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Detailed recording of furnace C397,
Derrinsallagh 4 (E2180),
M7/M8 Contract 2

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Abstract

Furnace C397 was lifted as a block with its underlying subsoil, following its partial excavation in the field. Detailed excavation of the block off-site has revealed new details of the construction of the furnace. It is not a simple "bowl furnace", but rather an evolved variety of the non-slag tapping slagpit furnace, featuring a furnace arch mainly or entirely below original ground level, connecting the furnace pit with an external working hollow. The base of the pit is below the level of the base of the arch, so it is clear the furnace was not designed to be able to tap slag, despite a similarity in design with slag-tapping furnaces. The sides of the arch and pit were formed of very carefully smoothed clay, but it is not clear if this was an applied lining, or made by wetting and smoothing the face of the original cut. The smooth face was very well preserved, showing use of the arch had been very careful.

The natural substrate was fired for some variable, but locally considerable, distance behind the face, and was deeply vitrified on the south side, with lines of vitrification and slagging developing in a concave manner, suggestive of a "burr" below a blowhole. Blowing at right angles to the arch is the most common configuration, and this probably indicates the manner in which the furnace was blown initially. However, later use of the furnace involved blowing from the side opposite the arch. The location of the blowhole on this wall was preserved as was the large slag cake in front of it. The final use of the furnace had developed a rather atypical slag block, which appears to have resulted from constriction and eventual occlusion of the blast by development of a slag "hood".

The total slag remaining in the furnace (some had been previously removed during its initial partial excavation) amounted to some 20.7kg relating to its late use and the early "burr" weighed 6.8kg. The rather complicated history of this furnace means that it is not the ideal furnace from which to calculate the amount of slag produced during a single smelt. However, a figure of 20kg is not too dissimilar to the few examples of complete slag productions that have been measured from broadly similar furnaces in Ireland.

Parallels for the style of furnace can be sought locally, with possibly similar furnaces at Derrinsallagh 3 (Furnace C819 and working hollow C640) and maybe at other sites on this scheme. Further east of the M7/N7 scheme other examples may occur. Outside the area, very close parallels can be drawn with the furnaces from the Iron Age of N. Wales described, and reconstructed by Crew. The only major difference with Crew's reconstruction is that the Derrinsallagh example may have had overhanging wall, giving the furnace a domed or bottle shape.

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Methods

This furnace had been approximately half-sectioned during its original excavation in the field, and a description based on this appears in the Prelim Report. In the prelim report the orientation of the furnace was wrongly recorded, with the cardinal points rotated by 90°, because the field plan was oriented with North to the right, not to the top as assumed.

The furnace had then been lifted from the site (on the advice of the archaeometallurgical specialist), supported by plastic wrapping and resting on a palette. The block had been in storage for some considerable time before examination, so was extremely dry, requiring extensive wetting in order to excavate further.

The stored block measured approximately 500mm N-S and 540mm E-W. Some subsidence had occurred during lifting, so that the originally horizontal top surface of the block was tilted towards the original South by about 10°. Drawings made of the furnace during examination are drawn to a "best fit" horizontal, for the original horizontal was not recorded on the block.

During examination, the lifted furnace was first thoroughly cleaned, before the remaining infill of the furnace was removed. The furnace structure, which had considerable adhering slag, was then sampled.

Results

The furnace cut was not located during the examination. The inner face of the pit was carefully smoothed, suggesting that the wall of the pit was formed of reworked or emplaced clay, but no certain differentiation of a cut was made, with the heavy overprinting of the thermal alteration precluding recognition of subtle changes in the clay. Stone clasts from the natural boulder clay protruded slightly into the base of the pit, indicating that this at least was not lined. On balance of probabilities it is felt that the cut was probably very close to the final pit form, with the cut surface carefully smoothed, rather than there being any considerable thickness of lining, but this point is uncertain.

The basal pit was shown to be not a circular structure as originally described, but a "figure of eight" shape, with the truncation produced by the lifting cutting the structure across the "waist". The main section of the pit had a gently concave base (modified slightly by the stones protruding from the natural boulder clay below), with slightly angular breaks of slope at the foot of the walls. The lowest point on the base, offset towards the North side, lies at about 340mm below the level of truncation. Where the walls had not reacted, or become coated in slag, they were carefully formed, with a smooth surface formed of clay slurry, and with a slightly overhanging orientation.

The lower section of the pit appears to have sub-circular, with a diameter of approximately 360mm. The level of truncation was probably close to the original ground level, at which the furnace appears to have been approximately 320mm diameter. The overhang on the sides was particularly marked to North and East, that to south being altered by a slag-filled embayment (see below).

To the west side of the preserved pit, the "waist" area had a floor at about 200mm below truncation, with markedly angular breaks of slope at the bottom of the overhanging walls. The waist was about 260mm wide on the floor at its narrowest and 220mm wide at the level of truncation.

Heat-produced alteration of the silty clay surrounding the pit (as mentioned above, the equation of the furnace pit with the original cut is not quite certain, so these altered clays probably include mainly natural, with a superficial skim of reworked clay) was quite complex. At the level of truncation a marked oxidised halo extended about 30mm from the pit margin, although on the eastern side of the furnace this was truncated by the cutting of the lifted block. The oxidised halo was fairly superficial, and thinned rapidly with depth, with the lower walls of the pit showing little alteration apart from mild baking. The base of the pit had a variable reddened skim, which seemed particularly marked near the natural stones in the pit floor.

On the south side of the furnace there was a strong and wide reduced-fired alteration in an arcuate form around the early burr. Elsewhere a zone of reduced-firing extends beneath those sections of pit wall with adhering slag.

The margins of the late blowhole were fired to a strongly oxidised red-orange as would be expected in this location.

The observed infill of the furnace comprised five main components:

1. The basal section of the pit was filled by a poorly-compacted charcoal-rich dark deposit. This is equivalent to c451 of the site records. This deposit was probably up to about 120mm thick in the furnace pit, extending and thinning into the "waist", where it was approximately 70mm thick.
2. A second charcoal-rich deposit overlay c451. This was equivalent to c450 of the site records. This material was very rich in slag fragments. Most of the deposit had been removed in the original excavation. The western edge of the deposit was a line forming the continuation of the sub-circular pit margin across the "waist". The slag did not continue into the waist, where the fired clay deposit (c402) lay directly on c451.
3. The uppermost remaining fill of the pit was a well compacted deposit of fired clay, mainly oxidised-fired and often forming large planar slabs. This material was c403 of the site records. Much of this deposit had been removed from the furnace during the initial excavation. The deposit included several large slabs of fired clay, which were inclined into the pit. These would appear to represent fragments of the furnace superstructure which fell internally during degradation. One particularly substantial slab lay across the boundary between the furnace pit and the "waist", in a position corresponding to the limit of c451; it is just conceivable that this was a deliberately-placed slab to block the arch during the last use of the furnace.
4. To the east side of the pit was a major (approximately 15kg) dark-coloured slag mass attached to the wall. Full description of this mass must await its future detailed investigation. The upper, outer, side of the mass contained what appears to be the location of the blowhole. A strongly oxidised lower margin leads to a hole 75mm wide by 30mm high,

connected to an internal cavity dipping at 30-40° into the slag mass.

The mass extends 200mm into the furnace (reaching the centre of the sub-circular pit) and extends laterally over a distance of approximately 240mm. The block thus subtends an angle approximately 120° from the centre of the pit. The mass has a fairly smooth planar central upper surface approximately 65mm wide which dips down into the furnace above the central cavity. The lateral faces of the mass dip more steeply and form webs onto the furnace sides in both directions.

On the lateral walls of the pit slag totalling 4.6kg was attached around to an angle of 50° to the blowing axis on either side; the gap without attached slag is centred on, but not quite symmetrical with, the gap into the "waist". The lower part of the slag layer attached to the walls thickens downwards before terminating abruptly at a level 160-200mm below the truncation surface. This level is probably equivalent to the base of c450.

These slags form part of the material referred to as c452 in the site records.

5. Parts of the southern and eastern sides of the pit show intense vitrification of the pit wall close to the truncation surface. The vitrification appears as a paler grey material than the slag described in (4) above. Distinction between in-situ vitrification of the wall and adhering pale slags is difficult, and should be resolved in future analytical investigations.

This vitrification extends to a maximum depth of about 15mm into the wall on the east side of the pit, but to the south of the pit there is a more complex situation where the vitrified material appears to be up to 20mm thick on either side of an embayment in the wall 240mm wide and 80mm deep. The embayment is filled with a dense pale slag, with some concentric featurings on the flat upper surface. The total weight of this slag block is approximately 6.5kg. The precise form of the lower part of the slag here is not known, but would be revealed by sectioning of the sampled material. The embayment represents the zone of strong reaction with the furnace wall seen immediately below the blowhole; a reaction zone which typically generates a dense, coarse-grained slag referred to as the "burr".

The site records indicate that a further fill (c449) existed, forming a shallow (sag?) fill over the abandoned furnace, but there were no remnants of this in the lifted block.

Interpretation

The furnace was interpreted in the field as a circular "bowl furnace". Following this examination, that interpretation is no longer tenable. The "circular bowl" has been shown to be approximately half of a figure of eight structure. The "waist" of the structure shows incurving sides, and may be reconstructed as a furnace arch. The arch would have been 240-280mm high and 200mm wide, with its top approximately 40mm above the truncation surface. The finely-preserved smooth internal face of the arch suggests that it received little damage in use (or had been recently repaired). This suggests in turn that any arch-blocking was more external to the furnace and also that this part of the furnace must have remained relatively cold.

The furnace pit can be interpreted as the basal pit of a non-slag tapping furnace, of a kind commonly referred to as a slagpit furnace. The floor of the arch lies at a level 160mm above the base of the slagpit, so tapping the furnace would not have been possible.

The working hollow outside the furnace was not recognised as such during the initial excavation, but is represented by "spread" c402 and possibly also spread c401. The extension of c451 into the furnace arch raises the possibility that it was originally contiguous with, and therefore the external charcoal rich spread c402. The base of c402 should be viewed as part of cut c397. Cut c397 therefore has an overall length (NW-SE) of approximately 1.15m.

The recognition of a slagpit furnace with a furnace arch is highly significant. Such furnaces have been suspected elsewhere previously, but the evidence from Derrinsallagh 3 is unequivocal. The presence of an arch is an indicator that furnace cleaning and repair was not possible through the superstructure. Experimental work has shown the significance of access to the furnace for slag clearance and repair; the interior of the furnace must be reachable, it must all lie within an arm's length. Once the shaft reaches a critical height, approximately 600mm, it becomes impossible to repair the furnace although some repair of the blowhole area is likely to be required after each smelt (Crew 1991). A furnace arch is one solution to this (a removable tuyère block is another). A large furnace arch also facilitates removal of large slag blocks and possibly also removal of the bloom itself.

The reconstruction of the superstructure of this furnace is problematic because of the lack of large sections of fired ceramic. Several other sites have produced sections of vitrified furnace with a convex vitrified face, but particularly in this context the material from the Derrinsallagh 4 extension should be mentioned (Young 2008). The vitrified material from c660 could be interpreted as a blowhole within an overhanging wall, which is very reminiscent of the situation in c397.

The pit of c397 has markedly overhanging sides and the question is to what extent that curve continued above the level of truncation. Without sectioning the blowhole on the east side it is difficult to be certain, but it would appear that the blowhole was on an overhanging section. Continuation of the overhang above the blowhole would be unlikely, since the hot-zone of the furnace would impinge on the wall and be likely to cause extreme damage.

There is little direct evidence for the thickness of the walls of the furnace. The curvature of the walls of the arch suggest, despite being incompletely known, that the wall here was perhaps 100mm in thickness, and a broadly similar thickness is suggested by the width of the zone between the cut of c397 and the limit of spread c406 to the east.

Pleiner (2000) illustrated several examples of slagpit furnaces with overhanging pit sides, but with a straight shaft above. The advantages of such a geometry would be likely to include minimising the contact between descending slag and pit wall, to make it easier to clear the pit after use.

The collapsed material in this furnace was mainly on the less altered (unvitrified) side of the furnace and it is unclear whether the planar slabs were originally so, or had been compressed flat. Planar vitrified material was recorded within the present scheme at Clonrud 4 (Young 2008e).

Quite apart from the preservation of the furnace arch, this furnace is remarkable for its evidence of a change in blowing orientation during the lifespan of the furnace. The final use of the furnace entailed blowing through the blowhole on the southeast side of the furnace, opposite to the furnace arch. This final phase of use left 21kg of slag, mainly attached to the furnace walls (plus any slag removed from the furnace during its initial excavation; material which has not yet been traced). The main slag mass in the furnace is of very unusual form. It has neither the form of a typical smelting slag cake (sometimes called a furnace bottom), for which good examples are known from sites such as Tullyallen 6 (Young 2003a) and Adamstown (Young 2006), but is equally not typical smithing slag.

The downward deflection of the air blast into a slag tube is commonly seen (author's personal observation) when a smelt produces too much slag on the blowing wall, which descends over the air inlet and chills against the incoming cool air forming a slag hood. Once the air flow into the furnace is impeded a vicious circle is set up in which the reaction becomes concentrated into a smaller area and the build-up of slag in the blowing area is encouraged.

Once the air supply becomes completely occluded (as probably happened here), the temperature of the furnace will fall rapidly and the reaction halts. In this case, it would appear that the slagging of the furnace was too severe to be deemed worth cleaning and it was abandoned. What is not currently clear (but might be determined with sectioning of the main slag mass), is whether the furnace had ever been worked successfully in this configuration. The accumulation of slag around the pit walls terminated downwards at the top of the charcoal layer c451. This suggests that c451 was a deposit left in the furnace from previous smelting. It is unclear if the wall slags were all from the last smelt, but it is possible that they were.

The late axial blowing of the furnace replaced a more conventional earlier configuration with blowing from the south, at approximately right-angles to the furnace arch. In this configuration a deep burr developed, which was left in place when the furnace was reoriented. The deep vitrification around the burr suggests sustained use, but it is unknown how much use the furnace had before being realigned.

Discussion

The detailed understanding of non-slag tapping furnaces in Ireland is progressing only slowly. It is clear that these slagpit furnaces were really quite diverse in detail, but very few have been examined in sufficient detail to permit either the determination of their morphology or the development of a typology.

Parallels for the style of furnace can be sought locally, with possibly similar furnaces at Derrinsallagh 3 (Furnace C819 and working hollow C640; Young 2008c) and maybe at other sites on this scheme. Further east of the M7/N7 scheme other examples may occur (Cappakeel West and Morrett; Young 2005). Outside the area, very close parallels can be drawn with the furnaces from the Iron Age of N. Wales described, and reconstructed by Crew (Crew 1987, 1989, 1991, 1998). The only major difference with Crew's reconstruction is that the Derrinsallagh 4 furnace has overhanging pit sides and may have had an overhanging lower wall, giving the furnace a domed or bottle shape.

Pleiner (2000; p. 149) classed as "small" those slagpit furnaces with slagpit diameters of "35-40cm producing 20-25kg of slag". This weight of slag appears quite typical for early furnaces in Ireland (Derryvorigan 1 c092 – c21kg, Young 2008d; Tullyallen 6 – 17.5kg, Young 2003a; Adamstown 1 - 18.6kg, Young 2006). However, even if the Irish furnaces in similar in capacity, they appear to be very different in detailed morphology, particularly during the Iron Age. Moderate diameter furnaces with arches appear to be just one variety in use (as Derrinsallagh 4 c397) – with wider furnaces with no arch (Tullyallen 6, Adamstown 1), and paired furnaces (Clonrud 4, Derryvorigan 1?, Derrinsallagh 4?) of variable diameter also being common.

The large amount of information gained from this furnace, in terms of its morphology, the presence of an arch, and in terms of its reorientation with two successive blowing orientations, is considerable. The results form a stark contrast with the typical field description of such features, which are usually schematic and superficial.

Evaluation of potential

The effort of lifting this furnace and its subsequent detailed examination has paid great dividends and the proposal for lifting the furnace is to be applauded.

This furnace now represents one of the best-documented furnaces known from Ireland and it goes a long way to establishing the morphology of at least one of the furnace types in use in Iron Age. It is clear that multiple variants of the slagpit furnace were employed, and old models of the "bowl furnace" (Scott 1990) can be abandoned as previously proposed (e.g. Young 2003b).

A thorough analytical examination of the slags from this furnace would be highly desirable, given the detailed understanding of furnace morphology. Detailed investigation of multiple slag samples to understand the reactions taking place and their spatial relationships is recommended.

To pursue this level of understanding it is highly desirable that the slags removed from the initial partial clearance of the furnace are located and retrieved to be reunited with the new collections, so that the slag assemblage can be understood in its entirety.

Appendix 1: Description in the style of the stratigraphic report.

C397: cut of the basal pit of a complex slagpit furnace. The cut is figure-of-eight in plan, with the eastern section of the pit corresponding to the original field interpretation of C397 (sub-circular, 0.40m diameter), but in addition there was a further, shallower pit to the NW, filled with context C402 as well as C403, and possibly C401. The two pits were connected via a narrow waist 0.2m wide, corresponding to the furnace arch. The precise shape of the NW part of the cut is unknown, but it would appear to have been approximately 0.45m wide (SW-NE). The overall length (NW-SE) of C397 was probably approximately 1.15m. **C397** was one of a complex of features that included **C398**, **C399**, and **C400**. **C397** was cut into **C003**, and filled by seven deposits **C401**, **C402**, **C451**, **C450**, **C452**, **C403**, and **C449**. The natural was variously altered to **C404**, a well compacted orangey-red oxidised clay or to reduced and variably vitrified material **C405**, which both formed incomplete zones around the outside of **C397**. The first deposit was **C451** a loosely compacted black charcoal-rich silt. It measured at least 0.52m in length (extending outside the lifted block and may have been equivalent to **C402**), 0.40m in width, and 0.12m in depth. The second deposit was **C450** loosely compacted black very coarse mixed slag-rich silt. It was restricted to the eastern section of the cut and measured 0.34m in length, 0.40m in width, and 0.10m in thickness. The third deposit **C452** was a mass greyish-black slag attached to the southern and eastern walls of the eastern section of **C397** and extending up to 0.20m into the pit and was up to 0.20m thick. The fourth deposit **C403** was well compacted orange oxidised sandy-clay, with frequent red oxidised clay lumps. It measured 0.60m east-west, 0.32m north-south, and 0.10m in thickness. **C403** may have been the remains of the collapsed superstructure of **C397**. The fifth and uppermost deposit in the eastern section was **C449** a well compacted medium brown clay with occasional charcoal inclusions. It measured 0.22m in length, 0.28m in width, and 0.03m in depth. **C402** was the lower fill of the shallow NW part of the **C397** and was possibly equivalent to **C451**. **C401** was a spread, or fill of C397 lying to the west of **C402**.

C397	cut of the basal pit of a complex slagpit furnace. The cut is figure-of-eight in plan, with the eastern pit corresponding to the field interpretation of C397, but in addition there was probably a further, shallower pit to the NW, filled with context C402 as well as C403, and possibly C401, linked to the eastern pit via a narrower "waist". The precise shape of the NW part of the cut is unknown but was probably 0.45m wide and extended about 0.70m to the NW of the narrow central section. The narrow waist was 0.20m deep, 0.20m wide and 0.10-0.15m long. The SE pit measured 0.38m east-west, 0.40m north-south, 0.34m in depth. The eastern section of the cut has a sharp break of slope at top, more gradual at base, concave sides, locally overhanging, and a slightly concave base. The central waist has steep overhanging sides with an abrupt break of slope onto a sub-horizontal base. C397 was one of a complex of features that included C398, C399, and C400. Cut into C003 (locally oxidised to C404 and vitrified to C405), filled by C451, C450, C452, C403, C449.
C404 (natural)	Oxidised fired clay in surrounds of C397. Probably mainly altered in-situ natural (C003) although some finishing of the cut with soft clay may have been undertaken. Well compacted orangey-red oxidised clay. Measured 0m-0.05m in width, 0.05m in depth. C404 formed an incomplete ring around the outer extent of C397. Particularly prominent on the SE side of the cut. Above C003, under C405.
C405 (natural)	Reduced fired/vitrified clay in surrounds of C397, together with its locally vitrified surface, well-indurated green-brown vitrified clay. C405 formed an irregular incomplete ring around the outer extent of C397, and was widest on its west side where it measured 0.05m - 0.08m in width. The context may be largely altered natural, although it may include some material that was sufficiently molten to have flown down the wall. Above C404, under C451.
C451	Lower deposit of C397, loosely compacted black charcoal-rich silt. Forms the lowest fill in C397 and extends across the eastern pit and the waist. May correspond to C402 in the W pit. Measured at least 0.52m in length, 0.40m in width, 0.12m in depth. Above C405 and C403, under C452.
C450	Deposit of C397, loosely compacted black very coarse mixed slag-rich silt lying in the central part of the eastern pit. Measured 0.34m in length, 0.40m in width, and 0.10m in depth. Above C451, under C403.
C452	Deposit of C397. Slag attached to the eastern and southern walls of the eastern pit. Occupies an irregular area 0.40m long by 0.20m wide and up to 0.20m thick. Above C451, under C403.
C403	Deposit of C397, well compacted orange oxidised sandy-clay, with frequent red oxidised clay lumps. Measured 0.60m NW-SE, 0.32m NE-SW and up to 0.12m in thickness. C403 may have been the part of the collapsed superstructure of C397. Above C452 and C451, under C449.
C449	Upper deposit of C397. Well compacted medium brown clay with occasional charcoal inclusions. Measured 0.22m in length, 0.28m in width, 0.03m in depth. Above C403, under C002.

In addition I would recommend that spread C402, and possibly spread C401, should be considered as fills of the working hollow section of C397.

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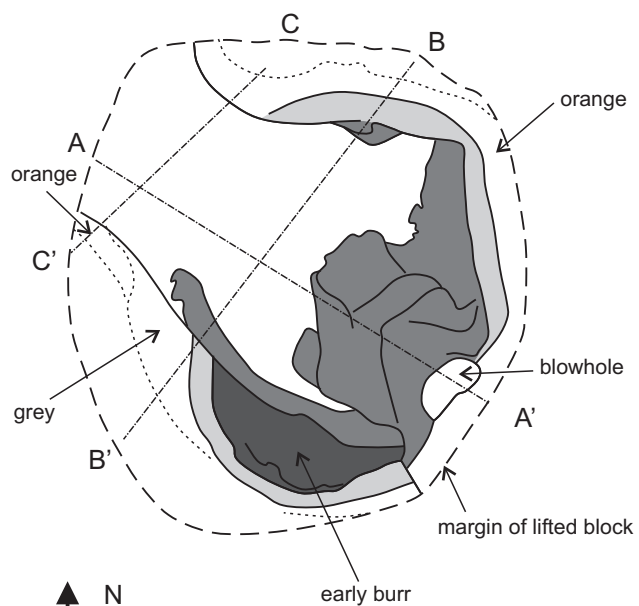
Figure Captions

Figure 1. Plan and sections of furnace c397.




Figure 2. Plan of furnace c397 superimposed on pre-excavation plan #232, showing the suggested outline of the furnace and its working hollow, as indicated by the adjacent spreads.

Figure 3. Tentative longitudinal (a) and transverse (b) sections of the furnace as it might have been in use. Both successive blowholes are shown – the early one in (b) would not have been open during the later use of the furnace using the axial blast (a).

Figure 1



500mm

-  early burr
-  slag from later use
-  vitrified material

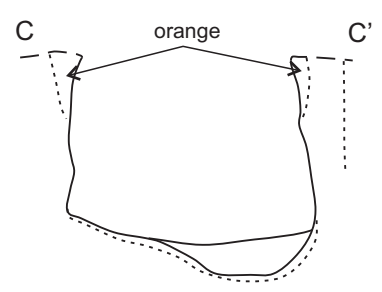
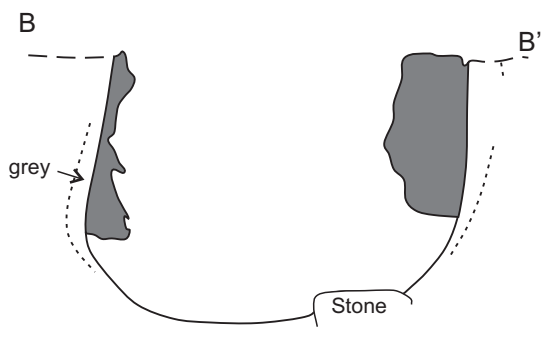
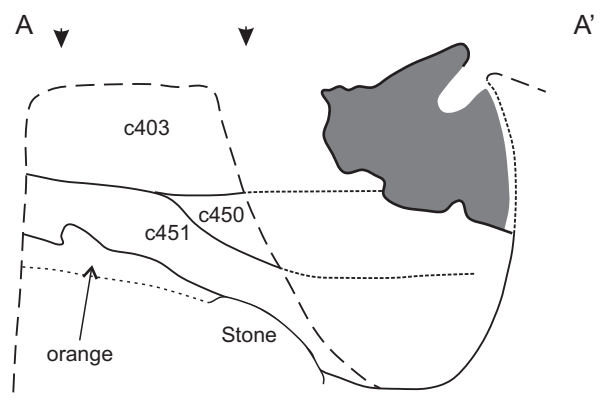


Figure 2

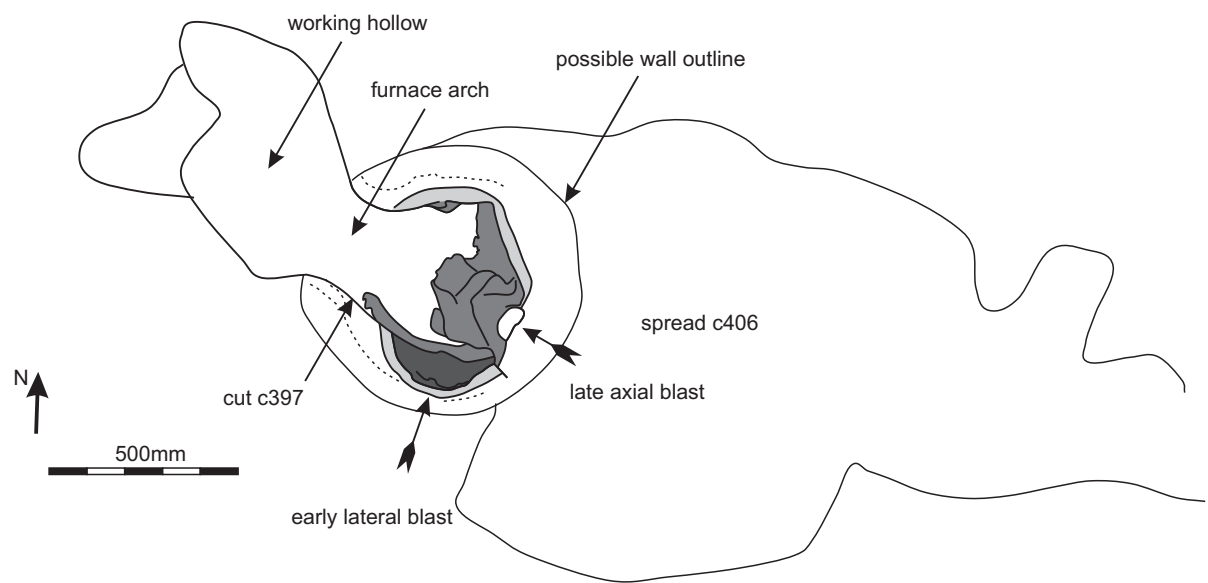
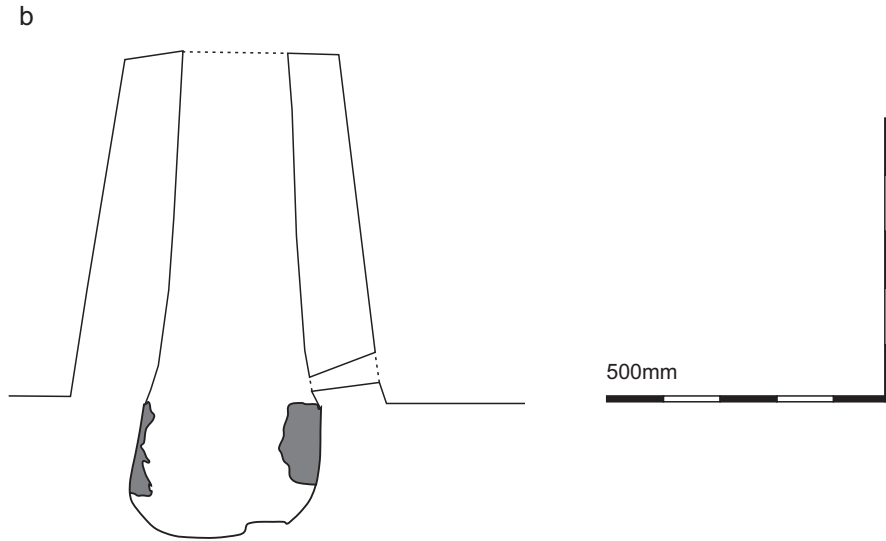
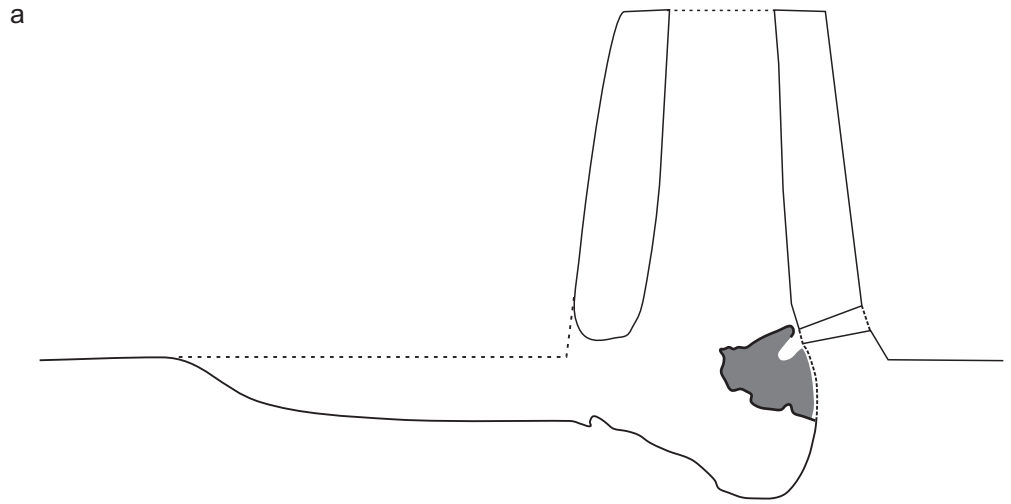


Figure 3



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