Who's afraid of the bowl furnace?

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ABSTRACT: This paper explores the history of the idea of the bowl furnace from its origins in the 19th century to its near death in the 1970s. The bowl furnace occupied a dominant position in models of early iron production in Europe (for the purposes of this paper a bowl furnace is taken to be one which is roughly as wide as it is tall and lacking any significant superstructure). Since the early 1970s (principally in Britain) the idea of the bowl furnace has gone out of fashion to such an extent that it seems heretical (or at least schismatic) to argue for its rehabilitation. A review of the history of the idea of the bowl furnace can teach us lessons about the rules we use to recognise evidence and distinguish between competing explanations of such evidence.

The establishment of the bowl furnace as an idea

The idea of the bowl furnace originates from observations made in the 19th century by travellers and colonial officials. In his monumental *Metallurgy*, published in 1864, Percy proposed that 'in ancient times iron was always extracted from its ores in the state of *malleable iron*; and to this day the same method is practised by the natives of India, Borneo, and Africa' (Percy 1864, 254). He also described various furnaces in use in India in the late 19th century including shaft furnaces as well as furnaces which appeared to have no superstructure (Percy 1864, 264). Gowland, who lived for twelve years in Japan, took a keen interest in traditional metalworking techniques, 'by reason of the light which they throw on the unwritten history of early metallurgy in Europe' (Gowland 1899, 267). Gowland also illustrated (Fig 1) an iron smelting furnace from Sudan which he described as '12–14 inches in diameter and about the same depth' (Gowland 1899, 312). He also suggested that such furnaces could be more complex with a low, domed superstructure.

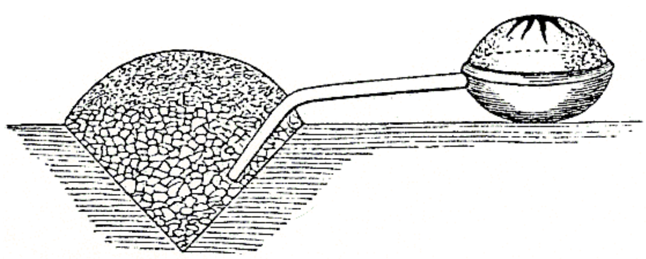

Figure 1: Sudanese furnace (after Gowland 1899)

Neither Percy nor Gowland actually used the term bowl to describe the shape of low furnaces; the term only appears to enter common usage following the publication of *Metallurgy in Antiquity* by Forbes (1950). Forbes was keen to identify and categorise different types of furnaces and to arrange these into a typological sequence with the assumption that the simplest types were inefficient and early, while more developed and efficient types were later. Forbes recognised the bowl furnace as no taller than it was wide, generally consisting of 'a clay-lined hole in the ground' (Forbes 1950). In his 1956 *Notes on Prehistoric and Early Iron in the Old World* Coghlan suggested that the archaeological remains of early furnaces were difficult to assign to different types because of their partial survival. Nevertheless, he identified three major types: the bowl furnace, the pot furnace and the shaft furnace. He defined the bowl furnace as 'a bowl-shaped hole in the ground, lined with clay' (Coghlan 1956, 88).

Early archaeological evidence for the bowl furnace

The 1950s saw the publication of archaeological excavations which appeared to provide examples of bowl furnaces for iron smelting. Fox's excavations at Kestor in Devon identified a series of roundhouses, one of which seems to have been the scene of prehistoric metalworking (Fox 1954). Fox suggested that a small feature cut into the ground, which contained a fired and vitrified clay lining as well as some slag, was the remains of a bowl furnace used for smelting iron (Fox 1954, 42). Jobey's excavations at West Brandon, Durham uncovered prehistoric enclosures and roundhouses (Jobey 1962). Within the area excavated (but not within a roundhouse) Jobey identified two rock-cut features which were interpreted as bowl furnaces (Fig 2). These were 'slightly over twelve inches in diameter and eight inches in depth' and contained 'a saucer-shaped layer of charcoal and slag droplets, cradling large runnels of slag' (Jobey 1962, 19). The upper fill of the feature contained 'irregularly shaped fragments of clay furnace lining up to two inches in thickness, most of them showing vitrification on the inside surfaces' which were interpreted as the remains of a domed cover for the furnace (Jobey 1962, 19).

Experimental validation of the bowl furnace

At the same time that bowl furnaces were being identified in the British archaeological record, iron was successfully being manufactured in experimental bowl furnaces. In Ireland, O'Kelly carried out successful experiments with a bowl furnace although these were never fully published (O'Kelly 1961). Wynne and Tylecote (1958) also carried out a series of experiments into iron smelting in a bowl furnace. They tested a wide range of variables, including ore and charcoal ratios, number of tuyères, tuyère angle, ore and charcoal size, blowing rate and packing method. They managed to produce small blooms of iron from some of the experiments, however, they do not seem to have been encouraged by the results and Ronnie Tylecote began a series of experiments using a shaft furnace (Tylecote *et al* 1971).

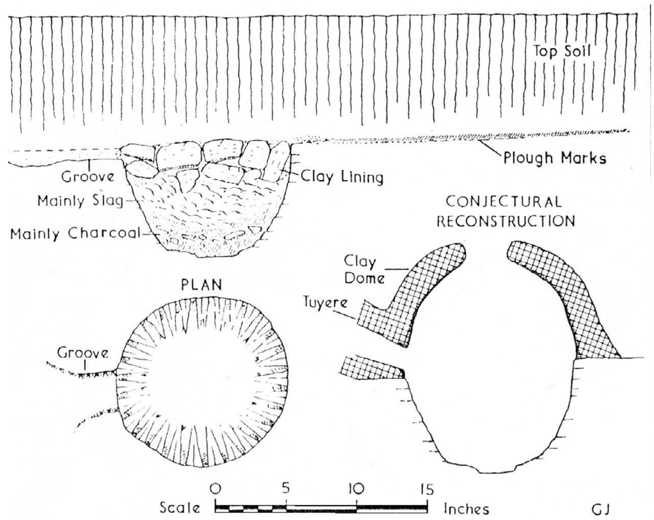

Figure 2: West Brandon furnace (after Jobey 1962)

The death of the bowl furnace?

In 1965 Tylecote published a review of ethnographic literature relevant to early iron smelting which hinted that archaeometallurgists were beginning to feel unhappy about the idea of the bowl furnace, 'very few recent pre-industrial furnaces seem to be what the archaeologist has been *tending* to call bowl furnaces' (Tylecote 1965, 341; my emphasis).

Cleere's publication of his review of furnace typology in 1972 critiqued previous typologies for focussing on the furnace superstructure which rarely survived intact (Cleere 1972). Cleere's main criterion for the typological division of different furnaces was the way in which the slag was separated from the bloom, such as by tapping the slag (Cleere 1972, 23). The bowl furnace occupied a position within Cleere's typology but he sounded a note of caution based on his own excavations at Holbeanwood. He reported that he had excavated twelve furnaces and that nine of these had no superstructure and so could have been interpreted as bowl furnaces. The remaining three had surviving superstructure which showed that they were shaft furnaces. The implication was that many reported 'bowl furnaces' may have been shaft furnaces but that they had lost their superstructure.

Cleere's paper had a lasting impact on the idea of the bowl furnace. The second (1977) edition of Coghlan's *Notes on Prehistoric and Early Iron in the Old World* echoed Cleere's reservations and suggested that 'it is by no means easy always to identify a true bowl type smelting furnace from another type of furnace the superstructure of which had been destroyed before excavation'

(Coghlan 1977, 25). In his PhD thesis Cleere went further 'it is considered that type A.1 (the "bowl furnace" referred to so often in the literature) was technologically non-viable and that all the so-called bowl furnaces may be properly interpreted as the hearths of shaft furnaces of the general B.1 type' (Cleere 1981, 157). In 1985 Tylecote indicated that 'many people have serious doubts about the use of this type of iron smelting furnace' (Tylecote and Merkel 1985, 9). By 1986 Tylecote was arguing that the West Brandon furnace was not a bowl furnace but 'the bottom of a shaft furnace' (Tylecote 1986, 140). At the time that this author began training in archaeometallurgy the bowl furnace was regarded as an embarrassing mistake.

Some hope for the bowl furnace?

While what can only be described as a paradigm shift was underway there were some comments in support of some aspects of bowl furnace technology. Although McDonnell argued that most archaeological evidence interpreted as bowl furnaces actually represent the truncated remains of shaft furnaces (McDonnell 1986, 42), he suggested that a rich ore might be reducible in a small furnace and produce very little slag (McDonnell 1986, 43–4). Similarly Tylecote's second (1992) edition of *A History of Metallurgy* suggested that bowl furnaces might have been used but that 'the slag runs down to the bottom forming a cake or furnace bottom or, in some cases, just small rounded particles or "prills" of slag' (Tylecote 1992, 49).

A more sustained (though rarely read) defence of the bowl furnace was made by Rodney Clough in his doctoral thesis. In part inspired by Brown's reports of iron smelting in Kenya, Clough argued that a bowl furnace could be used to smelt very rich ores which would produce very little slag (Clough 1986). Jean Brown's ethnographic survey of metalworking in Kenya ranged across a wide area and covered both the manufacture of metal and the working of smelted metal (Brown 1995). Despite the fact that the archaeometallurgical community in Britain had by now rejected the idea of the bowl furnace, Brown described the use of hearth or bowl furnaces in Kenya. These were usually circular and 0.2–0.3m deep and 0.2–0.3m wide. It is striking that the bowl furnaces described were used to the east of the Rift Valley where rich magnetite ores were available, while shaft furnaces were used to the west of the Rift Valley where less rich hematite or limonite ores were available (Brown 1995, 45–8).

How might bowl furnaces have operated, and how are we going to recognise them?

Ethnographic sources, archaeological evidence and experimental reconstructions have often suffered from a certain looseness when it comes to defining the bowl furnace. On one hand, a great variety of structures and features have been described as bowl hearths and on the other nearly identical structures have been ascribed different names. The most variable aspect is the nature of any superstructure. In some cases the term bowl hearth or furnace is used to describe the simplest hole in the ground (Pleiner 2000, 145), while in others some degree of superstructure is allowed (*eg* Jobey 1962).

There are clearly a variety of possible furnace forms between the cylindrical shaft furnace and the simplest of bowl furnaces. The recognition and characterisation of such furnaces in the archaeological record is hampered by the range of post-depositional factors (not least ploughing) which have truncated stratigraphic layers that may have contained any superstructure. The identification of fragments of fired and even vitrified clay within the fills of furnaces has often led to the suggestion that such furnaces could have had low banks or walls around them or even a domed superstructure (Jobey 1962). While such furnaces have often been referred to simply as bowl furnaces, terms such as 'developed bowl furnace' (Wynne and Tylecote 1958) and 'domed furnace' (Pleiner 2000, 163–72) have also been used, although the latter term is often reserved for larger furnaces resembling pottery kilns. The confusion over the nature of any superstructure is highlighted by Cleere's illustration of a bowl furnace with a domed superstructure but which is defined as having 'no superstructure' (Cleere 1972, 21–2).

The distinction between a bowl furnace with no superstructure, one with low walls or banks, and fully domed furnaces may be of considerable importance. Where modern experimenters have attempted to operate the simplest of bowl furnaces (*eg* Girbal 2013; Wynne and Tylecote 1958) they have usually struggled to achieve a high enough temperature and/or reducing atmosphere to smelt significant quantities of iron. Almost all modern experiments using a bowl furnace have quickly adapted the form of the furnace through the addition of low walls, *eg* the banks of turf used by Girbal (2013), the low walls of the 'developed bowl furnace' of Wynne and Tylecote (1958) or O'Kelly's domed furnace. Walls, banks and superstructure all serve to insulate the contents of the bowl furnace and so improve heat retention and maintenance of a reducing atmosphere; however, the furnace remains fundamentally different to the shaft furnace.

In the shaft furnace (usually 2–4 times taller than its diameter) the charge is introduced at the top of the furnace and as charcoal is burnt and ore transformed, the furnace is topped up with additional charge. The shaft furnace (and this definition could include a range of blast furnaces) is a reaction vessel which sees a number of important material flows. The solid fuel and ore are charged at the top of the furnace. As fuel is burnt in the hot zone of the furnace, solid charge slowly descends to the hot zone. The gaseous combustion products formed in the hot zone transform the ore (into metal and slag), rising through the furnace superstructure as they do so. The metal and slag that form in the hot zone may rest where they are formed or may descend further to the lowest part of the furnace below the tuyère. The height of the furnace (as well as the blowing rate) plays a significant role in determining the nature and progress of chemical reactions which take place inside the furnace. Whether iron, steel or cast iron are produced will depend to some extent on the height of the furnace.

Even using a very broad definition of a bowl furnace (to include furnaces with no superstructure as well as domed furnaces), there are still important differences compared with shaft furnaces. The restricted height of a bowl furnace means that there is little material above the combustion zone and the flow of materials or gases is very limited. Some of the most successful experiments using a bowl furnace have employed a charging procedure quite different from those used in shaft furnaces. Shaft furnaces are most commonly charged by adding charcoal and ore together or as alternating layers. While bowl furnaces can be charged in a comparable manner, some of the best yields have been obtained when the ore is charged (or pre-charged) at the back of the furnace and charcoal at the front. This procedure is most famously known from its application on a rather larger scale in Catalonia and recorded by Percy (1864).

Experimental and ethnographic evidence indicate that it is possible to smelt iron in a bowl furnace. The direct recognition of a bowl furnace in the archaeological record, however, is likely to be extremely difficult. Leaving aside the possibility that smelters tore down part of any furnace to retrieve their blooms, all archaeological features show signs of having suffered from numerous erosive processes which often leave only the below-ground portions intact. To recognise the bowl furnace it may be necessary to think laterally.

It is generally accepted that furnaces served to contain a fire and that their architecture can be optimised to retain as much heat as possible and control the atmosphere inside the furnace. Much more fundamental, however, is the role of the furnace as a reaction chamber in which iron ores can be reduced to form a bloom and then the bloom separated from any waste slag. The size and form of the furnace will be determined to some extent by the quantity of ore and fuel charged as well as the volume of slag which forms; and both of these factors will depend on the nature of the ore.

When smelting a relatively poor ore substantial quantities are needed to obtain an acceptable bloom and substantial quantities of slag will be produced. 20kg of relatively poor ore (containing 70% iron oxide) could be expected to yield a 2kg bloom and 20kg of slag (containing 60% iron oxide). With the addition of the necessary quantity of charcoal, the charge becomes too large to be accommodated in a bowl furnace with a diameter of 0.3m. In addition, the 20kg of slag which forms will choke the furnace. The only way to successfully smelt a relatively poor ore is in a shaft furnace which could be topped up with additional ore and charcoal during the smelt, and the quantity of slag which forms will have to be accommodated in a pit under the furnace proper (Fig 3) or tapped from the furnace (Fig 4).

When a much richer ore is used the situation changes considerably. Smaller quantities of ore and fuel will be needed and less slag will be made (assuming that the smelters wanted to make the same sized bloom). Assuming an ore which contains >90% iron oxide then a charge of just 6kg of ore will be sufficient for 2kg of bloom, and the total charge will be small enough that it can be accommodated in a small bowl furnace (Fig 5). In addition a small charge of a rich ore will yield very small amounts of slag (~4kg in this case) and its formation will not present significant problems. The slag does not need to be tapped and does not need a pit under the furnace in which it can gather. Indeed if such small quantities of slag are produced it might be expected that a significant proportion of these will be 'small rounded particles or "prills" of slag' (Tylecote 1992, 49).

The 1939 excavations at Trevelgue Head in Cornwall yielded a substantial assemblage of slag which contained no tap slag and no large furnace bottoms (there were several small furnace bottoms up to 0.2m across and 0.1m deep). The most abundant type of slag from the site comprised prills of slag (Dungworth 2011). In addition, the chemical analysis of the ore suggested an average iron oxide content in excess of 90wt%. The richness of

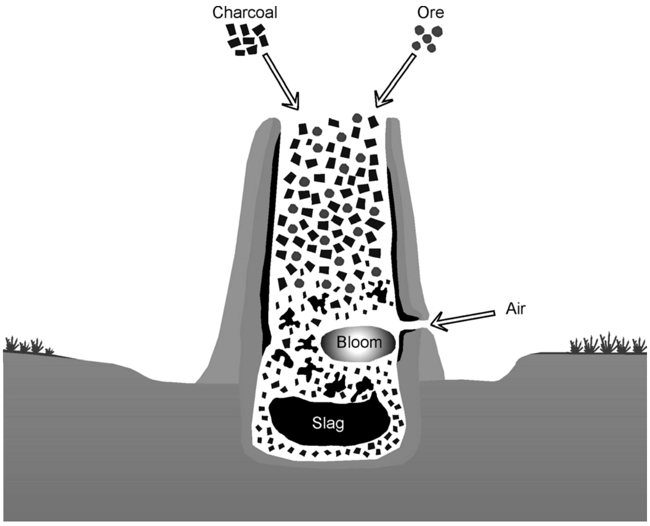

Figure 3: Idealised shaft furnace (non-tapping)

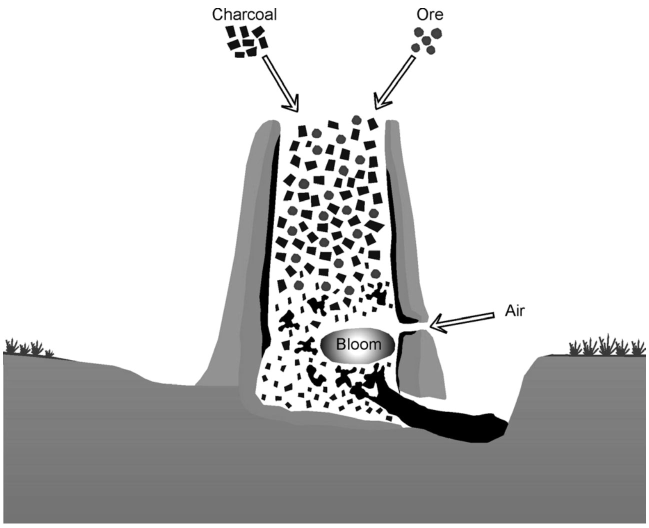

Figure 4: Idealised shaft furnace (tapping)

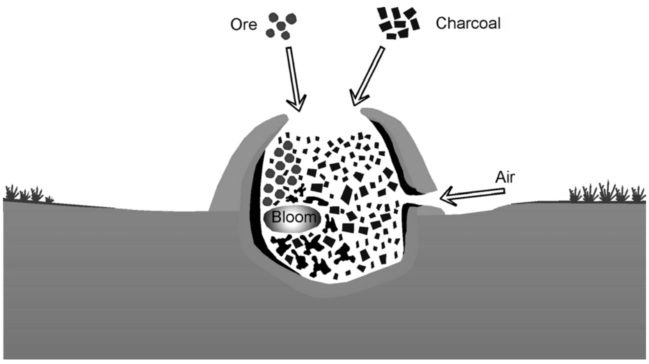

Figure 5: Idealised bowl furnace

the Trevelgue Head ore and the morphology of the slag both fit with suggestions made by Tylecote, McDonnell and Clough about the bowl furnace. Slag from West Brandon (prills) has recently been found amongst the collection left by Ronnie Tylecote to the Historical Metallurgy Society.

Attempts to identify different types of furnace have traditionally privileged the direct evidence of furnace architecture but the limited survival of superstructure often makes this rather unsatisfactory. A closer examination of slag morphology and a reconstruction of the circumstances under which it formed, flowed and solidified may offer a more successful approach. In addition it is now possible to re-evaluate some early bowl furnace iron smelting experiments and suggest that some of the rather disappointing results were in part because the ores used were leaner ores which were better suited to smelting in a shaft furnace.

Why did archaeometallurgists abandon the idea of the bowl furnace?

The bowl furnace grew as an idea during a period in which historians of technology rarely conducted any archaeological excavations and so had relatively little appreciation of the limitations of archaeological evidence (especially site formation processes). Equally, archaeologists often did not understand early iron smelting technologies and how these might manifest themselves in the archaeological record. There are some very good reasons why any claim that a particular archaeological feature is a bowl furnace should be treated with caution. Furnaces which appear to have no superstructure may simply reflect truncation and do not necessarily indicate the full nature of the furnace while it was in use. This does not, however, really explain why the idea of a bowl furnace for iron smelting was so comprehensively rejected. Indeed my recent conversion to the idea of the bowl furnace has been met with puzzlement and disbelief by some leading researchers.

It can be argued that ideas about the bowl furnace (including its adoption and rejection) are bound up with the nature of models for technological change and development. It has often been assumed that technological knowledge not only gradually accumulates over time but that most technological development forms part of a single chain connecting the earliest and most primitive techniques with the latest and most advanced techniques. By the 1970s the idea of the bowl furnace for iron smelting upset the conventional metalworking evolutionary sequence.

Gowland discussed the form of early iron smelting furnaces but he was writing at a time when it was still not universally accepted that iron smelting metallurgy was developed after copper smelting metallurgy. Gowland proposed that if iron smelting was invented first then it was probably in small bowl furnaces which would take domestic hearths as their model (Gowland 1899). If, on the other hand, copper smelting was invented first then it is likely that shaft furnaces of some type would have been in use prior to the development of iron smelting technology. In the years which followed it gradually became clear that copper did indeed precede iron and that shaft furnaces were used for copper smelting prior to the development of iron smelting. Thus by the 1970s archaeometallurgists were faced with the situation where iron smelting in a bowl furnace appeared to be a technologically retrograde step. Why would early iron smelters use the inefficient bowl furnace if shaft furnaces for copper smelting were already available? The bowl furnace for iron smelting did not fit with an evolutionary model of technology and this contributed to its rejection. Essentially the direct evidence for bowl furnaces was weak and did not accord with the dominant paradigm.

The period during which the bowl furnace fell from favour coincides with the growth of experimental archaeometallurgy and this may also have contributed to its rejection. In attempting to recreate some ancient iron smelting technique, experimenters will inevitably try to imagine what it was like for the ancient smelters. They will aim to put themselves in similar (technological) situations and imagine how the ancient smelter would have coped. By experimentally recreating elements of the ancient situation, such as a bloomery furnace, it may be possible to discover explanations that might never be arrived at without such experimentation. However such an approach is not without its dangers: experimenters will inevitably project some of their modern, rational world view onto the ancient smelters. For many experimental archaeometallurgists, the bowl furnace appeared to be small-scale, inefficient and simply too primitive. Many modern experimenters may have preferred the shaft furnace (especially those in which slag was tapped from the furnace) in part because they are impressive. A large furnace is constructed and filled with lots of raw materials. Anyone who has seen slag tapped from a bloomery iron furnace cannot fail to be impressed by a process which is magical and theatrical. In addition the shaft furnace (with slag tapping) is perhaps the only way in which to make a large bloom, and in the machismo world of experimental iron smelting the size of the bloom is the measure of success.

Conclusion

The idea of the bowl furnace for iron smelting has been around for over a century and it has gone from a universally accepted part of the canon of ancient furnaces to almost complete rejection in Britain. The slag from Trevelgue Head has convinced this author that the bowl furnace is a possibility. This is not to claim that all excavated furnaces lacking a shaft were bowl furnaces; many shaft furnaces only survive in a form which might superficially resemble a bowl furnace. The nature of the slag produced by the bowl furnace appears to some extent to be distinctive. In this respect a slag assemblage dominated by slag prills (and probably associated with rich ores) is perhaps an indicator of smelting in a bowl furnace. At present only Trevelgue Head, West Brandon and, possibly, Bryn y Castell can be pointed to as sites which may have employed bowl furnaces for iron smelting.

We all live and work within ideological and paradigmatic frameworks but we are often only vaguely aware of them. Paradigms are often most visible once they have been abandoned and the rejection of the bowl furnace is a prime example of this. It is to be hoped that we can learn from this example and develop new ideas outside dominant ideologies and paradigms. A first step has to be the recognition that our work is framed within ideologies and paradigms (even if we often lazily refer to these as 'common sense'). To achieve this we need to be more tolerant of ideas which cannot be disproved but which do not 'fit'. We need to provide some space for ideas which might seem wrong but which we cannot necessarily disprove – they may seem wrong simply because they cannot be accommodated within the existing paradigm (and the existing paradigm may not be perfect). In this context we need to provide space for ideas about the bowl furnace, wind-powered furnaces, wood-fuelled furnaces, liquid steel and many other ideas.

The historiography of the bowl furnace should teach us to be open-minded, for, as Gowland (1899, 304) remarked:

> 'nothing is a greater hindrance or more destructive to scientific investigation and research than the acceptance of a theory, or supposed fact, the truth of which is not supported by proofs of an absolutely conclusive character, and especially so if such theory or supposed fact is propounded or accepted by men eminent in the subject concerned'.

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