE 2008,8040.6	Large Bar, Urmeneta-y-Tuayacan	SS *Lapwing*	Off Isle of Wight	1872	110
2	PE 2008,8040.4 PE 2008,8040.5	Bar ingot, Logan Bar ingot, Logan	SS *Lapwing*	Off Isle of Wight	1872	7 7
2	PE 1994,0405.4 PE 1994,0405.5	Cathodes	SS *Benamain*	Bristol Channel	1890	5.0 6.0

TABLE 5. Tin ingots

Quantity	Registration number	Type and marks	Wreck	Provenance	Date	Weight (kg)
1	PE 1999,0911.1	Bar ingot	VOC *Waddingsveen*	Table Bay, Cape Town	1697	33.5
1	PE 2012,8014.1	Bar ingot	'Guernsey Lead Wreck'	Fermain Bay, off Guernsey	Early eighteenth century	5
2	PE 1997,0203.1 PE 1997,0203.2	'Hats' truncated pyramids Broken 'hat'	EIC *Vansittart*	Off Banca Isles, Indonesia	1792	0.7 0.8
1	PE 1999,0106.2	Bar ingot Chyandour works, T.S. Bolitho	SS *Liverpool*	Off Anglesey	1863	12.7
1	PE 1999,0106.3	56 lb Bar ingot William Harvey & Co. Hayle	SS *Liverpool*	Off Anglesey	1863	26
1	PE1995,1202.1	28 lb Bar 'Carvedas'	SS *Cheerful*	Off St Ives, Cornwall	1885	12.7
3	PE 1995,1202.2 PE 1999,0106.4 PE 1999,0106.5	Straws	SS *Cheerful*	Off St Ives, Cornwall	1885	0.136 0.147 0.125
1	PE1999,0106.1	28 lb Bar ingot Tamar Tin Smelting Works	SS *Cheerful*	Off St Ives, Cornwall	1885	12.7

copper shields from north west Canada long before the first recorded European contact (and which were previously believed to have been of native copper) [2, 4; pp. 7–15]); see Table 6 and endnote 8.

TRADE

Trade in metals over long distances has a very long history [5, 6], and recent research has revealed just how far metals could travel. Detailed study of the Medieval Jewish *Geniza* documents reveal, for example, that much of the non-ferrous metal used in India around a thousand years ago came from sources in Europe [7]. Even so, the European voyages of discovery opened new maritime routes and sources of materials. The sudden appearance of European trading vessels quite literally all over the world commencing in the decades around 1500 revolutionized international trade. Spices, textiles and luxury foodstuffs such as sugar, together with slaves, probably accounted for the bulk of the trade, both in volume and value, but metals were always of great importance. These could be the gold and silver necessary to make purchases (Table 1); various non-ferrous metals, especially lead (Table 2) and later zinc (Table 3), which were used as ballast in addition to forming regular trading cargoes that included copper (Table 4) and tin (Table 5); and, increasingly through the centuries, iron.

A consequence of this sudden domination of world maritime trade by European vessels was the equally rapid domination of non-ferrous metals, particularly copper, tin and lead from European mines. This lapsed somewhat in the seventeenth century, but revived strongly in the early eighteenth century and flourished for over a century before collapsing as quickly as it had arisen in the second half of the nineteenth century. This study charts the progress of the production and trade in non-ferrous metals through the four centuries from 1500 to 1900 as illustrated by the metal ingots and their composition.

EARLY DAYS

From the commencement of long-distance maritime trade from Europe, the Portuguese were sending large quantities of non-ferrous metals, either in the form of artefacts or ingots, to West Africa [8; pp. 125–132, 9] and beyond to Asia. The copper ingots typically took the form of *manillas* or hemispheres; the latter were known as 'melons', and are exemplified by those from the wreck of the *St Anthony*, which sank off Gunwalloe Cove, St Michael's Bay, Cornwall

FIGURE 1. Copper 'melon' ingots from the *St Anthony* wreck; each ingot is approximately 20 cm in diameter

TABLE 6. Composition of copper ingots (analyses by atomic absorption spectrophotometry and inductively coupled plasma atomic emission spectrometry)

Registration or BM laboratory number*	Ship/ingot	Element (weight %)										
		Cu	Zn	Sn	Pb	Ag	Fe	Ni	As	Sb	Bi	S
PE 1985,0704.2	*St Anthony* (melon)	98.2	0.01	<0.15	0.88	0.064		0.07	0.07	0.30	<0.03	
PE 1985,0704.3	*St Anthony* (melon)	97.8	0.022	<0.15	1.14	0.058	0.05	0.06	0.09	0.40	<0.03	
PE 1985,0704.4	*St Anthony* (melon)	96.1	0.021	<0.15	0.87	0.056	0.02	0.07	0.12	0.27	<0.03	
PE 1985,0704.5	*St Anthony* (melon)	98.8	0.02	<0.15	1.50	0.053	0.07	0.07	<0.05	0.37	<0.03	
PE 1985,0704.6	*St Anthony* (melon)	98.0	<0.01	<0.15	0.42	0.066	0.02	0.07	<0.06	0.30	<0.03	
23497Z*	*St Anthony* (melon)	96.6	0.01	<0.15	1.10	0.048	0.02	0.05	0.05	0.33	<0.03	
23498X*	*St Anthony* (melon)	97.7	<0.01	<0.15	1.09	0.05	0.02	0.07	0.08	0.39	<0.03	
23499V*	*St Anthony* (melon)	95.2	0.008	<0.15	1.36	0.05	0.11	0.05	<0.05	0.39	<0.03	
23500R*	*St Anthony* (melon)	98.6	<0.01	<0.15	0.72	0.059	0.04	0.07	0.11	0.48	0.03	
23501P*	*St Anthony* (melon)	97.4	<0.01	<0.15	1.24	0.056	0.04	0.08	0.14	0.51	<0.03	
23502Y*	*St Anthony* (melon)	98.6	<0.01	<0.15	0.81	0.041	0.03	0.05	<0.06	0.29	<0.03	
23503W*	*St Anthony* (melon)	99.4	0.009	<0.15	1.07	0.048	0.02	0.09	<0.05	0.51	<0.03	
23504U*	*St Anthony* (melon)	97.1	<0.01	<0.15	1.13	0.05	0.09	0.07	<0.05	0.34	<0.03	
23505S*	*St Anthony* (melon)	96.3	0.009	<0.15	0.75	0.064	0.03	0.08	0.12	0.45	0.03	
23506Q*	*St Anthony* (melon)	98.8	0.01	<0.15	1.26	0.053	0.03	0.05	0.11	0.38	<0.03	
23507Z*	*St Anthony* (melon)	98.0	<0.01	<0.15	0.51	0.058	0.03	0.07	0.23	0.31	0.03	
23508X*	*St Anthony* (melon)	99.9	<0.01	<0.15	0.47	0.058	0.04	0.08	0.17	0.31	<0.03	
23509V*	*St Anthony* (melon)	98.4	0.009	<0.15	1.69	0.054	0.07	0.07	0.11	0.49	<0.03	
23510Y*	*St Anthony* (melon)	99.0	<0.01	<0.15	1.29	0.052	0.02	0.06	0.12	0.40	<0.03	
23511W*	*St Anthony* (melon)	97.1	<0.01	<0.15	1.06	0.044	0.02	0.08	0.08	0.26	<0.03	
MED285*	EIC *Albion* (battery plate)	99.1	<0.01	<0.15	0.034	0.087	0.015	0.088	0.86	0.04	0.17	
MED286*	EIC *Albion* (battery plate)	97.5	<0.01	<0.15	0.152	0.066	<0.01	0.167	1.64	0.09	0.12	
MED287*	EIC *Albion* (battery plate)	94.9	<0.01	<0.15	0.168	0.063	0.005	0.159	1.57	0.08	0.12	
MED288*	EIC *Albion* (battery plate)	99.3	<0.01	<0.15	0.041	0.101	0.006	0.095	0.92	0.05	0.22	
MED289*	EIC *Albion* (battery plate)	99.3	<0.01	<0.15	0.204	0.065	0.005	0.170	1.66	0.09	0.14	
MED290*	EIC *Albion* (battery plate)	99.1	<0.01	<0.15	0.054	0.095	0.008	0.107	0.95	0.06	0.23	
MED269*	EIC *Winterton* (granulated copper)	97.7	0.03	<0.1	0.030	0.066	0.030	0.013	0.44	<0.01	0.09	
MED273*	EIC *Winterton* (granulated copper)	98.8	0.03	<0.1	0.010	0.073	0.037	0.015	0.54	0.02	0.11	
MED277*	EIC *Winterton* (granulated copper)	96.1	<0.01	<0.1	0.089	0.059	0.083	0.029	0.46	<0.01	0.10	
PE 1985,0705.1	EIC *Hindostan* (small bar)	98.5	<0.01	<0.15	<0.01	0.080	0.017	0.032	0.58	0.03	0.25	
PE 1985,0705.2	EIC *Earl of Abergavenny* (small bar)	96.7	0.01	<0.15	0.015	0.058	0.033	0.132	1.41	0.04	0.17	
PE 1985,0704.8	EIC *Admiral Gardner* (battery plate, RHS) †	99.9	0.05	<0.15	0.017	0.068	0.023	0.021	0.31	<0.03	0.15	
PE 1985,0704.8	EIC *Admiral Gardner* (battery plate, LHS) †	99.9	0.07	<0.15	0.020	0.074	0.038	0.021	0.34	0.03	0.17	
PE 1994,0405.1	EIC *Carnbrae Castle* (14lb battery plate)	100.0	<0.01	<0.01	0.017	0.116	<0.005	0.244	0.44	0.02	1.13	<0.02
PE 1994,0405.2	EIC *Carnbrae Castle* (28lb battery plate)	97.3	<0.01	<0.02	0.116	0.100	<0.005	0.088	0.35	<0.02	0.57	<0.02
PE 1994,0405.3	EIC *Carnbrae Castle* (56lb battery plate)	99.5	<0.01	<0.01	<0.01	0.125	<0.005	0.185	0.37	0.02	0.98	<0.02
PE 1994,0405.4	SS *Benamain* (cathode)	100.1	<0.01	<0.01	<0.01	<0.001	<0.005	<0.008	<0.02	<0.02	<0.01	<0.02
PE 1994,0405.5	SS *Benamain* (ingot)	99.8	0.02	<0.01	0.116	0.008	<0.005	<0.008	<0.01	<0.01	<0.01	<0.02

Notes

The analyses were carried out using atomic absorption spectrophotometry (AAS) following the procedure of Hughes *et al.* [13], except for the EIC *Carnbrae Castle* and SS *Benamain* ingots, which were analysed using inductively coupled plasma atomic emission spectrometry (ICPAES) [14].

The ICPAES and AAS analyses should have precisions of *c.*±1–2% for copper and ±10–50% for the minor and trace elements, deteriorating as the respective detection limits are approached.

Manganese, cadmium, cobalt and gold were also sought but were not found to be present above their respective detection limits of *c.*0.001, 0.002, 0.004 and 0.005%.

'<' denotes less than the quoted detection limit.

†RHS = right-hand side, LHS = left-hand side.

*The analyses with numbers followed by a check letter or preceded by 'MED' were made on samples taken from other ingots from the same cargoes, but which were not acquired by the Museum.

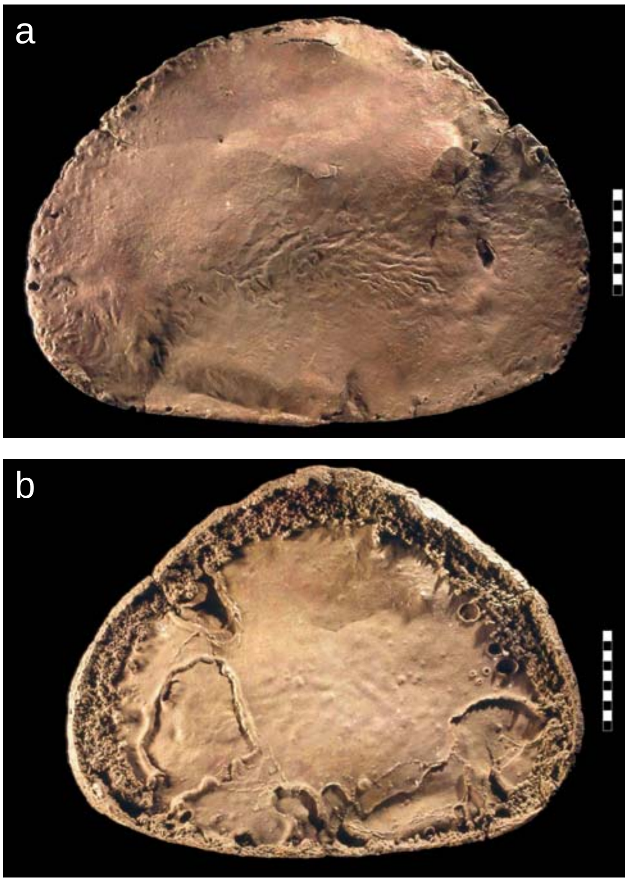

FIGURE 2. *Reißscheibe* ingot from the Elbe wreck (PE 2002,0503.1): (a) the upper surface; and (b) the underside, which has been lifted from the melt (see Figure 4). Scale bars show 1 cm divisions

FIGURE 3. Merchant's mark incised on the Elbe wreck copper bar ingot (PE 2003,0306.1). The field of view is approximately 5 × 3 cm

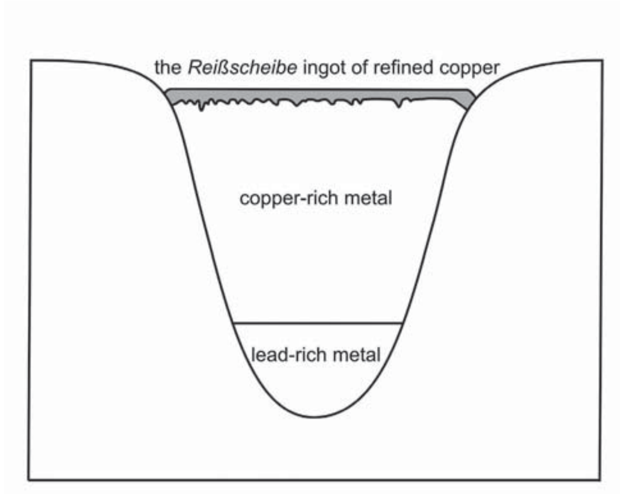

FIGURE 4. Diagram showing the principle of the *Reißscheibe* refining process

FIGURE 5. The upper surface of *Reißscheibe* ingot PE 2002, 0503.1 showing evidence that the smelter's mark was impressed while the ingot was still being sprayed with water. The field of view is approximately 5 × 3 cm

in January 1527 (Figure 1 and Table 4) [1, 10],[2] or by the more recently discovered spectacular cargo from an as yet unidentified Portuguese vessel that sank off the coast of Namibia in the 1530s [3]. Apart from one melon from the Namibian wreck that bears the mark of the Fuggers (who controlled much of the central European metal trade) the copper melons are unmarked and, although they could have come from the Falun mine in Sweden, are more likely to have originated from the Hungarian (now Slovakian) mines of central Europe. Quantitative analysis of the *St Anthony* ingots shows they have the distinctive antimony content (Table 6) [1, 9], which is associated with the Hungarian copper [12].

In the early sixteenth century, the Hungarian ingots would have crossed Europe to be loaded at Antwerp, but by the end of the century the Low Countries were no longer accessible, due to the wars of the Dutch rebellion, and ingots instead went north down the Elbe to Hamburg. The British Museum has acquired copper ingots from a wreck site in the Elbe estuary off Wittenbergen [15–18]. These include two *Reißscheiben* ingots (Figure 2), a bar and a large hammered plate ingot. The material was found during dredging operations in the 1970s and, although little was recovered from the ship itself, many tons of copper ingots were raised together with numerous coins and merchants' seals that suggest the vessel is most likely to have sunk in the late 1580s or early 1590s. The *Reißscheiben* (literally translated as ripped up or ruptured discs) ingots bear the stamp of the Pallers, a prominent Augsburg merchant family. The hammered plate has both the Paller stamp and that of the 'Hungarian' city of Neusohl (now Banská Bystrica in central Slovakia). The bar

TABLE 7. Composition of stibnite and copper ingots (analyses by X-ray fluorescence and scanning electron microscopy-energy dispersive X-ray spectrometry)

Registration number	Ship/ingot	Element (weight %)										
		Cu	Zn	Sn	Pb	Sb	As	Fe	Ni	Ag	Co	S
PE 2008,8040.3	Off north Kent coast ('pudding basin' of stibnite)	<0.2	<0.2	<0.3	*c*.0.5–1.0	maj	<0.3	*c*. 0.1	<0.1	<0.15	<0.1	maj
PE 2008,8040.1	Off north Kent coast (*Reißscheibe*)	94.2	<0.2	<0.3	3.5	0.7	<0.3	0.5	0.1	0.15	<0.1	
PE 2008,8040.2	Off north Kent coast (*Reißscheibe*)	99.2	<0.2	<0.3	0.2	<0.3	0.3	0.3	0.1	<0.15	<0.1	
PE 2008,8040.6	SS *Lapwing* (large bar, Urmeneta-y-Tuayacan; upper left surface)	98.8	<0.2	<0.3	0.1	<0.3	<0.3	0.3	0.3	<0.15	0.2	2.1
PE 2008,8040.6	SS *Lapwing* (large bar, Urmeneta-y-Tuayacan; upper right surface)	98.5	<0.2	<0.3	0.2	<0.3	<0.3	0.4	0.3	<0.15	0.2	1.8
PE 2008,8040.4	SS *Lapwing* (bar ingot, Logan)	99.5	<0.2	<0.3	0.3	<0.3	<0.3	<0.1	<0.1	<0.15	<0.1	<0.2
PE 2008,8040.5	SS *Lapwing* (bar ingot, Logan)	99.3	<0.2	<0.3	0.3	<0.3	<0.3	<0.1	<0.1	<0.15	<0.1	<0.2

Notes
The analyses were carried out using X-ray fluorescence on drilled samples, except for sulphur, which was determined by using a scanning electron microscope fitted with an energy dispersive X-ray spectrometer (SEM-EDX).
'<' denotes less than the quoted detection limit; 'maj' denotes major element.
Precision should be *c*.±1–2% for the major elements and *c*.±5–10% for the minor elements, deteriorating to *c*.±50% at the detection limit.
The two Urmeneta-y-Tuayacan analyses are from either end of the same ingot.

FIGURE 6. *Reißscheibe* ingot PE 2008,8040.1 showing: (a) the smelter's mark impressed into the soft metal; and (b) an incised merchant's mark. In each image the field of view is approximately 3 × 5 cm

FIGURE 7. Two Malaysian tin 'hat' ingots, PE 1997,0203.1 and 2. The ingot on the right contains 30% lead. The ingots measure approximately 10 × 10 cm at their bases

ingot also carries marks incised into its surface (Figure 3), which are likely to be merchant marks made in Hamburg. The distinctive shape of the *Reißscheiben* is interesting, and originates from the method by which the copper was refined and any silver recovered [19]. It is quite likely that the smelted copper would contain some lead from the ores and, if necessary, more could be stirred into the molten copper. The mix was then allowed to cool, whereupon the lead containing the majority of the impurities including any silver would separate out and, as it is heavier, would sink to bottom of the vessel, Figure 4. Water was then sprinkled onto the top of the molten copper causing the surface to freeze, so that it could be lifted out as a separate ingot of purer metal, which was often stamped at this stage, Figure 5. Presumably the distinctive shape was an indication that the metal was likely to be of higher purity, as confirmed by analysis,[3] although other *Reißscheiben* have been found to be less pure, see below and Table 7.

Similar ingots have been recovered from two separate wreck sites off the north Kent coast of vessels that were probably on their way to London, Table 4. Cannon recovered with the ingots suggest the vessels dated to the late sixteenth century and late sixteenth to early seventeenth century. Throughout the Medieval and post-Medieval period Britain imported almost all of its copper requirements from either Scandinavia or Germany, as documentary evidence makes clear, but before these discoveries, no ingot material has ever been found in Britain. These ingots, together with the melons, at last provide some idea of the physical form of the ingots that were being traded. As with the broadly contemporary Elbe ingots, the sixteenth-century ingots found off the coast of Kent have both stamps made while the metal was still soft and incised merchants' marks similar to those made by the Hamburg merchants, Figure 6. Analysis showed that the metal was rather impure for a *Reißscheiben* ingot and the level of antimony (0.7%) suggests the ingot was from central Europe, Table 7.

During the sixteenth century there was a rapid expansion in both the consumption and production of metals in Europe, but by the seventeenth century copper production was curtailed. The reasons were twofold. First, the Thirty Years' War had a devastating effect on the whole of central and northern Europe for much of the seventeenth century. Second, the Hungarian mines faced an additional problem. As previously noted, the copper from the central European mines was often argentiferous and some mines were only viable while the silver recovery remained profitable. The huge quantities of American silver flooding into Europe brought about a collapse in the price of the metal, forcing many of the copper mines to cease production.[4] During the seventeenth century Europe thus became an importer rather than exporter of copper. For example, Japanese copper was imported into Europe in quantity, as demonstrated by the small bar ingots from the VOC *Waddingsveen*, which sank in 1697 with a cargo of copper and tin, Tables 4 and 5.

A WORLD MARKET

The international trade routes were opened up from the late fifteenth century by the Spanish to the west and the Portuguese to the east and during the sixteenth century they held a virtual monopoly on European trade. Initially these were run very much as state enterprises and only later became trading companies along the lines of those operated by their rivals [24, 25]. However, from the end of the sixteenth century the state monopolies were challenged and soon superseded by these privately funded trading companies, notably the Dutch Verenigde Oostindische Compagnie (VOC) [26, 27], the English East India Company (EIC) [28, 29], and the French Compagnie Français pour le commerce des Indes Orientales (CFIO) [30].

Although the various trading companies and private traders that dominated seventeenth-century trade were all European, the metals entering the international markets came from a variety of sources. Silver came from the Americas (and also Japan), gold came initially from West Africa, then China (Table 1: CM 1986,0934.1), South America and finally, Australia, California and South Africa.[5] Zinc came principally from China [33, 34], and tin from South East Asia [35, 36], with tin from south west England re-entering the international market only late in the century [37]. In fact the only non-ferrous metal of European origin that regularly formed part of the cargoes in European vessels was lead, which was often a ballast cargo; as a result European lead ingots have frequently been recovered from EIC or VOC wrecks, Table 2 [38]. Although lead was (and still is) widely available and relatively cheap around the world, for some reason European lead, much of it from Britain [39], found a ready and continuing market in India and the Far East.

Although maritime commerce was dominated by European companies and carried in European vessels, much of the trade took place well away from Europe itself. Thus there was a flourishing trade between the Americas and the Far East and between the Far East, South East Asia and India. For example, tin was traded between South East Asia

TABLE 8. Composition of tin ingots (analyses by atomic absorption spectrophotometry)

Registration number	Ship/ingot	Element (weight %)												
		Ag	Sb	Zn	Pb	Sn	As	Cu	Cd	Au	Co	Fe	Ni	Bi
PE 1997,0203.1	EIC *Vansittart* (complete)	<0.001	<0.03	<0.003	<0.01	100.2	0.12	<0.01	<0.001	<0.006	<0.003	0.008	<0.003	<0.01
PE 1997,0203.2	EIC *Vansittart* (broken)	0.005	<0.03	<0.003	30.9	70.5	0.07	0.017	<0.001	<0.007	<0.003	0.019	<0.003	<0.01
PE 1995,1202.1	SS *Cheerful* (‘Carvedas’)	<0.001	<0.03	<0.003	0.016	100.7	0.17	0.490	<0.001	<0.007	0.016	0.010	0.004	0.020
PE 1995,1202.2	SS *Cheerful* (straw)	<0.001	<0.03	<0.003	<0.01	100.8	0.16	0.075	<0.001	<0.006	0.008	0.101	<0.003	0.025
PE 1999,0106.1	SS *Cheerful* (Tamar)	<0.001	<0.03	<0.003	<0.01	100.3	0.11	0.115	<0.001	<0.007	0.009	<0.01	<0.003	0.026
PE 1999,0106.2	SS *Liverpool* (Chyandour)	<0.001	<0.03	<0.003	0.042	101.1	0.13	0.065	<0.001	<0.007	0.012	<0.01	<0.003	0.014
PE 1999,0106.3	SS *Liverpool* (Harvey)	<0.001	<0.03	<0.003	0.013	100.0	0.19	0.183	<0.001	<0.007	0.046	0.048	<0.003	0.030
PE 2012,8014.1	‘Guernsey Wreck’	0.005	<0.03	<0.003	0.33	97.5	0.11	<0.01	<0.001	<0.007	<0.003	0.019	<0.003	<0.01
PE 1999,0911.1	VOC *Waddingsveen*	<0.002	<0.03	<0.003	1.00	98.2	0.18	<0.01	<0.002	<0.008	<0.003	0.055	<0.003	0.017

Notes
‘<’ denotes less than the quoted detection limit.
Precision should be *c*.±1–2% for the major elements and *c*.±5–10% for the minor elements, deteriorating to *c*.±50% at the detection limit.

TABLE 9. Composition of zinc ingots (analyses by atomic absorption spectrophotometry)

Registration number	Ship/ingot	Element (weight %)												
		Ag	Sb	Zn	Pb	Sn	As	Cu	Cd	Au	Co	Fe	Ni	Bi
PE 1990,1204.1	VOC *Witte Leeuw* (bun)				0.40				0.040			0.070		
PE 1997,0202.1	EIC *Diana* (complete)	<0.001	<0.03	94.7	0.60	<0.1	<0.05	0.049	0.058	<0.007	<0.003	0.243	<0.003	<0.01
PE 1997,0202.2	EIC *Diana* (broken)	0.003	<0.03	97.3	0.89	<0.1	<0.05	<0.01	0.401	<0.006	<0.003	1.12	<0.003	<0.01

Notes
‘<’ denotes less than the quoted detection limit.
Precision should be *c*.±1–2% for the major elements and *c*.±5–10% for the minor elements, deteriorating to *c*.±50% at the detection limit.

and India, with ingots often in the form of distinctive ‘hats’ as exemplified by those from the EIC *Vansittart* wrecked off the Banca Isles, Indonesia in 1792 en route from Batavia to Calcutta, Figure 7. Analysis shows one of these ingots to be of comparable purity to those on the VOC *Waddingsveen*, also from Batavia, and the nineteenth-century Cornish ingots, but with 30% lead the other ingot had clearly been adulterated, Table 8.

The trade in zinc forms an even more interesting story. The discovery of the metal is traditionally associated with India [40–44],[6] and (although almost no Portuguese trade records survive from the sixteenth century) there is some evidence that it entered international trade in the sixteenth century in Portuguese vessels. From the end of the sixteenth century until the early nineteenth century, however, Chinese zinc dominated international trade, even to India itself [24, 34, 44, 45; pp. 84, 93 and 146, 46; pp. 116, 147 and 304], Tables 3 and 9. This is all the more extraordinary as zinc production in China seems only to have developed into a fully fledged industry in the sixteenth century [47, 48], yet both the Chinese producers and the European traders based in China somehow recognized the potential of this new metal. Much of the trade seems to have been with India (as demonstrated by the zinc ingots from the EIC *Diana* which sank in 1816 en route to Calcutta, Table 3 [49]), rather than with Europe, whose merchants, up to the eighteenth century at least, were not quite sure what to do with zinc or how best to market it [33].

DOMINATION, COMPETITION AND DECLINE

Throughout the eighteenth century the Industrial Revolution gathered pace in Europe, particularly in Britain. A number of developments greatly facilitated the mining and smelting of metals [50, 51; Chapter 2]. These included the application of steam power to tasks such as draining mines or blowing furnaces and the introduction of the reverbatory furnace that allowed coal to be used directly as a fuel to smelt metals. These and many other developments greatly increased production and the efficiency of operations, thereby reducing the price of metals to the extent that, for example, in the early nineteenth century British copper sold for a lower price at the Khetri copper mines in India than the local product, even though the mines lay hundreds of

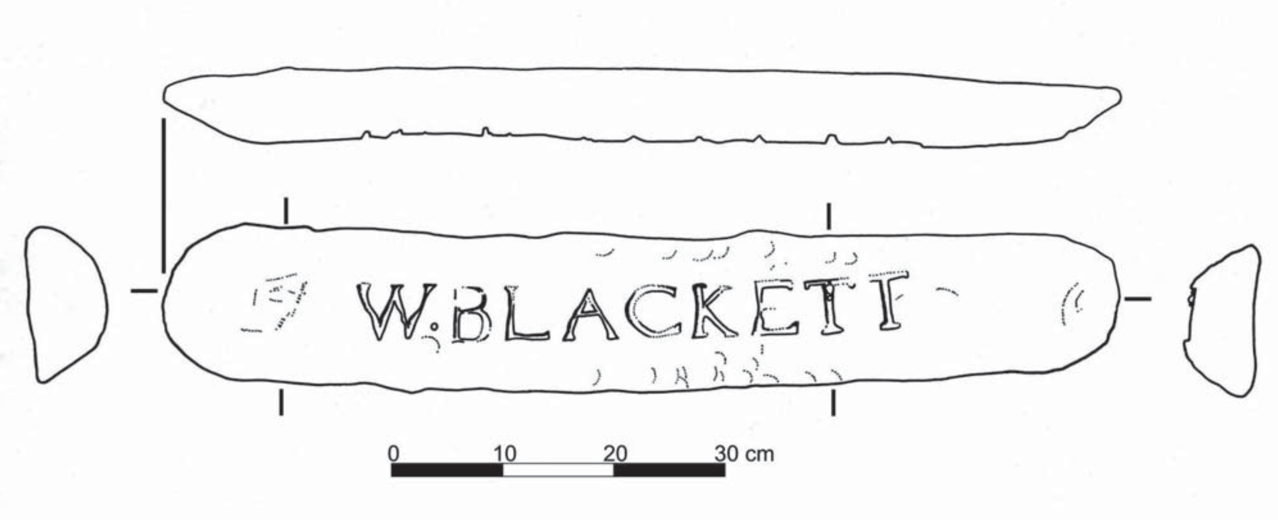

FIGURE 8. Line drawing of a typical lead ingot, PE 1993,0607.1, which bears the moulded name 'Blackett', showing it was from the north Pennine mines of the long-established firm of Wm. Blackett. Similar ingots from an unknown wreck have been found offshore at Poompuhar, Tamil Nadu. Drawing: B.R. Craddock

kilometres from the nearest port [44]. The metal producers were anxious to secure contracts to supply the EIC and other traders; for instance Matthew Boulton supplied copper coinage from his Birmingham manufactory to the EIC for its possessions in India [52], and Nicholas Donnithorne negotiated the supply of Cornish tin to the EIC in the late eighteenth century (and was thereby credited with revitalizing the industry) [37].

European (especially British) metals – iron, copper, tin, lead and, after the 1830s, zinc – dominated world markets. The form of the ingots became more standardized, with lead and tin tending to be long bars that typically weighed 30–80 kg and included the company name, Figure 8, and Tables 2 and 5.[7] The tin was of high purity, Table 8. Copper was usually traded either in the so-called 'battery plates', that is flat rectangles of metal suitable to be introduced to the battery hammers used to beat them into sheet metal (Figure 9), or as small cigar-shaped bars. This copper was often of decidedly inferior purity and eighteenth- or nineteenth-century copper from British sources is often characterized by remarkably high bismuth contents (Table 6), which would render the metal almost unworkable without further refining [55, 56].[8] Finally, although for obvious reasons it is less often recognized on wreck sites, another form of transporting copper was as granules, chests of which were traded regularly, including the material from the EIC *Winterton* reported and analysed here. The granules were probably intended for brass making by the cementation process as recommended by, for example, the Bristol brass makers [50; pp. 52–62].

The ever-increasing scale of output, especially of copper, put pressure on the British mines to maintain supply. By the end of the eighteenth century production from the great mine of Parys Mountain in north Wales was faltering as the deposits were worked out [57; pp. 130–135]. From the 1820s ores began to be imported into Britain from all over the world, but especially from Chile, to augment local production. However, there was no question of the ores being smelted locally at these far flung mines and even the United States sent its ores to Britain for smelting, with Swansea, nicknamed 'Copperopolis', the major centre for this industry [58, 59].

The proportion of foreign ores smelted in Britain rose inexorably through the 1830s and 1840s, but still no modern smelting facilities were established outside Europe. This was due in a large part to the absence of local infrastructure and lack of suitable coal supplies, but was also brought about by an anomalous British import duty [59]. At the insistence of the British copper miners, a duty was paid on copper ores coming into the country, but if the copper produced from these imported ores was intended for export then the duty was waived. The Swansea smelters pressed for a total abolition of the duty but were opposed by the mine owners and so a compromise was agreed in 1842 whereby the duty was halved but now applied to all ore imports irrespective of the destination of the smelted copper. This was a disastrous decision as, once a duty had to be paid on all imported ores, it was clearly cheaper to smelt outside Britain. Within the space of a few years smelters had been established in Chile, financed from Britain, using Swansea technology [60; pp. 331–332] and even using Welsh coal. Realising the threat to the home smelting interests the British government abolished the duty totally in 1847, but the damage was done as the Chilean smelters were established and proving very successful, with more copper smelted in Chile than in Britain by the 1850s. Worse still, their success was being noted and copied in the United States and elsewhere so that by the 1860s production in Chile and Britain had been overtaken by that in the United States [61; p. 31]. Even so, the prestige of Swansea lived on, smelting from domestic and imported ores continued and, in addition, raw copper was sent from around the world (notably from Chile) for refining in Britain.

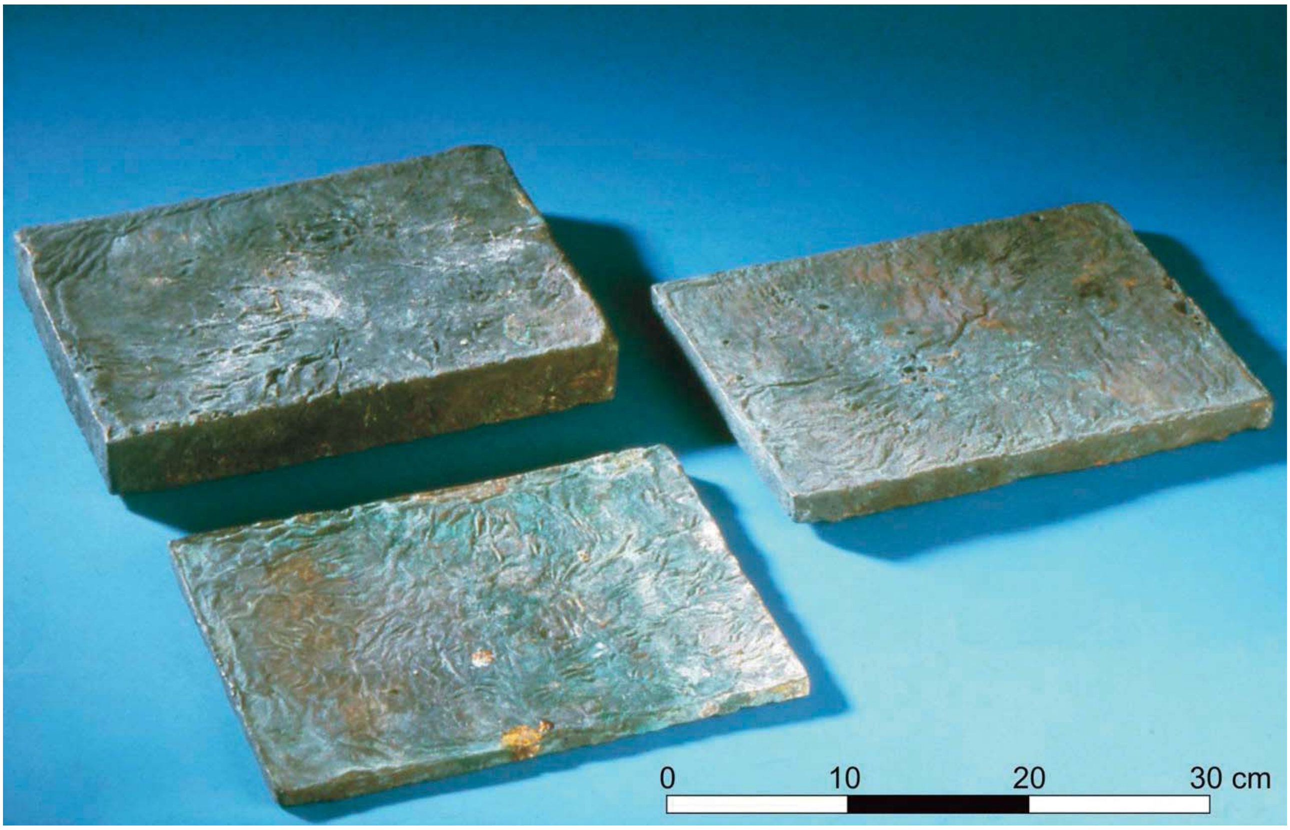

FIGURE 9. Three typical European 'battery plate' copper ingots (PE 1994,0405.1–3), weighing approximately 14, 28 and 56 pounds respectively (6.5, 12.3 and 25.5 kg)

The ingots of impure copper destined for refining were variously known as Chili bars, Chili cement or cement copper and the principal impurity needing to be removed was residual sulphur [62; pp. 46–48]. A cargo of both Chili bars and refined Chilean copper has recently been recovered from the wreck of the SS *Lapwing*, which sank off the Isle of Wight in 1872, and examples obtained for the Museum's collection, Table 4. This has enabled a Chili bar to be scientifically examined for the first time. The bar is marked 'URMENETA-Y-TUAYACAN'. The Urmeneta family was one of the most important Chilean copper miners and smelters, having close commercial ties with British interests, for example with the firm of Logan, which had smelting and refining facilities based in Liverpool [61; pp. 38–39]. Analysis of the Chili bar shows it contains 2.1% sulphur, Table 7.

FIGURE 10. Early copper cathode from the *SS Benamain*, PE 1994,0405.4

As this will be present as copper(I) sulphide (Cu_2S), it will account for approximately 10% of the weight of the metal, which would render the copper completely unusable.[9] The two refined ingots of Logan copper in the collection are predictably much purer (<0.2% sulphur), Table 7.

The Chilean copper would have been fire refined, the traditional method in which the metal is melted in an oxidizing atmosphere to burn out the sulphur and to oxidize the other impurities. This method was joined from the 1860s by electrolytic refining [62; pp. 227–230]. First carried out at Pembrey near Swansea, the method was initially intended to recover the small amounts of precious metals that foreign copper and ores often contained rather than to produce pure copper. It was soon appreciated, however, that high-purity copper had a much lower resistance to electric current than metal refined ordinarily and the demand for electrolytically refined copper rose sharply in the late nineteenth century as the electrical industry gathered momentum, particularly in Germany. The copper cathodes from the *SS Benamain*, which sank in the Bristol Channel in 1890 en route from Swansea to Germany, are possibly the earliest copper cathode ingots to survive (Figure 10), and their purity is much higher than in any earlier copper ingots, Table 6.

British copper smelters faced increasing competition, notably from Germany and the United States, and less than a century after the first Chili bars appeared in Europe, the last copper smelting plant had closed in 'Copperopolis' [57].

CONCLUSIONS

In post-Medieval Europe technical developments in mining and smelting greatly enhanced the production of metals. Fortunately, at just this time, European ships were exploring new maritime trade routes that encompassed the globe and the new markets proved an excellent outlet for European base metals. Through a combination of entrepreneurial skill and military superiority, European merchants rapidly dominated the international trade in metals. This ranged from trading the metal production of others, as happened in the Far East and can be seen in the Japanese cargo of the *Waddingsveen*, to taking over and developing the whole mining and smelting process in the Americas.

It is noticeable that although production and distribution were often disrupted by war, trade rapidly overcame these problems and maintained supply. In the sixteenth century, metals from central Europe were traded through Antwerp, on the River Scheldt in the Low Countries, before the Dutch rebellion closed that route and the trade moved to Hamburg on the Elbe, only to be disrupted again in the seventeenth century by the Thirty Years' War. It is likely that the Mughal wars in Rajasthan against Mewar in the sixteenth and early seventeenth century so severely disrupted zinc production that instead of exporting the metal India became an importer of zinc from China, in the form of ingots similar to those recovered from the *Witte Leeuw* and latterly the *Diana*.

International trade assured supply but often at the expense of local production. In nineteenth-century India indigenous copper could not compete with British imports even at the centres of local production. The imports were believed to be superior in purity, although many of the ingots found wrecked en route to India have been shown to be of lamentable quality, as exemplified by those from the *Carnbrae Castle*, see Table 6 and endnote 8.

Another clear trend is that from the sixteenth century onwards all the major markets in metals became increasingly dependent on the state of overall international maritime trade. The first manifestation of this was when silver from the Americas completely changed production and availability throughout the rest of the world. For several centuries the technical developments in European metal production kept it in the forefront of the burgeoning international trade in base metals, both in terms of the proportion of total trade as well as in actual tonnage. However, by the eighteenth century the ability to supply the necessary ore from local sources began to raise concern. For example, Thomas Williams, the 'Copper King' of the Parys Mountain mines in north Wales was seemingly always desperate to find new markets for the ever-expanding production of copper from his mines, while at the same time desperately trying to maintain output from the mines as the existing veins were worked out [57].

The solution was to locate and develop ore sources outside Europe. During the nineteenth century these new sources came increasingly into prominence, replacing European ore, first for copper, followed from the mid-century by tin, zinc and finally lead [63].[10] Initially, the new sources supplied the European smelters, but inevitably smelting facilities were set up in locations more convenient to the ore sources, although these were usually still financed and controlled by the European companies, as production in Europe itself declined.

Overall, metal production provides a classic case of globalization, but one that has been developing throughout the last 500 years.

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NOTES

1. In 1987, nine ingots were reported [1], which had grown to 30 by 1997 [2]. Full documentation of the collection is kept in the Department of Conservation and Scientific Research, file envelope 5120.
2. The cargo also included melons of silver, one of which was acquired (Table 1) for the British Museum. Its uncorroded state and very low gold content led to doubts over its association with the copper melons. However, recent analyses of Late Medieval silver from Poland, from the same central European source as the melon, also indicated very low gold contents [11].
3. Six of the ingots have been analysed elsewhere [18] by a combination of atomic absorption and inductively coupled plasma spectrometry. This showed they had a rather consistent composition with about 1.5% lead, 0.3% nickel, 0.13% arsenic, 0.05% antimony, 0.01% silver and iron at a barely detectable level.
4. American silver also had a profound effect throughout Asia. Medieval India was chronically short of silver until the sixteenth century [20, 21], when huge amounts were obtained from the European trading companies to pay for their purchases. Hasan has demonstrated that almost all of this silver originated in the Americas [22]. In China it is estimated that between the sixteenth and early nineteenth century some 500 million *taels* (approximately 18000 tonnes) of silver entered China as payment for merchandise, dramatically affecting the economy and the currency [23].
5. Gold from whatever source almost invariably contains substantial amounts of silver and, since ordinary processes such as cupellation were ineffective in removing silver, special parting processes were devised [31]. In antiquity the finely divided gold was heated with common salt, saltpetre (especially in India) or alum, which removed the silver and left pure gold. These processes were slow and did not always give a very pure product. Although much better results could be achieved with sulphur, elemental sulphur is volatile and in the Medieval period it was found that antimony sulphide (stibnite) was much more stable while retaining the astringency of sulphur – hence it was termed 'wolf metal' by alchemists and gold refiners [32]. The major European sources in the post-Medieval period were the Harz Mountains and the Black Forest and contemporary reports describe how stibnite ore was heated from above in an inverted container causing the pure stibnite to melt and drip into a round receptacle below. The stibnite set and without further processing was marketed as an ingot in the shape of a 'pudding basin'. One such ingot (PE 2008,8040.3: Table 3) has been recovered from the early seventeenth-century wreck that sank off the north Kent coast, which was also carrying copper ingots, one of which was acquired: PE 2008,8040.2. The vessel was probably sailing to London where the stibnite might have been used as a pigment or, more likely, by the gold refiners. This ingot is thought to be the only early example of prepared stibnite to be preserved in a curated collection.
6. In the Late Medieval period the only zinc production in India, and probably the world, was at Zawar, then part of the state of Mewar, in Rajasthan [41, 42]. A long war between Mewar and the Mughal Empire at the end of the sixteenth century and beginning of the seventeenth century is very likely to have disrupted production long enough for Chinese imports in European vessels to become established in India. Zinc production at Zawar never fully recovered and the traditional process ceased permanently during the Mahratta wars at the end of the eighteenth century [43, 44].
7. Tin was also traded as thin rods known as straws, weighing only a few hundred grammes and often packed by the thousand in casks for transportation. This form of ingot has a long history, examples having been found in Anglo-Scandinavian levels dated to the eleventh century AD at York [53; p. 788, Plate LVIIIb], and many were found on the sixteenth-century 'Gresham Wreck', which sank in the Thames Estuary [54]. They also have a wide geographical spread, as straws were the usual form in which Nigerian tin was transported across the Sahara from Kano by the Arab traders in the early nineteenth century. Why such an idiosyncratic form should have been so enduringly popular is unknown, but perhaps the straws could be used directly in the tinning of other metals by wiping, in which tin was applied by rubbing a stick of hot tin that was molten at one end over the surface to be coated: the used examples found at York had melted tips.
8. Contemporaneous sources hint at such problems in the complaints made by the Royal Navy over the copper bolts supplied by Cornish producers [55]. Sheet brass from Bristol at this time had only traces of bismuth, typically under 0.1%, but cast brasses have a significantly higher content, usually over 0.1% [56].
9. The copper also contained approximately 0.2% cobalt, which is unusually high in recent copper and has already proved a useful indicator of the source of the metal in much the same way as bismuth characterizes copper from south west Britain.
10. The Walkers Parker Company was the major British lead producer in the latter part of the nineteenth century and probably the last company to smelt mainly local ores. The ingot from the SS *Lifeguard* (1892: Table 2) now in the collection was produced when the company was already in sharp decline [63].