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As similar as black and white: steelmaking crucibles from South and Central Asia

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In recent years, fieldwork by archaeometallurgists, and laboratory analysis of the materials found at sites of early iron- and steelmaking, have led to the discovery that liquid steel was being made in parts of South and Central Asia a thousand years ago, long before it was manufactured in Europe. Research students and members of staff of the Institute of Archaeology have been in the forefront of these investigations, some of the results of which are described here.

In the West the earliest production of liquid steel is usually credited to the British industrial revolution, and particularly to the work by Benjamin Huntsman, who pioneered the process in England in the 1740s. In Europe prior to that time, soft iron and mild steel were worked only in their solid state, because of the exceptionally high temperature of more than 1400 °C required to melt them. However, in several places in Asia, liquid steel had already been produced for almost a millennium by exploiting particular clays that made possible the production of pottery capable of withstanding the necessary high temperatures. Recent research by archaeometallurgists has now shown that, in Central Asia and in the area that today comprises southern India and Sri Lanka, two visually very different (white and black) traditions of making the pottery vessels or crucibles employed in this process developed (Figs 1, 2).

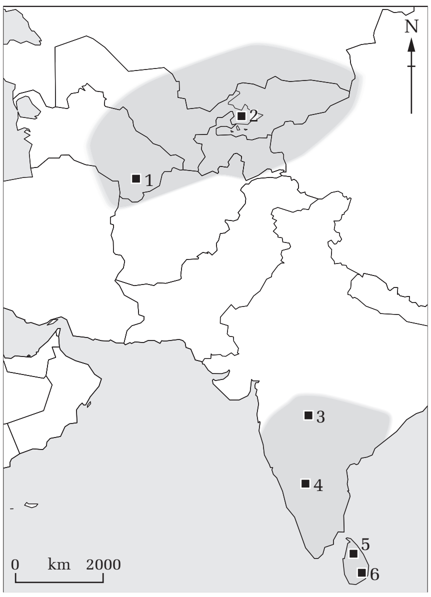

Figure 1 *Central and South Asia showing the approximate extent of areas of ancient crucible steelmaking and the location of sites mentioned in the text: (1) Merv, (2) Akhsiket, (3) Konasamudram, (4) Gattihosahalli, (5) Knuckles Range, (6) Mawalgaha.*

South Asia

Throughout the eighteenth and nineteenth centuries, India attracted the attention of European naturalists, ethnographers and other travellers interested in the exotic plants, animals, materials and traditional crafts of the subcontinent. Among the more highly praised (and priced) materials were cakes or ingots of high-quality steel, free of such impurities as slag and sulphur that used to contaminate European steel at that time. The metal made from Indian ingots, which were known as wootz (the name is an anglicized corruption of an old Indian word), was superior for making fine blades with exceptionally hard cutting edges; and the surfaces of many artefacts manufactured from these ingots also displayed the decorative pattern of very fine lines known as damask in steel, textiles and other materials. The quality of this damask (or Damascus) steel triggered much research across Europe – not least under the auspices of the British Royal Society, including such well known scientists of the day as Michael Faraday and Henry Wilkinson – in an effort to solve the mystery of its production and manufacture. Modern metallurgical technology was stimulated by, and developed in parallel with, the study of these Indian steel ingots, driven by the almost mystical reputation for beauty and performance of the products manufactured from them.

Despite the former fame of Indian steel, little attention has been paid to the extraordinary ceramic material that enabled it to be melted. The special quality of the material shows in the ability of the crucibles made from it to survive temperatures greater than 1400°C. Most pottery melts at temperatures as low as 1200°C, making it useless for melting steel. During the 1980s and 1990s, Thelma Lowe, who was then a doctoral student at the University of California, Berkeley, investigated this crucible material from several sites in southern India, including Konasamudram (Fig. 1), and found that a particular mineralogical structure gave the material its extraordinary strength.[1] During the past ten years, several research students at the Institute of Archaeology have carried out similar studies in both southern India and Sri Lanka, for example at the sites of Gattihosahalli and Mawalgaha (Fig. 1), where this unique material was made.[2]

The material is in general a highly porous and very black pottery (Fig. 2). The clay used in its manufacture was mixed with roughly equal amounts of rice chaff, which, upon firing, burned away, leaving an open network of pores and minute silica-rich remains of ash. A series of analyses recently undertaken at the Institute showed that the clay is chemically different from that used for other pottery, indicating that it was specifically selected for this process. Clearly, the craftspeople were well aware of what they were doing, and they did it on a massive scale. Each wootz ingot was quite small and probably weighed between 100 g and 1 kg, but this small size was counterbalanced by the vast number of ingots produced. To this day, massive heaps of broken crucibles cover the outskirts of several Indian villages, and are testimony to a time in the eighteenth and early nineteenth centuries when Indian wootz ingots were sold by the shipload to European and Arabian merchants, serving international markets. But the antiquity and origins of this steelmaking technology remain a matter for speculation. Written accounts and trade records stretch back a few hundred years only, although one site of steel-ingot manufacture, in the Knuckles range north of the Central Highlands in Sri Lanka (Fig. 1), has been reliably dated by radiocarbon to the middle of the first millennium AD.[3]

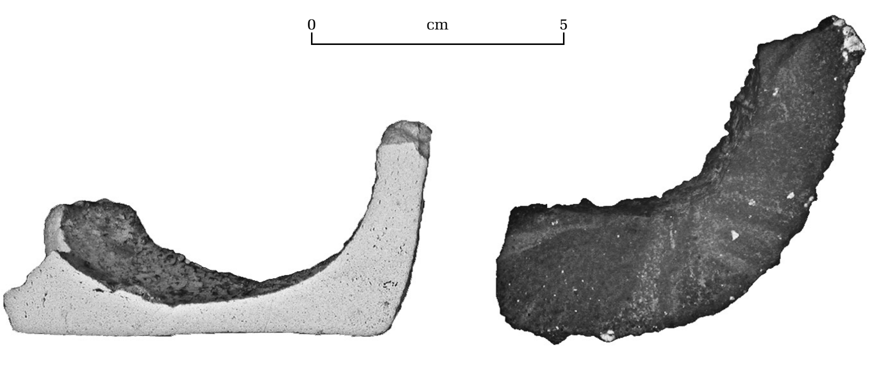

Figure 2 *Cross sections through two ceramic fragments of the bases of steelmaking crucibles; left: a white-fired one from Akhsiket in Uzbekistan, right: a thicker black-fired one from Konasamudram in southern India.*

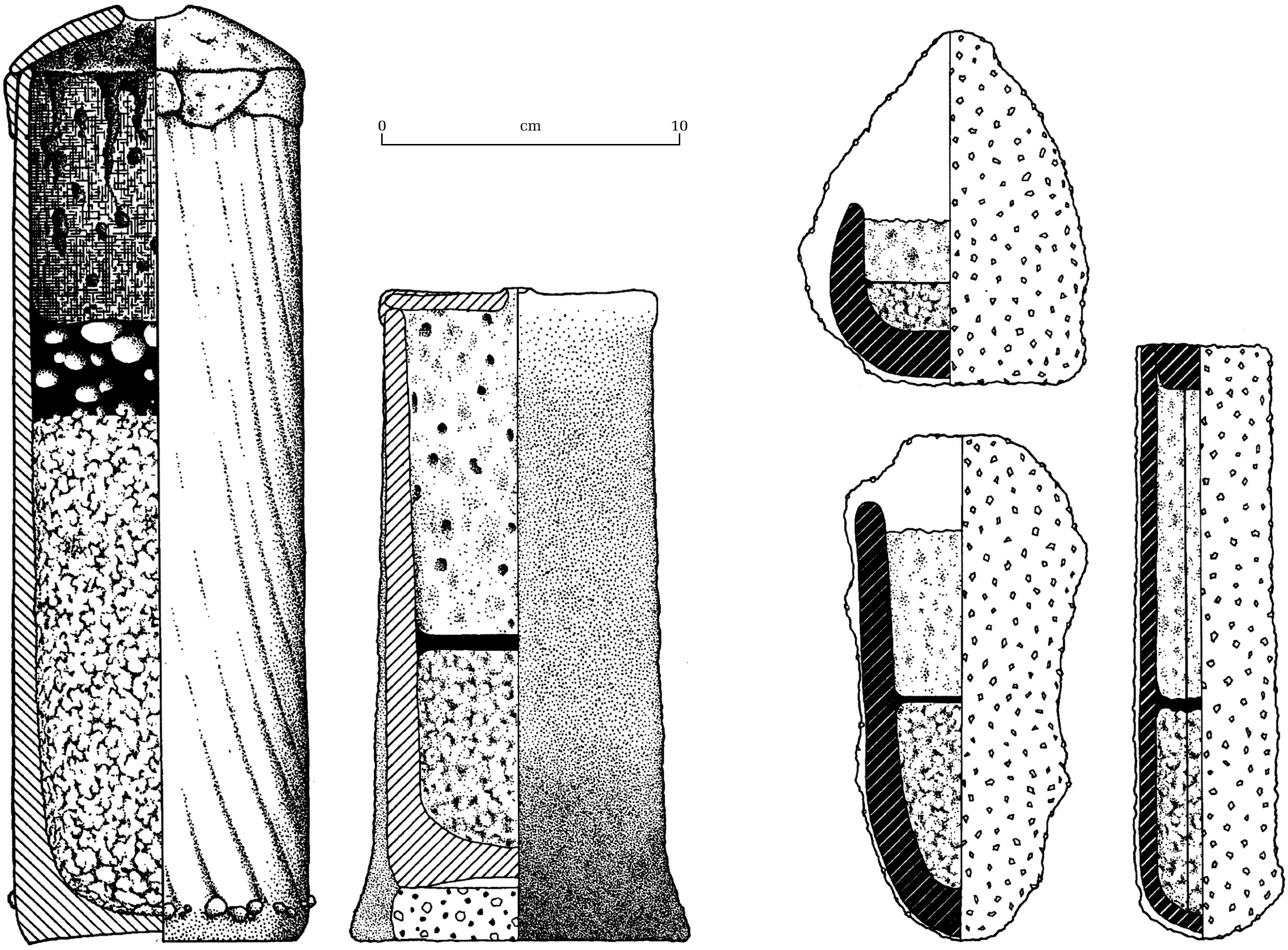

Figure 3 *Reconstructions of (left) two large crucibles typical of Central Asia and (right) three smaller ones typical of South Asia.*

Central Asia

Until recently few Westerners were aware of, and even fewer had direct experience of, the archaeological riches of Central Asia. But since the dissolution of the Soviet Union it has become possible for archaeologists from the West to undertake research in the region by participating in international projects in the newly independent Central Asian republics. Several members of the Institute of Archaeology have seized these new opportunities by undertaking fieldwork, including archaeometallurgical research, in Turkmenistan at the ancient urban centre of Merv, as well as much farther east at the ancient site of Akhsiket in Uzbekistan (Fig. 1). From both places we now have well dated and comprehensively studied evidence for the production of liquid steel in crucibles as early as the eighth to twelfth centuries AD.[4] Again, the scale of production was massive, with hundreds of thousands of individual crucibles being made at Akhsiket alone, each of which would have produced about 4 kg of high-quality steel.

Several historical sources indicate that the steel ingots were traded within the Islamic world south and west, to major markets in Persia, but also farther west to places such as Damascus in Syria. There is even some indication that steel ingots were produced in this way in Islamic Spain, for example in Andalucia, before the end of the Christian reconquest in 1492.[5]

The steelmaking process

A detailed metallurgical study at the Institute of the remains from many of the sites has now demonstrated that the same technical process was used in both Central and South Asia to produce the steel. In both regions, iron was first smelted in the traditional way, using small furnaces. Then, this iron was broken into small pieces, mixed with an equal amount (by volume) of plant matter, and placed in the crucible. The crucible was then sealed to prevent air getting in during the operation, with a few small holes left to allow pressure to be released as the vessel was heated. At high temperature, the iron begins to absorb carbon from the plant matter, up to about 2 per cent by weight. This transforms the metal into steel, and simultaneously reduces the melting temperature from more than 1530°C for pure iron to around 1400°C for steel. The liquid steel collects at the bottom of the vessel until all the iron is transformed. By then, the remaining carbon and any slag floats on top of the metal, and the reaction automatically comes to an end. After cooling, the crucible is broken open, the ingot removed and the vessel discarded.

Despite the similarities in the ancient steelmaking processes employed in Central and South Asia, there is one astonishing difference – that in the crucibles themselves (Fig. 3). In Central Asia, they are much larger, holding up to about half a litre of liquid steel, as well as enough excess volume to contain the initial plant matter and eventually the slag. Also, they are made from a very different type of clay, which, when fired, turns into pale cream to white pottery of almost porcelain-like quality (Fig. 2). This pottery is very dense, has very few pores, and despite the much larger vessel size it is only about half as thick as its black South Asian counterparts. Chemical and mineralogical analyses of this pottery have shown that it was made from a very special type of clay, completely different from the one used to make the domestic pottery of the time. To modern materials scientists, such clay (which closely resembles fire clay and china clay) is known to be even more heat resistant than the type used in South Asia.

Conclusion

For more than a millennium, until the nineteenth century AD, steel produced in Central and South Asia was of a quality much higher than its European equivalent. At present, we cannot identify where the technology for making liquid steel originated, but it is apparent that in most parts of Asia where steel was made the same metallurgical principle (the method of carburization) was used in the process. It was only when the European technology of the blast furnace introduced cast iron to India that a new way of making steel, which involved melting together the hard and brittle cast iron with traditional soft iron, was developed there. The possibility exists that the latter process was used much earlier in China, where cast iron was produced more than two millennia ago, but at present we have no archaeological evidence pointing in that direction.

The metallurgy involved is the same for South and Central Asia, but the ceramic traditions are very different. In South Asia, a black-firing, porous and relatively thick-walled ceramic material was used, probably at the limit of its stability when in use, which allowed only small vessels to be built. In Central Asia a white-firing, denser and much more refractory (heat-resistant) ceramic material was employed, which enabled more voluminous vessels with slender walls to be built, and hence much larger steel ingots to be produced. The similarity, in composition, appearance and date, of these Central Asian steelmaking crucibles to early Chinese porcelain may well indicate that an as yet unknown transfer of ceramic (and perhaps metallurgical) technology took place between Central and East Asia. As archaeometallurgical research continues, we can expect more discoveries to throw new light on the ancient history of iron- and steelmaking in Asia and the associated developments in ceramic technology.

Notes

1. See T. Lowe, N. Merk, G. Thomas, "An historical mullite-fibre-reinforced ceramic composite: characterization of the 'wootz' crucible refractory", in *Materials Issues in Art and Archaeology II*, P. B. Vandiver, J. Druzik, G. Wheeler (eds), 627–32 (Pittsburgh: Materials Research Society, 1991).
2. See, for example, G. Juleff, "Early iron and steel in Sri Lanka: a study of the Samanawalewa area", (Mainz: Philipp von Zabern, AVA-Materialien 54, 1998) and S. Srinivasan & D. Griffiths, "Crucible steel in south India – preliminary investigations on crucibles from newly identified sites", in *Materials issues in art and archaeology V*, P. B. Vandiver, J. Druzik, J. Merkel, J. Stewart (eds), 111–25 (Pittsburgh: Materials Research Society, 1997).
3. M. Wayman & G. Juleff, "Crucible steelmaking in Sri Lanka", *Historical Metallurgy* **33**, 26–42, 1999.
4. D. Griffiths & A. Feuerbach, "Early Islamic manufacture of crucible steel at Merv, Turkmenistan", *Archaeology International 1999/2000*, 36–8; A. Feuerbach, *Crucible steel in Central Asia: production, use and origins*, PhD thesis, UCL Institute of Archaeology, University of London, 2002; and Th. Rehren & O. Papakhristu, "The Ferghana process of crucible steel smelting", *Metalla (Bochum)* **7**, 55–69, 2000.
5. M. Karlsson Dinnetz, "Literary evidence for crucible steel in medieval Spain", *Historical Metallurgy* **35**, 74–80, 2001.