Experiment, Archaeology & Art - The Turf to Tools Project

Turf to Tools (2014, 2016) was originally conceived as "... an ongoing investigation in to landscape, material and craft, inspired by local archeological investigations in Rhynie, Aberdeenshire." The archaeological foundations centred on the work of Dr. Gordon Noble's investigations of Pictish sites, notably the 'Rhynie Man' stone, and later the excavations by Ross Murray at the 'Iron Age Craft Working Site' of Culduthel, nearby. To date, a total of nine bloomery iron smelts have been undertaken for T2T, the two main series at the Scottish Sculpture Workshop at Lumsden (close to Rhynie). These included tests of the unique local Macaulayite ore and peat as a potential fuel. Local materials would be utilized using prototypes established by the archaeology, through methods refined by experimentation, with an aim to replicating a specific object, being the axe depicted with Rhynie Man. Taken together, this project illustrates an interface between archaeological research and practical experiment, extended into artistic vision.

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This is the full version of the paper behind a presentation at the European Archaeology Association EAA23 conference at Belfast, Ireland, September 1, 2023, Session 729 - EXARC: Reconstructing Past Narratives Through Experimental Archaeology.
A shorter version, covering just the experimental iron smelting and bloom to bar processes (less lavishly illustrated) is pending publication.

Introduction:

The Turf to Tools project (T2T) was initially conceived as "... an ongoing investigation in to landscape, material and craft, inspired by local archeological investigations in Rhynie, Aberdeenshire."

> "During summer 2013, a nearby archaeological investigation unearthed evidence of metal working within a Pictish fort. Taking inspiration from the finds, SSW Artist and Technician Eden Jolly attempted to recreated a bloomery iron furnace, working with information provided by archaeologist Dr. Gordon Noble to explore the methods and practices involved to produce workable iron from raw iron ore. From this, the conversation diversified to a wider exploration of skill, process, and material – material as a resource but also as a subject of procurement within both modern and historical landscapes." (UN, 2016)

Nuno Sacramento, then director of the Scottish Sculpture Workshop (SSW), located in rural Lumsden, close by to Rhynie in Scotland, would organize this "...cross-disciplinary project, (where) the focus is on collaboration and peer exchange, working with artists, artisans, scientists, historians and academics..." (UN, 2016)

The initial core group would include both technicians Eden Jolly and Uist Corrigan, fellow artisan blacksmith Kelly Probyn-Smith plus archaeologist Gordon Noble and artist / writers Deirdre O'Mahony and Maxime Hourani. As SSW operates as a community of resident artists, often valuable input was provided by others not directly involved in the project.

As mentioned, from the very start, the archaeological investigations at Rhynie by Noble would serve to frame this undertaking. (Gondek & Noble, 2017) So T2T was centred to what was loosely defined as a 'Pictish' cultural set : North Eastern Scotland, post Roman to pre - Viking (so 400 - 800 AD). It is a period where the minor chiefdoms are expanding to small kingdoms, and Rhynie appears to be the site of one of those political centres. In terms of prototype objects, this period presents some major problems, as this is a material culture not well represented by artifact in archaeology.

Remains of bloomery iron smelting furnaces are fragmentary at best, and the functional details of building and operating these furnaces is still under testing by way of experimental archaeology. Looking for specifically first Scottish, then narrowed to Pictish, period samples at first seemed unlikely. Fortunately, it proved possible to find descriptions by Ross Murray of a small scale historic iron production site at Culduthel, just outside Inverness (about 80 km to the west of Rhynie). (Murray, 2007) Both the close location, and the rough dating that site from 200 to 400 AD, is almost good as it could be within the random nature of archaeological discoveries. My own past work with small scale bloomery furnaces would prove critical, allowing for a fuller understanding of exactly how available iron ore could be transformed into workable iron bars.

As an undertaking, T2T would be comprised of three primary working sessions, initial prototype builds plus main campaigns later August to early September of 2014 and 2016, with a completion planned for early September of 2023 (immediately following the EAA23 conference). The rough working plan was for Phase 1 (2014) to centre on iron smelting, Phase 2 (2016) to include bloom to bar, and Phase 3 (2023) to include bar to object. To date, a total of eight individual iron smelts have been mounted. Participating in individual firings would be post graduate students, staff of regional living history museums, artists and writers. In terms of public outreach, a number of the smelting events in 2014 and 2016 were specifically mounted as open demonstration events. In this all the integration of archaeological research, experimental testing and contemporary arts was a fundamental part of the project.

Method : Culduthel

The excavations at Culduthel Mains Farm, Inverness, of a group of iron smelting and further bloom processing furnaces would serve as the archaeological basis for the test furnaces built for Turf to Tools.

> “ The ironworking debris is a substantial and important assemblage, comprising over 250 kg of material. This is the largest Iron Age slag assemblage from mainland Scotland. In addition to this are 16 stones associated with furnace structures, one bag of possible iron ore and approximately 7 kg daub with adhering vitrified material. This assemblage is significant due to the stratified nature of the majority of the material, particularly as quantities were recovered in association with recognizable hearths or furnaces.
> ...
> ... three different furnace types may have been present at Culduthel : simple bowl, simple stone built and more substantial stone built furnaces.” (McLauren & Heald, 2007)

The site at Culduthel contains the remains of a large number of furnaces, with evidence of not only primary iron smelting, but also secondary bloom to bar processing and likely bar to object production as well. The main form of the furnaces is a heavy stone base with a clay superstructure, although basically the upper portions only survive as fragments. Individual sizes vary from 40 x 60 cm down to 30 x 40 cm interior diameter (ID), the use of larger stones resulting in a kind of boxed oval shape. Several further clues were indicated from the remains :

- the larger base stones created a C shape, with smaller stones indicating a lower break line / arch, suggesting a bottom extraction method
- the bases of several furnaces included heavy fragmented charcoal deposits containing drips of slag
- a number of clay fragments showed impressions of wicker and finger prints
- several of the furnaces showed multiple layers of slag, indicating repeated use cycles
- one section was either composed of smaller height stones, or had stones missing, strongly suggesting bottom side extraction of the bloom.

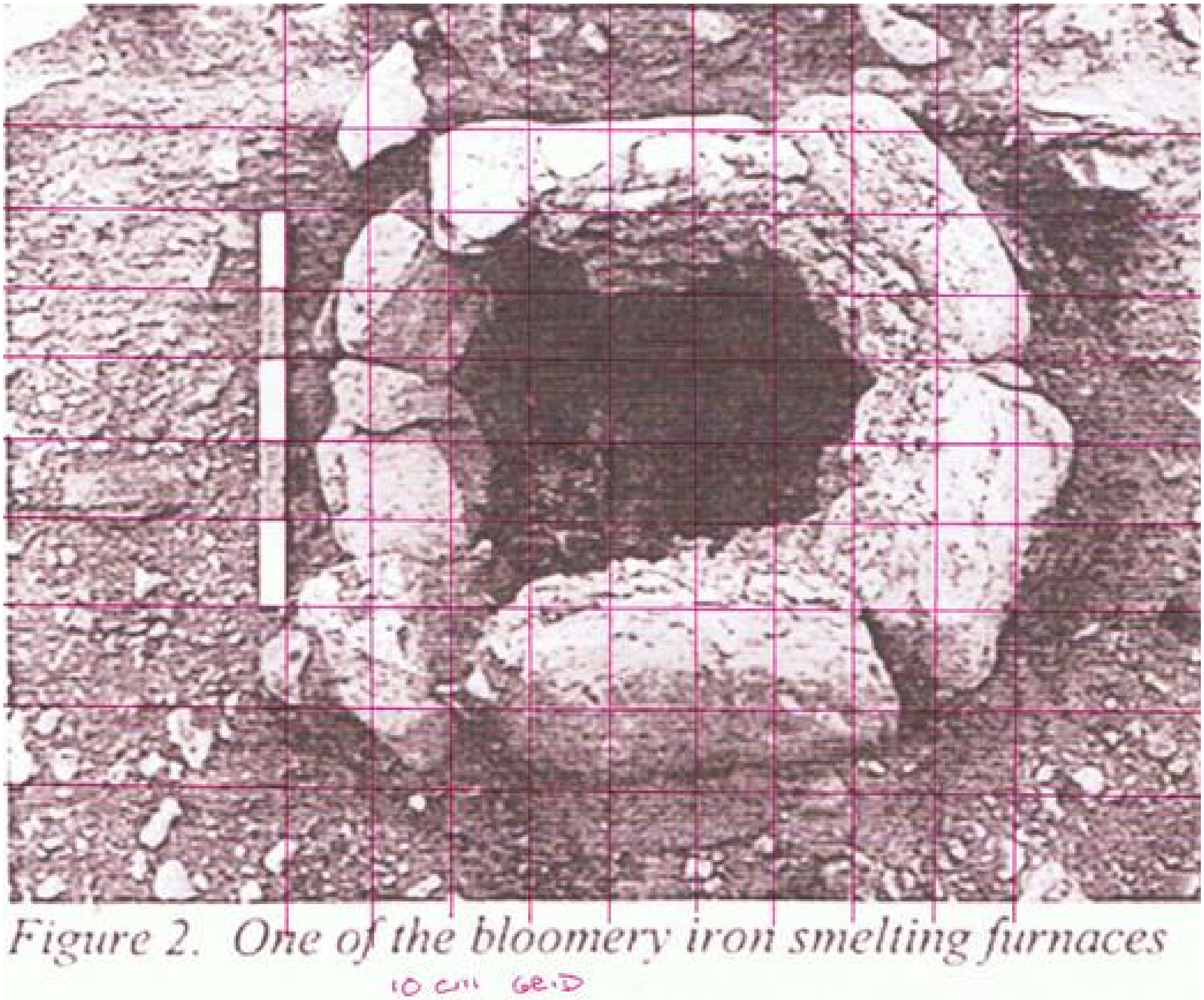

Figure 1 : One of the furnaces uncovered at Culdthel, with a 10 cm grid overlay (a)

As is typical with almost any furnace remains, little more than the base area remains. Any attempt at full reconstruction, much less into a functional system, remains somewhat speculative. To aid in creation of a working furnace, experience gained from large number of earlier experimental bloomery iron smelts was applied (a total of 55 at the start of this project).

The most significant unknown because of the limited remains available from archaeology is always the details of the air system itself, both in terms of how air is inputted into the furnace as well as the equipment used as the supply.. It is certainly well understood that historic systems used as reference all use some type of human powered equipment. Although a number of tests of various bellows have been made,

the main problem with using human power is assembling the number of volunteers needed for the constant (and exhausting) pumping required over the 4 – 6 hours of a typical smelt. (1) For that reason, mechanical blowers were employed in all these experiments. It is understood that the higher volumes possible via electric powered blowers normally can be expected to result in larger yields and often denser final blooms (Sauder & Williams, 2002)
A second unknown is the combination of stack height (distance above air input) and base depth (distance below air input), both of which have proved critical to effective smelting. There is a dance between ore type, available charcoal, clay used, and the amount of air (both volume and pressure) which combines to the final ideal size and layout of the furnace. Change too much of one, and all the other elements need to be modified.

The basic design for all the furnaces was the well tested 'short shaft' type (2), basically a clay cylinder roughly 60 – 70 cm tall (shaft height) and 25 – 30 cm ID. A base depth of at least 10 cm and measurement above the tuyere (stack height) of at least 40 cm have proved minimal measurements in extensive testing. Walls were composed of a mix of equal amounts by volume of powdered commercial clay, course sand and dry shredded horse manure, roughly 8 cm thick at base and tapering to 5 cm at the top.. As indicated by Culduthel, the superstructures were placed on a base plinth made of natural stones, this base filled with charcoal fines. The material of the tuyere varied, either ceramic or copper. Ideally this placed 15 – 20 cm above the fines surface (base depth), set 5 cm beyond the interior wall and roughly at a 20 degree down angle. Furnaces were equipped with a wide lower extraction arch plus a smaller tapping arch. Slag tapping would be carried out only as required to prevent levels blocking the air flow, with the furnaces often also self tapping (incontinent).
A similar sequence was used for all experimental tests, again repeating the method proven by earlier work. Once the furnace body has been pre-heated it is first filled with rough (unsorted) charcoal, followed by charcoal which has been broken and screened for pieces between 2.5 (walnut) to 0.5 cm (pea) size. Air is supplied, and after the total of the interior is enveloped, typically adjusted for a burn rate at 5 - 7 minutes per kg, with charcoal added each time the top level falls about 5 cm, typically about 500 gm/ 1.5 litre. Ore is added in small amounts, spread as evenly as possible between charcoal additions. As the iron oxide reduction process is overall exothermic, internal temperatures (indicated by time of fuel consumption) can be dampened down by supplying ever larger amounts of ore to uniform charcoal charges, normally starting at 1 kg per roughly 2 kg charcoal, and over the sequence

increasing incrementally to as much as 3 kg per charge. As these experiments are intended just to illustrate iron production, not necessarily most efficient or massive blooms, a typical total added ore amount are 25 – 30 kg. The expectation is a bloom in the range of 3 – 5 kg, so a yield of 12 – 20 %.

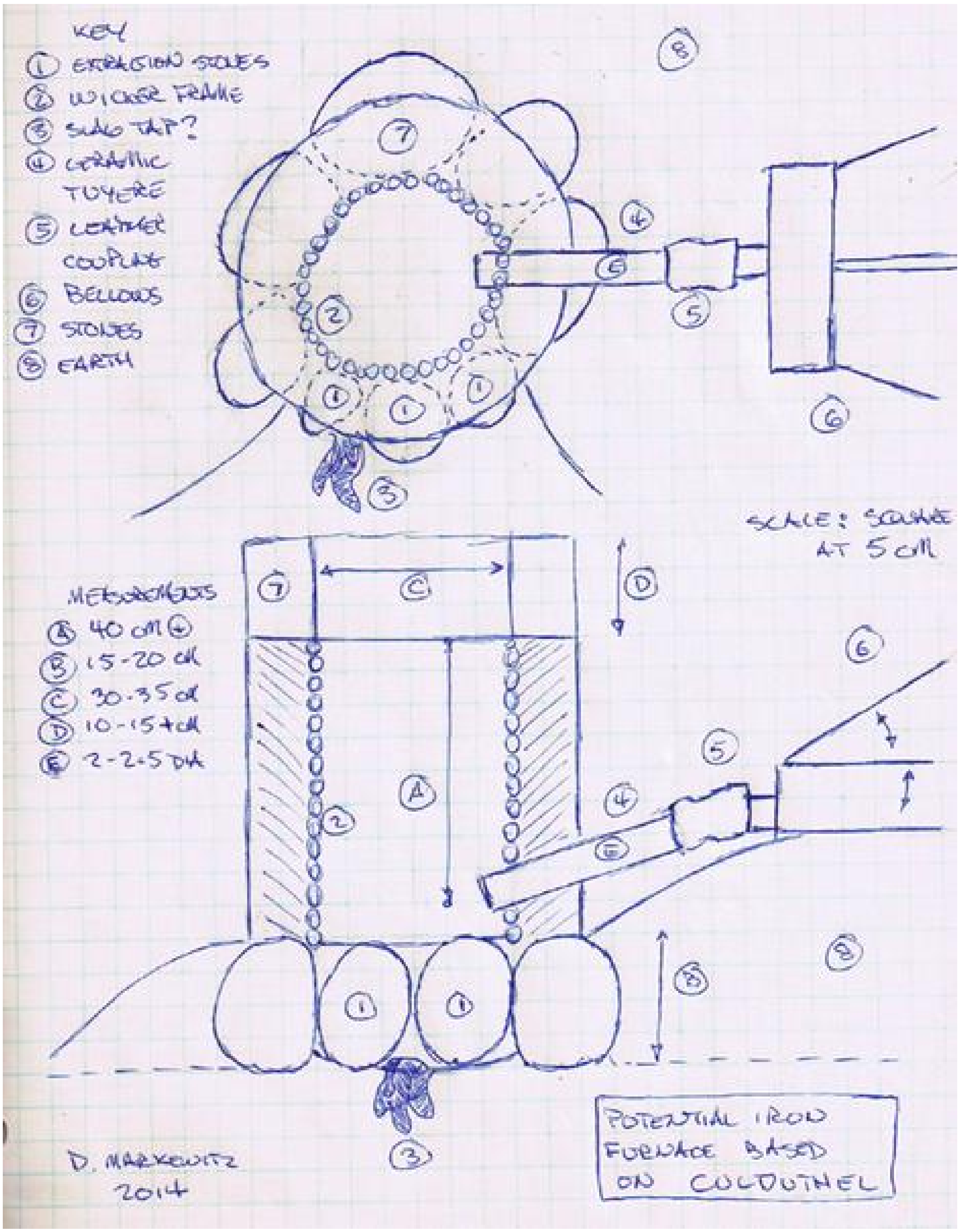

Figure 2 : Potential working bloomery furnace, from archaeology at Culduthel

Dependable instrumentation for the measurement of air volumes was not available throughout this series, so any numbers reported are rough estimates only. Temperatures inside the furnaces were sometimes measured, using a digital thermometer and wire thermocouples, but as these are not critical to the results, they are not reported here. Charcoal was measured by volume (standard bucket) where that quantity was weighed as an average.

The Experiments :

Two prototype test smelts were undertaken , August 2013 at SSW and June 2014 at the Wareham Forge, the primarily purpose to test out the overall furnace construction plan.

Prototype A - In Scotland, the core team would consist of Eden Jolly and Thomas Stackhouse (only the second time they had attempted a bloomery iron smelt). The smelt was one of a number of activities carried out before the public as part of the SSW Summer Celebration event.
An ore analog was prepared using 25 kg red oxide (at 81% Fe_2O_3) plus 1.25 kg silica sand, 0.5 kg alumina and 2.5 whole wheat flour, to a total of 29.25 kg (dry weight), for a total potential iron content of 48.5 %. The result was a 5.2 kg bloom, yield at 18 %.

In Ontario, the core team would consist of Dr. Ron Ross, Neil Peterson and myself. The build used an on hand wicker basket as an internal form, which created a conical shape, 24 cm ID at the top, 35 cm ID at the clay base, 61 cm tall. (3) The clay shaft was set on top of natural stone base roughly 21 cm tall. The combination of irregular stones and rigid internal form was found to create significant problems with extensive cracking as the clay shrank on drying, although the use of an internal form certainly made construction easier and quicker. Several gaps into the range of 5mm wide had to be filled with damp clay after the normal air drying and gentle pre-heating fire of wood splits. Exaction through a bottom arch resulted to considerable damage to the furnace, which basically pulled slightly apart into two half sections vertically. Despite this, it was felt that the structure could have been braced and repaired for a second use.

Figure 3 : After firing, partially sintered clay walls showing wicker impressions

The tuyere was a pre-made ceramic tube with an ID of 2 cm, (4), set (all roughly) 16 cm above the fines base, 4 cm beyond the interior wall, allowing for a stack height of and 22.5 degrees down angle.

Overall, the smelt itself was successful, with 31 kg of a standard ore analog composed of red iron oxide (Fe2O3) (5) reduced to a 5.2 kg bloom (yield at 17 %). Air was supplied via an industrial electric blower, volumes in the range of 400 – 500 litres per minute (LpM), deliberately to a lower amount to better simulate the kind of volume available via human powered equipment. (Markewitz & Peterson, 2021)

Phase One was undertaken in August of 2014 at the Scottish Sculpture Workshop. It consisted of a total of three primary smelts, with an additional firing test plus one secondary experiment. All the furnaces at SSW were built on a platform consisting of a standard wooden shipping skid, topped with a protective layer of concrete paving slabs. This both protected the concrete floor working space, and allowed the furnaces to be carefully (!) moved about.

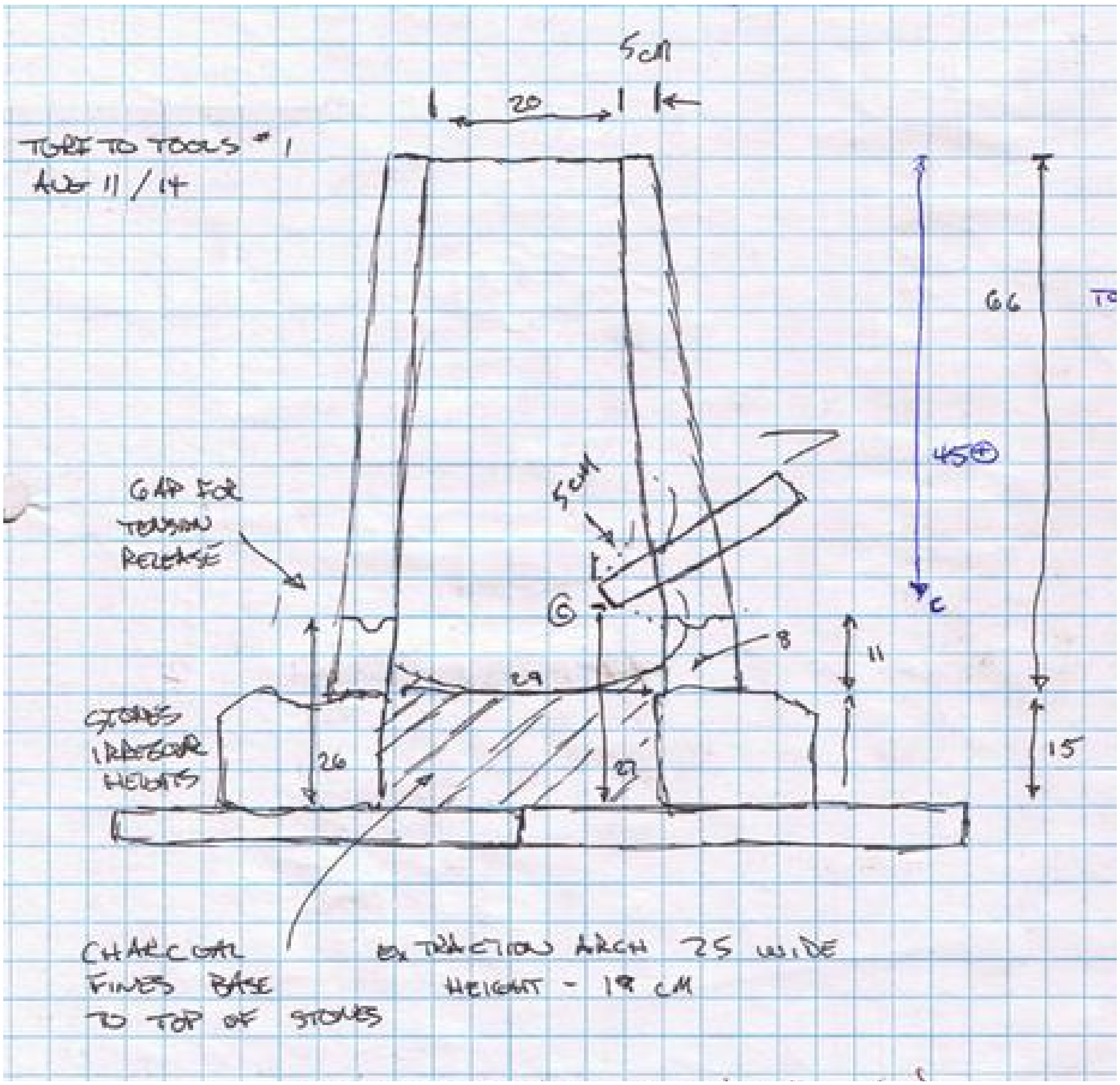

Figure 4 : Layout of the Phase 1 furnace, Phase 2 was similar

Again, a base plinth was constructed of a number of roughly similar sized natural stone blocks, supporting a slightly conical clay shaft, made of the 1:1:1 mix of clay : sand : shredded horse manure. This was completely hand built without any internal form, the wall thickness tapering from about 8 cm at the base to 5 cm at the top

edge. At the top the ID was 20 cm, at the base 29 cm. With the base plinth packed with 15 cm deep of charcoal fines, the total shaft height was 66 cm.
One important build feature was recommended by visiting artist George Beardsley. After the first row of clay pieces were added to the stone base, the top was uniformly flattened, then a shallow impression was created in the centre line on the top of the clay. This was then dusted with charcoal fines, before the addition of the second build layer of clay. This feature, later dubbed 'the Beardsley Break', prevented any cracks caused by clay shrinkage against the random stone pieces from extending further upwards into the body of the furnace. The impressed channel formed at the same time prevented any escape of hot interior gasses from the working furnace.

Figure 5 : the Beardsley Break, before dusting with charcoal fines (i)

The tuyere was a standard ceramic tube, set 5 cm beyond the interior wall , to 22.5 degrees down. The base depth was 11 cm and the stack height at 45 cm. Holes of 0.5 cm would be placed spaced every 10 cm vertically through the furnace walls, located at 90 degrees to the tuyere location, allowing for temperature measurements. A practical feature of these holes is first to see how ignition is proceeding up the furnace interior. Additionally, as a tongue of flame is visible as burning gasses escape, some estimate of the relative internal pressures within the furnace can be made.

Smelt 1.1 would be a partial test of a unique local ore - Macaulayite. The simple components are (%) Fe_2O_3 78.4, SiO_2 10.48, Al_2O_3 3.71, H_2O 7.4, so an overall potential iron content of 55 %. (6) The material gathered however was visibly very sandy in texture, and so the exact iron content the 16.2 kg of Macaulayite used is unknown. After breaking, this was mixed with 7.8 kg of fragments of industrial taconite, (normally about 65 % Fe). An additional 6 kg of standard red analog was also used to bring the total added to 31 kg. Air was supplied via a small electric leaf blower, volume unknown. As was expected because of the silica and alumina contained in the Macaulayite, considerable slag was generated and tapped off. After a bottom extraction, the end result was disappointing, with a bloom of 2.3 kg, yield at 7.5 %.

Smelt 1.2 used the same furnace, with some minor repairs around the extraction arch. This would be less of an experimental investigation than for the purpose of increasing experience within the SSW staff, Eden Jolly replacing myself as primary smelt master. There had been some erosion of the interior clay walls around the tuyere, typically of any clay built ‘virgin’ furnace. This changed the insert distance of the tuyere to 5 cm. A fresh bed of charcoal fines was laid, increasing the base depth to 15 cm. This would be a larger volume smelt, using 33.5 kg of broken taconite and 7.5 kg of red analog for a total of 41 kg added. One large bloom mass of 2.9 kg plus several larger pieces combined at 1.8 kg were recovered, a total weight of 4.7 kg, yield of 11.5 %. During extraction, there was considerable damage done to the furnace body.

After smelt 1.2, the construction of a new furnace was required, along the same general plan as the previous one. The same set of stones and positions were retained for the plinth. On completion the new furnace had a stack height of 64 cm, 20 cm top ID and (estimated) 27 cm bottom ID. The tuyere was placed identically to that previously, the new stack height as 48 cm.

Experiment 1.A would involve testing the potential temperature generation of peat as a fuel, a question suggested by project contributor Deirdre O'Mahony. This was undertaken as an extended drying fire process of the new furnace. The material used was commercially produced peat pellets, consisting of dug and shredded peat compressed into 'sausages' roughly thumb diameter and length. These were broken (with considerable difficulty) into the same size pieces used for the normal charcoal (so between 2.5 to 0.5 cm). Over a period of one hour a total of 43 kg of broken peat was added, with the same air supply as for 1.2. Near the end of this test, temperatures of as high as 1250 C were recorded. This is certainly within the range required for bloomery iron production. Balanced against this was a clear indication a yellowish colour in the volumes of smoke produced, normally a sign of sulphur being present. As sulphur quickly degrades the quality of any iron created, it is uncertain that at least this form of peat would be useful for successful iron smelting.

Figure 6 : Showing the large amount of smoke generated during the peat test.

Smelt 1.3 would be carried out as a day long public demonstration.
In discussion it was felt that the small blower used in the two previous smelts, although producing volumes which may have been similar to human powered bellows, was the primarily reason yields had been so low. In an attempt to increase burn rates

(so internal temperatures) a second, more powerful leaf blower unit was employed at the point where only 4 kg of ore had been added. The total ore used was 40 kg, again a mixture of taconite at 13 kg and red analog at 27 kg. The end result was an impressive and extremely dense 11.6 kg bloom, a 29 % yield.

Experiment 1.B was an additional investigation that was added to the end of this smelt. Under Emma Harrison, a total of 5.2 kg of beef bone pieces were added at the end of the main ore charges. These were placed as three roughly similar amounts, each covered with a standard bucket measure (1.9 kg) of charcoal, then allowed to burn down to the bottom of the furnace. The intent of this experiment was to see if the addition of bone would result in a calcium layer deposit on the bloom. (Harrison, 2015) The final conclusion here was the bloom itself showed no effect, but there was the generation of a considerable amount of pale yellow and viscous slag, over the dark black and fluid iron rich slag that would be normal. Almost no physical traces of the consumed bone pieces were found.

Figure 7 : Harrison adding bone at the end of the smelt sequence.

Phase 2 was mounted in September 2016, the gap largely due to the funding requirements of mounting an international project. The primary intent of Phase 2 was to convert created blooms into working bars, and finally into replica objects. An additional three iron smelts would investigate other locally available raw materials.

Again, a new furnace was constructed, on the same model as that used in earlier tests. Irregular natural stone blocks filled with charcoal fines as a base plinth, topped with a shaft of clay / sand / horse manure mix. The conical shape stood 68 cm tall, was 20 cm ID at the top and 30 cm ID at the base. The walls tapered in thickness from 8 cm at the base to 4 cm at the top edge, again using a Beardsley Break at the lower level. The tuyere used was made of heavy forged copper 45 cm long, tapering from 5 cm ID at 0.3 cm thick to 2.5 cm ID at 0.6 cm thick on the insert end. (7) The tuyere was set inserted 5 cm into the interior at 20 degrees down angle, place to give a working stack height of 49 cm. This furnace would be used for all three smelts, although considerable repair was needed between the first and second use. Air would be supplied via an electric leaf blower (no volume measurements).

Smelt 2.1 would continue the theme of utilizing local materials. Ore was gathered from a vein of geothite remaining at the Lecht Mine, near Tomintoul, about 40 km due west of Lumsden. (8) As with any abandoned works, any remaining ore found is likely to be questionable in quality. Several buckets of what was considered (despite limited experience gathering natural ores) rock bearing enough iron. This was broken into fragments ranging from 1cm down to 0.3 cm (peanut to rice size), with any pieces visibly containing little iron discarded. During the standard smelt sequence four heavy tappings of black iron rich slag were required. With a total ore amount of 37.5 kg, the results were disappointing with a crumbly textured bloom at 3.5 kg, yield of only 8 %.

Smelt 2.2 was a test of the possibility of peat as a fuel. Again, commercial compressed peat pellets were (labouriously) broken into 2.5 to 0.5 cm pieces. With ignition, it was clear that there was considerably more volatiles contained that would be seen with charcoal. The burn rate (volume over time) was found to be considerably faster than typical with charcoal, an average of 4 - 5 minutes per kg. Internal temperatures were measured several times, these indicating that the internal temperatures were considerably lower than considered ideal, with 1150 C as the highest recorded. One change to the basic method was the addition of three, one kg charges of iron rich tap slag from 2.1 before ore was started. The purpose here was to quickly establish a working slag bowl system in the furnace, normally a technique that helps improve yields. The ore used was a variation on the standard red oxide analog, with 5 % whole wheat flour and 5 % fine oat meal used as the organic binder. Again the results were disappointing, with 35 kg of analog only creating 1.5 kg of broken bloom fragments, a yield of only 4 %. In addition 6 kg of metallic gromps (mixture of slag and iron fragments enough to be magnetically gathered) was recovered afterwards.

Smelt 2.3 should be considered experiential more than experimental. Work was managed primarily by Jolly and Corrigan, with myself more as observer. The main ore used was 22 kg of broken industrial taconite. In the final stages broken gromp fragments where mixed with Lecht ore at 1 : 1, using 6 kg of each. Once again the first charges were 3 kg of broken tap slag. The return this time was impressive, the total of 34 kg 'ores' creating a nicely dense 9 kg bloom, yield of 28 %. This metal was given a simple grinder spark test afterwards, suggesting a mid carbon (roughly 0.5 %) content.

Links to summary reports, layout drawings sequence data on individual smelts can be found in Appendix A : Smelt Links

Bloom to Bar

Several of the blooms created during T2T were compressed down into thick working bars, the next important step in the chain of processes that leads to the final object, a separate undertaking requiring it's own set of specialized equipment and skills. Several of the blooms created during T2T were compressed down into thick working bars. Individual blooms are partially compressed when the are first extracted from the furnace, working with hand sledge hammers to strike first strike off clinging fragments of the slag bowl, and to mechanically attach metallic gromps along the outside surfaces as much as possible. When possible, the full bloom is sectioned into more manageable pieces, typically cut with an axe into rough quarters for blooms of the size range produced here. All the work on rendering blooms to bars was undertaken using what would be considered 'traditional' blacksmithing equipment, coal fired forges and large sized anvils. Work done at the Wareham Forge (Ontario) included use of a 30 ton hydraulic press and 75 lb air hammer.

From Test B, a 1278 gm section was rendered down to a ‘brick’ shape at the Wareham Forge. During the process, a fragment at 51 gm was broken off and recovered. The final working bar was 957 gm, so a return at bloom to bar of 75 %, overall ore to bar of 13 %.

From Smelt 1.2 the bloom had been cut into two pieces at 1.6 and 1.2 kg, the smaller further divided into 300 gm and 900 gm. The two larger were compacted and worked at SSW. The 900 gms was reduced to a roughly consolidated plate at 600 gm, so a return at bloom to bar of 66 %, overall ore to bar of 8 %. This was further forged into a small bowl like artistic object. (9) The larger 1.6 kg piece was converted to a heavy bar at 800 gm, so a return at bloom to bar of 50 %, with overall ore to bar of only 3 %. An attempt was made to forge this bar into an axe, but a combination of poor fuel and minimal tools made this fail.

From Smelt 2.1, two rough quarter sections were compressed to thick plate shapes in August of 2023 at the Wareham Forge. The first started at 677 gm and finished at 389 gm, a return at bloom to bar of 57 %. The second started at 730 gm and finished at 525 gm, a return at bloom to bar of 72 %. Both bars spark tested as basically carbon free iron. The differences in return is likely due to the starting composition of the two sections, as the second was visibly denser at the start of the welding up process. In combination this represents a return of bloom into bar at 18%.

From Smelt 2.3, a section at 628 gm was compressed to a small bar at 258 gm, a return at bloom to bar of only 41 %. This process proved considerably more difficult, requiring twice the compacting / welding / folding steps as the material from 2.1. The reason for this was likely the increased carbon content in this metal, spark tested at about 0.2 - 0.3 % carbon, so more suitable as a cutting edge. (The difficulty and most significant loss was at the first step bloom to plate stage, which could have been as much poor operator technique as much as bloom quality!) The overall loss here was considerable, against the good yield for ore to bloom (28%)

Inspiration : The Rhynie Man Axe

In 1978 a large stone slab was uncovered just south of Rhynie. The enigmatic figure carved in one surface, dubbed the *Rhynie Man*, would channel the 'object' part of the project. The cartoon like figure, likely created some time about 400 - 600 AD, holds over his shoulder an axe. Who is depicted? What is the reason for his looming presence? What is the original reason for the figure’s exaggerated details : pointed teeth, big hooked nose, long hair or head-dress? (appendix B : Rhynie as Bogie) What are the construction details and use purpose of that axe? This axe would become the goal of the extended process of ore to bloom to bar to object. To make determining the details all more difficult, research suggested no artifact axes have been found in Scotland for the period of reference. Within all of Great Britain, only a mere handful have been found overall. Searching for a possible artifact prototype would prove not only difficult, but the use interpretations of that prototype became a major point of discussion within the project.

figure 8 : *The Rhynie Man picture stone, with the axe over one shoulder. (b)*

Of course extreme care must be taken with any attempt to translate the cartoon like style of the original carving into physical reality, most especially in the absence of any reference artifact. At best this depiction clearly is an artistic interpretation with proportions (and details) exaggerated for purpose, also with the figure positioned to make best use of the shape of the natural stone slab. The proportional size of the head of the figure is obviously too large in comparison with the hand and body size. (Normal 'hand width' of the human head is roughly three times the palm measurement, in the carving this distance is closer to four.)
For the purposes of estimating the dimensions of the axe, the proportion used by the original artist assumed to be accurate between the hands and the axe. The width of the hand has been considered at 10 cm. (10)

This generates the rough measurements :
Length = 20 cm
Blade width = 7 cm
Peen width= 3.5 cm
Eye width= 6 cm

Of course as the image is only a side profile view. Important to understanding the functional use and the construction methods used in production, is also considering plan / top down view. The angle of the cutting edge bevel determines effect on impact, distribution of mass over the body determines handling characteristics in motion. Obviously neither of these important defining measurements were possible to determine from the carving.

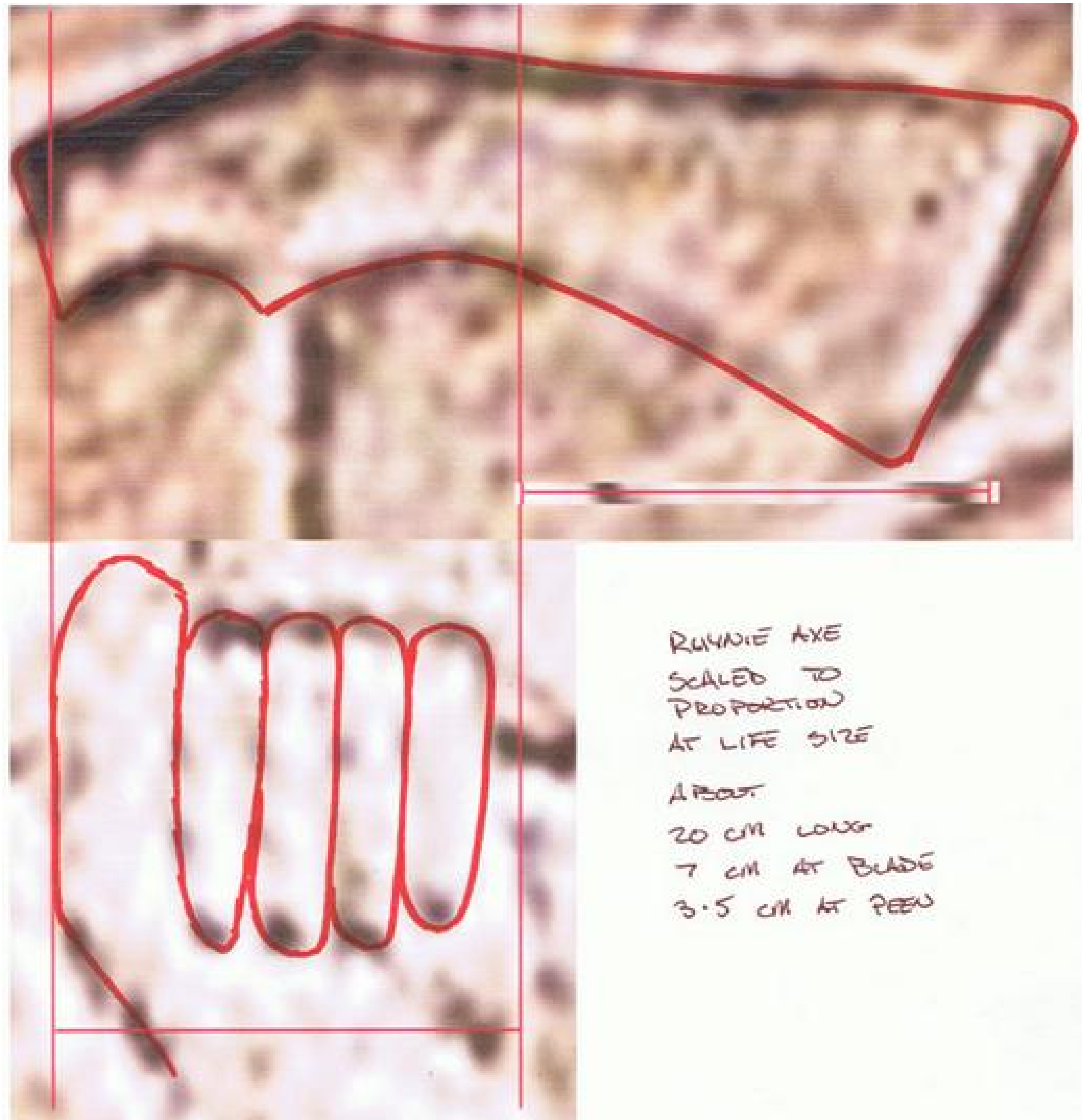

figure 9 : Rhynie Man Axe – converted to 'life'

Using the same method, the length of the handle as depicted is estimated at roughly 80 cm. The thickness of this shaft is one question. It is shown in the carving as a thin, single line. Is this a reflection of an extremely small diameter, or merely an artistic convenience? If depicting reality, this would suggest that the object's handle would have had to have been made of iron.

Searching for Artifact Sources :

> *" Axes, and in particular franciscas, are rare in Anglo-Saxon graves. Some 25 axes are known from Anglo-Saxon contexts, 15 of them franciscas. With the exception of the unique specimen from Sutton Hoo, all English axes are early (5th-6th cent.), and all have been found in the south (Wessex, Isle of Wight, Sussex, Kent and Essex) "* (Härke 1992) (11)

It was originally suggested that a good prototype would be the 'Axe Hammer' from the Sutton Hoo Burial, Anglo Saxon, from southern England, about 625 AD.

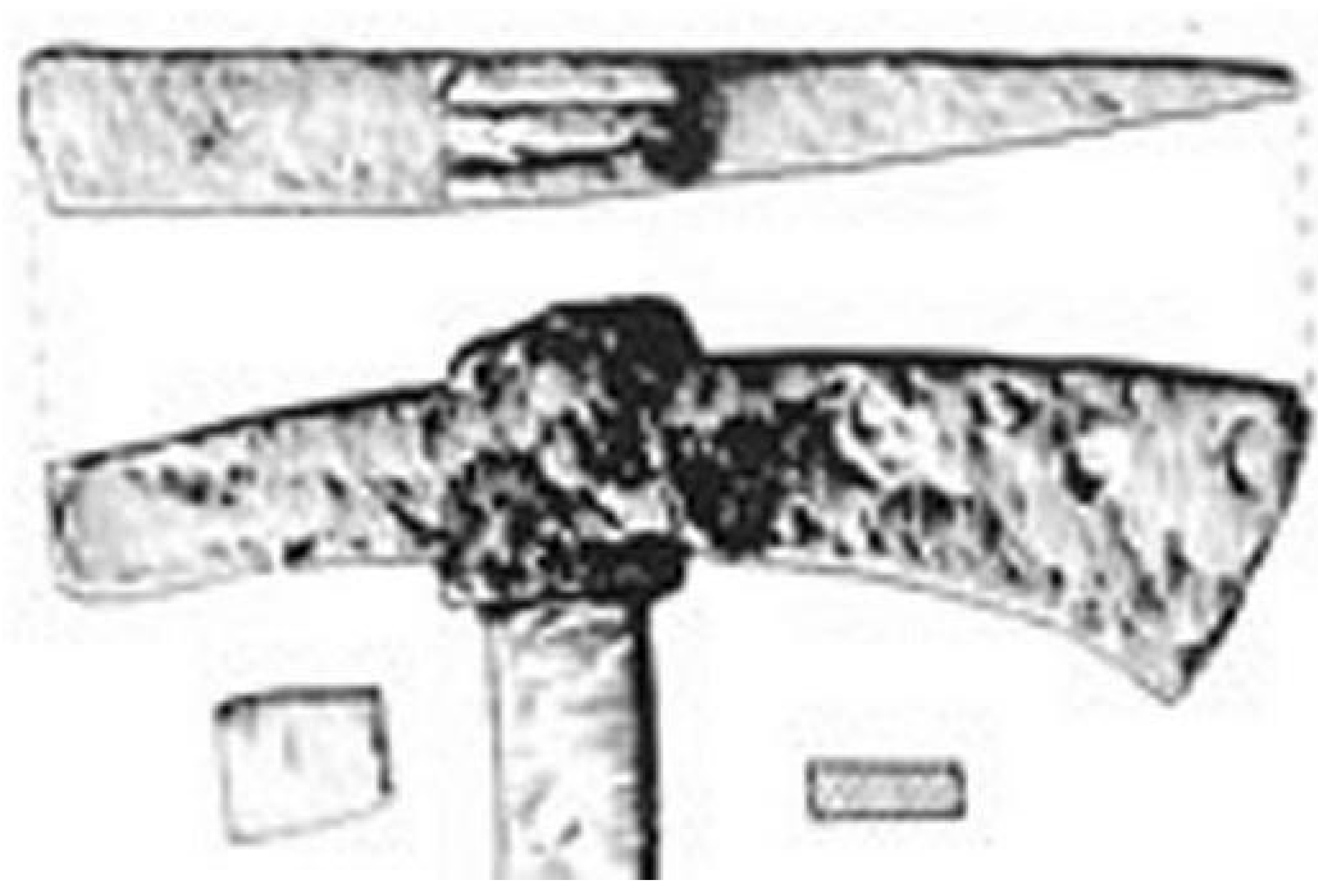

Figure 10 : The Axe Hammer from Sutton Hoo, life sized (c)

This is a unique object, without another known sample. Although roughly contemporary, it is from a different cultural set entirely, and also geographically distant. It also certainly appears to be a cavalry weapon from its overall design features.

Clear elements in the Sutton Hoo object :

- Thin forged iron handle, of a length suitable for single hand use. The handle material shifts from square to round profile for the last roughly 25 cm. It then ends in a swivel mounted ring. Equipped with a leather thong loop, this is the ideal way to secure this axe over the wrist, preventing possible loss while used as weapon when mounted. Ideally the round cross section would be wrapped with leather lace for better grip and comfort (although the artifact did not bear traces that suggested this).
- Long drawn out peen, creating a possible 'hammer' for dealing crushing blows.
- Handle attachment is to the centre of mass of the total head length. This suggests providing for a fairly symmetrical balance for a swinging impact (critical for mounted use).
- The eye most likely (because of shapes observed) to have been punched into the starting bar.
- The approximate volume is 80 - 85 cc, giving an estimated total head weight of 625 - 660 gm (12)

There are a number of clear differences between the Rhynie Axe as it is depicted and the sample Axe Hammer from Sutton Hoo :

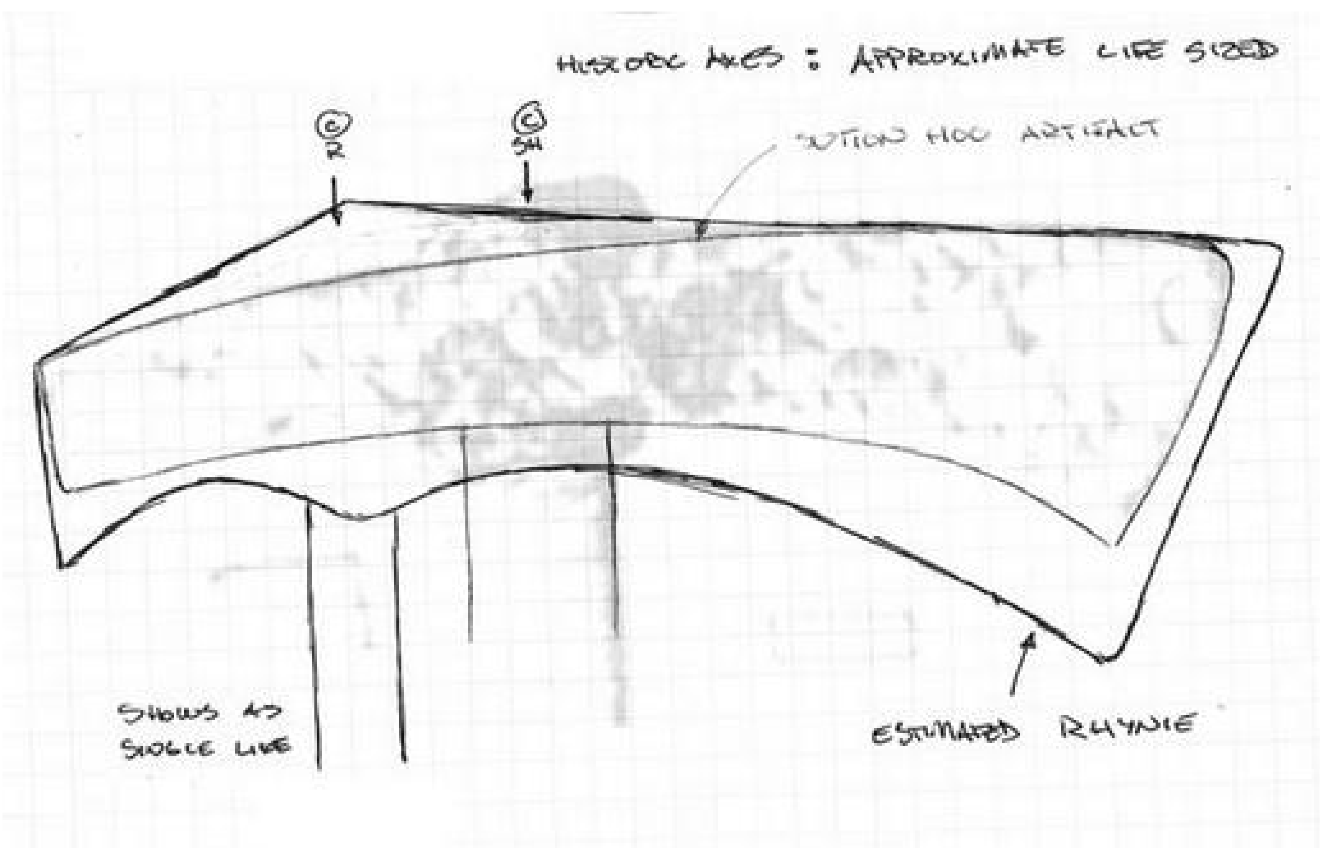

figure 11 : Profiles of Rhynie and Sutton Hoo axes compared

- Even at casual observation, the difference in raw size is clear between the two axes. Of course the cross section of the Rhynie Axe can only be speculated, and this alone will be significant in any attempt to estimate its possible total head weight.
- Although the handle shown in the Rhynie carving is a single line, so possibly also illustrating an iron shaft, It is suggested here that this is merely an artistic impression used for the ease of the original carver, and not necessarily an accurate depiction.
- The proportion of the handle length of Rhynie appears to be closer to 80 + cm. This handle length is more suitable for a two handled weapon, which in fact is what is seen in the carving. Sutton Hoo is 78 cm long, again more typical of a two handed use, but may also be indicative of the kind of reach needed for a cavalry weapon.
- The clear indications of 'wings' at the handle attachment point on Rhynie is a structural feature associated with wooden handles.
- The handle attachment on Rhynie is shown as being close to the peen end of the axe, a more standard tool or weapon axe design. On Sutton Hoo the handle is set roughly in the centre of the head, creating a long drawn out peen, considered to be a secondary striking surface. At the same time, this shape strongly influences the overall balance (and control) while in motion.

figure 12 : Replica of the Sutton Hoo Axe Hammer

A replica of the Sutton Hoo axe was created at SSW Phase 1 as a point of comparison, the primary difference from the artifact being it terminated in a simple loop, rather than the more complex end swivel of the original. Again, the replica was made from modern mild steel, using a coal forge and large anvil. The replica was not polished or sharpened, primarily for safety reasons while presenting to the public. Placed in the hand, its balance and feel in motion strongly suggested its purpose as a weapon, particularly for use from horseback.

Viking Age axes (800 – 1000 AD), from Scandinavia or beyond, although again culturally distinctive and later than the reference time period, where deemed worth consideration, if only for the large number of artifact samples available.

Fig. 41. Koll, Vardal, Krist. 2/3.
Fig. 42. Berg, Løiten, Hed. 2/3.

figure 13: Artifacts illustrated in Peterson's Typology (d)

Although the head shape illustrated here certainly does appear much closer to that depicted in Rhynie, Peterson's study is of Viking Age Norway, and the type K is described as from the 900's. (Peterson, 1919)

While observing a number of artifact and high quality replica Viking Age axes in Denmark, there was seen a clear division between the form of individual axes, clearly related to their primary intended use. Those designed for combat had wide blades and were almost triangular in overall profile, but extremely thin in cross section. Logging axes had distinctive wedge shaped cross sections, varying between those seen on modern felling and splitting purposes. A third grouping were 'fine tool' axes, primarily designed for wood shaping. These typically had long tapered cross sections, making for slender (sharp!) blades. (Markewitz, 2008)

Figure : 14 Prototype of a Peterson type K

Early in the investigations leading to T2T, a typical Peterson type K axe had been created (at the Wareham Forge, again in mild steel, using traditional blacksmith's equipment), with a thin 'fine trimming' edge. Set on a 60 cm long handle, it was clear to any experienced tool user that this axe could be easily controlled to take thin cuts off wooden beams, as for building construction or shaping ship timbers. (Although it was also equally clear that if used in combat it's ease of handling would prove extremely effective!)

In all artifact examples (regardless of origin) the body of the axes were forged from a block of bloomery iron, either with or without an added hard 'steel' cutting edge. With corrosion, the distinctive gain lines natural to this material often indicate the exact forging steps undertaken in forming any axe.
Again as comparison, Viking Age axes use several forging methods:

Eyes may be made by :
- slitting and drifting open,
- slitting the peen end and then wrapping to the rear and welding
- folding towards the front and welding

Edges may be made by :
- using the source iron only
- adding a lap welded steel edge to one side
- adding an inset and welded steel edge

For T2T an initial prototype replica was made of the Rhynie Axe, taking the discussion above into consideration.

Figure 15 : Prototype of the Axe – about life sized
Rough forged weight = 1005 gm

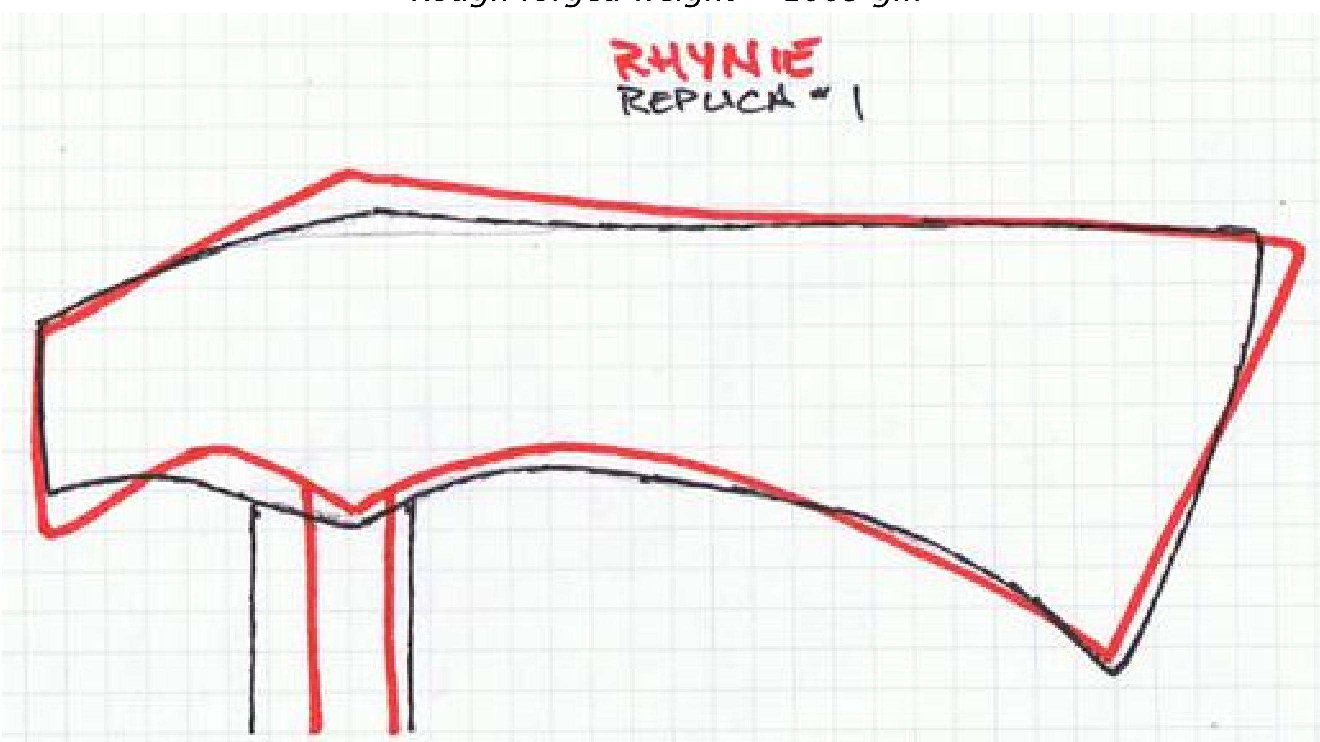

Figure 16 : Comparing the first replica to the carving as profiles, life size.

It can be seen that the rough forging is fairly close to the Rhynie profile. For the replica, the eye was slit and drifted open. This process is the easiest way to retain the quite heavy peen indicated in the source illustration. The eye was sized to allow mounting to a standard modern sledge hammer handle for ease of presentation (the size used may effect the overall result). It can be seen (figure 17) that the starting slit for the eye was made a bit too long, this primarily a function of the available tools.

The replica was forged from a block of modern mild steel, at the Wareham Forge, again using a 'traditional' bituminous coal forge and large (225 lb) anvil. (13) The work was assisted by use of a small industrial air hammer (which can induce certain shapes in process). No additional hard steel edge was welded on. The finished head was again not polished or sharpened.

The primary difference between this replica and the historic illustration lies in the degree of the upset bottom edge of the peen. The exact shaping around the eye wings and this peen edge likely could have been duplicated more exactly through some final hand forging. (After three hours of heavy work, it was decided to stop before human error was likely!)

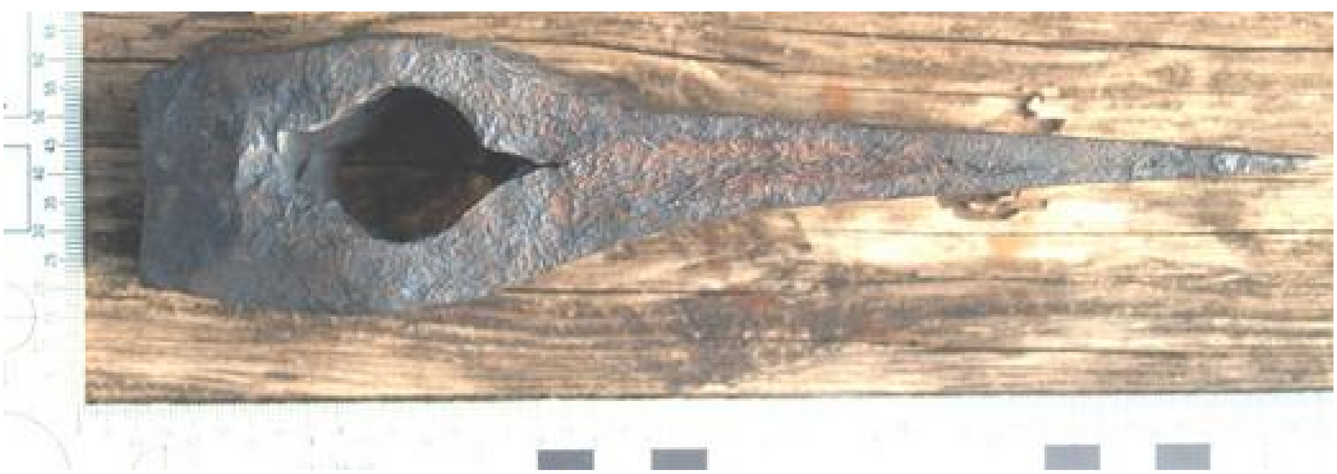

figure 17 : Prototype axe of mild steel - top view, life size

Without knowing the exact cross section of Rhynie, it is hard to estimate possible head weight. If Rhynie had a simple 'wedge' form (such as seen in Sutton Hoo) the estimated volume is roughly 160 cc, producing a head weight in the range of 1200 + gms. This would place Rhynie at roughly double the head weight of Sutton Hoo.

This however, is not considered the most likely cross section however. The replica blade was shaped as a 'fine tool' cross section. This reduces the overall weight, as a rough forging, to 1005 gm. It can be seen that the thickness of the peen is close to that at the eye, placing much of the mass to that end of the centre line of the handle. This overall shape results in a more balanced distribution of weight, increasing control of the cutting edge in actual use. The end result is a cutting tool that can be effectively controlled (with considerable precision) even when used in a single hand. (In contrast, axes with the simple wedge profile will 'hit harder', but at the cost of being considerably more difficult to control in flight.)

Although the original intent of the T2T project was to proceed from bloom to working bar into object in Scotland, a combination of equipment problems and available materials made this too difficult. At the start, SSW did not have anything more than the most basic blacksmithing equipment :
- a good sized antique anvil, but poorly mounted
- a portable ‘dish’ style forge, but in poor repair
- no working hammers (although new ones were purchased for T2T)
- a random selection of tongs, almost all too large sized for the work involved

The huge problem turned out to be fuel. What was sold locally as ‘Smitty Nuggets’ blacksmith’s coal was the highest sulphur content coal I ever experienced (in over 40 years of blacksmithing). Even working out of doors, the volume of toxic smoke produced was absolutely unacceptable. Sulphur is also a contaminant that adversely effects forge welding ability, one of the main processes required in compacting and purifying raw blooms into bars. Primarily for these reasons, creation of a replica Rhynie Axe from the blooms previously made was postponed to Phase 3, August to September 2023.

Creating the Bloomery Iron Replica

As discussed above, the estimated weight of the Rhynie Man axe is about 1000 gms as a rough forging. As already detailed, several sections of the blooms created during Phase 2 where retained to be further worked on at the Wareham Forge in Ontario. The combined weight of the bars rendered from Smelt 2.1 and 2.3 came to 1172 gm. These bars were further forged to better match the pieces needed to combine into a rough starting blank. There was additional (minor) loss, due to the typical flaking off of hammer scale during this process. The 2.1 plates were adjusted and one cut to match, the 2.3 bar cut into a small block for the peen and the other end

forged into a wide wedge for the cutting edge insert. The total weight at preparation for the final welding up was 911 gm, with 118 gm remaining unused.
The method chosen required two major hammer welding steps, first at the peen end, second from the edge back towards the body, this leaving a gap that would later be expanded to form the eye.
The finished replica was obviously somewhat smaller than the layout estimate, a rough forging of 739 gm, a loss during welding and forging to shape of a further 18% of the starting pieces. There would be further reduction expected if the axe was polished to 'bright' and completed to a sharp cutting edge.

Figures 19 & 20: Completed bloomery iron replica, top and right side view (with maker's mark)

the Axe Pin :

As a further extension into exploring the world of Rhynie Man, at SSW during Phase 1 Kelly Probyn-Smith undertook making a replica of the axe headed pin that had just been uncovered at the excavations. This small straight pin was a type most commonly used to secure a cloak at neck or shoulder (depending on the sex of the user). The upper terminal flared to an axe shape on one side, the other side being drawn out then formed to a spiral coil. This appeared on the radiograph reference images to end in serpent's head. Forging such a small object presents its own set of difficulties. Curiously the small set of 'jeweller's' sized tongs also recovered in the 2014 excavations would be the perfect tool for such delicate work.

Figure 18 : Rhynie Axe-Pin / detailed X-Ray / prototype replica by Probyn-Smith (e)

Informing the Public :

From the beginning of Turf to Tools, presenting the project to the wider public was an important part of the undertaking.
The smallest gatherings were the discussions between archaeologist, visual artists, practical technicians, writers and organizers. As SSW normally hosts a changing group of international visual artists on typically one month long residencies, this category was expanded beyond those directly involved in T2T itself. In this, an approach to incorporating archaeological findings into contemporary artistic practice was demonstrated. Often resident artists were drawn in and would undertake direct hands on experience with the traditional to historic crafts techniques being utilized in the project. Direct participants would include local volunteers, resident artists, post graduate students and staff of related living history museums.

During Phase 1, an evening of public presentations / lectures was scheduled and well attended, even if total numbers were somewhat limited by the rural location of Lumsden. The more formal presentations included a summery of the underlaying archaeology of Rhynie (Noble), historical basis to mechanics of iron smelting (Markewitz) and outline and goals of the project (Sacramento).

Importantly, several of the experimental smelts were conducted as previously advertised open public demonstration events at the Scottish Sculpture Workshop, starting with Prototype A. Smelt 1.3 was conducted on a Sunday, and despite typical wet Scottish weather, drew a considerable crowd, especially for the exciting process of extracting the hot bloom. A table of various samples related to iron smelting and the axe prototypes was set up, allowing the public to physically examine samples of local ore types, created blooms and finished bars. The creation of full sized replicas was key to allowing direct experience with the weights and working balances of the axes (deliberately not sharpened for this exact purpose). A running commentary explaining the project and the process was given over the five and half hours of the smelt. Smelt 2.2 was also open to public viewing, with similar demonstration method and results. In all public presentations, the interplay of archaeological information, experimental process and direct working experience was stressed.

Figure 21 : Bloom consolidation before the public, smelt 1.3.
Graduate student Emma Harrison to right rear.
Dirk Sporleder from the Scottish Crannog Centre, centre (with tongs).(ii)

Additional Arts and Documentation :

In terms of further artisan involvement, Smelt 2.2 included a test of a possible extension of the high temperature furnaces into ceramics production, under the direction of Scottish artist Katriona Gillespie. At the very end of the smelt during the burn down phase, a number of small, previously greenware fired, ceramic objects were added and covered with charcoal. With internal temperatures known to potentially be into the range of 1350 C these pieces experienced a range of effects. Some simply shattered due to the rapid and uncontrolled heating, through to those severely overheated resulting in melting of the clay body. Gillespie coined the term

‘Tocca Ferro’ (literally ‘touched by iron’) to describe this potential process. (Gillespie, 2016)

Expanding the potential audience for research and conclusions related to T2T was actively undertaken. As mentioned, the inclusion of writers O’Mahony and Hourani illustrated the original intent of the overall project to create a published text both describing the undertaking, but also commentaries on the intertwined roles of researcher, artist and technician, and reflections on the theme of humans within the environment. Unfortunately, the loss of a driving force in the form of SSW director Nuno Sacramento left this aspect unresolved. (14) At it’s simplest, there were many descriptions published on the internet, first via blogs from SSW (*SSW News*) and my own (*Hammered Out Bits*). Detailed information on each individual smelt was later made available on the my primary iron smelting documentation (*Experimental Iron Smelting*).

During Phase 1, an Irish based television production company approached with the intent of acquiring video footage of the project, with the intent of creating a documentary. Between being asked to provide our own footage from willing but un-trained hands, equipment failures, and later problems with file formats and transfers, the documentary was never completed.
What did prove successful was a public presentation at SSW with previously recorded video, combined with a remote access interview that was available as live streaming over the internet as ‘*Out of the Earth*’ (Jones, 2016). This was undertaken in spring of 2017, and is still available as video via YouTube.

Formal academic presentations detailing T2T were given at the following conferences:

- 2014, ‘*‘Turf to Tools’ at the Scottish Sculpture Workshop – A Parable of Prototype, Process & Production*’, at *Forward into the Past*, Wilfred Laurier University, Kitchener, ON, Canada
- 2014, ‘‘*Turf to Tools’ at the Scottish Sculpture Workshop’,* at *REARC5*, the Schiele Museum of Natural History, Gastonia, NC, USA
- 2015, ‘*Turf to Tools’ at the Scottish Sculpture Workshop - An Experience with Experiment’*, at *the International Conference on Medieval Studies*, Western Michigan University, Kalamazoo, MI, USA
- 2023, ‘*Experiment, Archaeology & Art - The Turf to Tools Project*’ at EAA23, Queens University, Belfast, Northern Ireland, UK.

Final Deposit :

The original intent of Phase 3 in early September 2023 was to again offer a public demonstration of a full bloomery iron smelt, based on lessons learned through the overall project. Unfortunately a change in management at the Scottish Sculpture workshop also resulted in a major shift in direction, including the loss of technical staff, and lack of interest in completing Turf to Tools. The considerable difficulties of organizing alternate hosting institutions and the complex undertaking of a smelt, while working from distant Ontario, Canada, has meant that this did not prove possible. Although time had been added specifically to travel bookings placed seven months in advance, in the end there would be no return to the Rhynie area.

Figure 22 : Eden Jolly (L) preparing to throw the bloomery iron replica into the bog on Skye (Author - R) (iii)

The final element of the project was always intended as a depositing of the completed bloomery iron Rhynie Man Axe replica back into a Scottish peat bog. In keeping with the original concept of ‘from the land – to the land’. To that end the replica created had been boldly marked with hot punched ‘T2T 2023’, so as to not cause any confusion to future archaeologists. Hosting at the Point of Sleat on the Isle of Skye had been offered by former ceramics technician Beth Bidwell, so it was decided to meet with Eden Jolly, and accompanied by Kelly Probyn-Smith, make the final resting place to complete Turf to Tools a bog pool nearby.

Conclusions :

figure 23 : Turf to Tools through objects : Norse trimming axe / Sutton Hoo axe hammer
(middle) tap slag / working bar / raw bloom / MacCaulayite ore
(rear) Letch ore/ MacCulayite / peat fragments

Bloomery Iron Smelting :

Combining the archaeological clues from Cudthel with a working system based on previous experience was quite straight forward. The problem of the cracks caused by drying clay affixed to irregular stones was solved by the incorporation of the Beardsley Break (another example of contributions from observing artists). The use of a copper tuyere over the more likely clay / ceramic in Phase 2 is considered at

least possible, although admittedly there may not be much in terms of direct evidence available to indicate this use historically.
As with other experiments, equipment to provide the needed air volumes becomes the largest distortion from any accurate replication of ancient methods. The difference in results between individual smelts utilizing the same ore analog is considered primarily the result of different blower units being employed.
The largest single difference between individual smelts, several in the same furnace, is clearly caused by the use of a wide range of ore types with differing qualities.

SMELT	INTERIOR cm	BASE cm	STACK cm	ORE	AMOUNT kg	Fe %	CHARCOAL min/kg	ORE min/kg	BLOOM kg	YIELD %	AIR
Prototype A	na	na	na	SSW analog		48.5					
Prototype B	~ 30	16	45	analog	31	51	5.7	6.9	5.2	17	compression blower
1.1	~ 26	11	54	MacCaulayite	16.2						
				taconite	7.8						
				analog	6						
				TOTAL	31	??	7.2	5.4	2.3	7	leaf blower A
1.2	~ 27	15	54	taconite	33.5						
				analog	7.5						
				TOTAL	41	62	3.8	4	4.7	12	leaf blower A
1.3	~ 25	~ 15	48	analog	27						
				taconite	13						
				TOTAL	40	58	6.6	6.8	11.6	29	leaf blower B
2.1	25	16	49	Lecht	37.5	??	8.7	5.5	3.5	8	leaf blower B
2.2 / Peat	25	~ 16	49	analog	35	51	5	3.1	1.5 pieces	4	leaf blower B
2.3	25	~ 16	49	taconite	22						
				Lecht	6						
				gromps	6						
				TOTAL	34	??	7	5.3	9	32	leaf blower B

Table A : Main data from individual smelts compared
Charcoal and ore additions are average over main smelting sequence

The ideal would be to have detailed analysis of the chemical components of all of the ores utilized, but without laboratory support, this was not possible. Two of the ore bodies (Macaulayite / Lecht) were gathered ‘by eye’, a method where individual field experience (certainly limited here) is critical to picking suitable material. So estimates of actual iron and silica contents of the natural contents of the ores (even the industrial types) is rough at best. As would be expected, results between ores varied considerably, and ore differences are considered to be the greatest modifier between individual smelts. It is worth noting that larger ore volume smelts most typically have better percentage returns even with the same ore. Normally any iron makers could be expected to be adjusting both furnace design and overall method to suit a single ore type, modifying individual elements to achieve the best possible results.

It is true that the conduct of Turf to Tools sits in a hazy realm between individual experience and scientific experiment. The people involved were largely not formally academically trained, and beyond providing for a location and funding raw materials, the program was carried out without major institutional supports such as instrumentation or laboratory access. Considerable practical skill and direct experience was certainly available, something usually lacking in most formal experiments.

In all cases at least some metallic bloom was produced however. This raises an important conceptual consideration, being the potential differences between ancient and modern definitions of success from effort. For the original Pictish workers, gathering the necessary raw materials, making enough charcoal, powering bellows, all represented large investments in time and effort, this balanced by the importance of even a small amount of metallic iron for later object making.

Bloom to bar

A bloom of itself is not able to be converted into useful objects. The secondary processing step of bloom to bar is far too often not considered by academic researchers, with the significant losses in mass not taken into account.

SMELT	BLOOM gm	YIELD %	BAR gm	FORM	YIELD %	CARBON ~ %	OVERALL %
Prototype B	1278	17	957	brick	75	0.6 - 0.7	13
1.2	900	12	600	plate	66	na	8
1.2	1600		800	bar	50	na	3
2.1	677	9	389	plate	57	none	5
2.1	730	9	525	plate	72	none	7
2.3	628	28	258	bar	41	0.2 - 0.3	11.5

Table B : Total returns – Ore to Bloom to Bar

It is important to remember the methods used to convert the blooms from T2T into working bars, where 'traditional' (coal forges, massive anvils) and 'modern' (air and hydraulic power) equipment was used. The skill and experience of the worker is quite significant as well, as forming and effectively hammer welding blooms into soft iron are unusual techniques even among contemporary artisan blacksmiths. (And as was the case with working up 2.3, even best of us can have a bad day!) With this caution, the yields reported here should only be considered as rough guides at best.

As modern workers, mechanical equipment and commercial sources simplifies acquiring raw materials, and industrial steel itself is both inexpensive and easily available. This is definitely not the situation for the ancient smith, where the considerable utility of iron, especially for tools and weapons, easily overwhelmed the high relative cost of it's creation. The perceived value of applied labour is definitely much different today than it was 1500 years ago. Certainly the impression of expending much effort against a small return will be completely different in ancient eyes.

The Rhynie Man Axe :

In estimating the exact details of the Rhynie Man Axe, a reasonable balance needs to be made between what is most certainly artistic license by the original carver against a possible depiction of exact reality. There remains the problem that there are very few existing artifact axes to draw parallels from, and it appears none at all from contemporary Pictish sources.
The use of the Sutton Hoo axe-hammer is suggested as not a reliable prototype, as its design is reflected in its quite distinctive intended function. It would appear that the primary reason for use of this artifact source is because of the single line handle in the Rhynie carving.
Expanding the potential artifact examples to include roughly contemporary Viking Age axes, of which there are certainly a great number, is strongly suggested here. The best 'fit' appears to be the Peterson Type K axe (admittedly, Norwegian and some 200 years later), plus numerous examples seen in Denmark. Combining these examples with actual forging methods, with a consideration of experience in actually handling axes of various types, does suggest this a 'most likely' prototype design.

The Rhynie Man Axe is thus considered a 'fine tool' type, roughly 1000 gm in head weight. It may have had either a slit and drifted eye, or an eye formed by slitting and welding the peen end, possibly a peen enlarged by welding in an additional block. It is not possible to tell if the blade would have had an inset carbon steel edge, but this is likely considering 'best possible' tool making practice. The high status attributed to the Rhynie Man certainly would demand this quality. Of course the actual angle of the cutting edge best determines potential use, and this remains quite unknown from the reference carving. Such a head, fitted with a wooden handle in the 60 - 80 cm long range, would produce an object easy enough to control with a single hand, but also producing considerable power if swung with two. It easily could have been a dual purpose tool or weapon, able to create fine shaping cuts in wood - or devastating power in battle.

Although the intent of Phase 2 was to devote several working days to the second stage process, bloom to bar, followed by the third stage, bar to object, this in the end did not prove possible. After several quite unsatisfactory tests, and considerable outside consultation, it was found that the only available blacksmithing coal was in fact imported from Poland. This itself was a major surprise, and certainly reflects directly back to the framing concept of human impact on natural resources, a process certainly much more dramatic in our current age.

Public Outreach :

A number of factors shaped the ability to inform the general public about Turf to Tools. The bulk of the work involved in T2T was carried out by small groups, primarily of artists and technicians, often physically quite isolated. Most importantly, the extremely rural physical location of the core work in Lumsden most certainly impacted the audience available. An attempt was made to share information about the project was made though academic venues. Realistically however, the lack of formal credentials limits the ability to be as effective here as might be hoped. The distribution of related information over the internet proved critical in providing wide access to the project’s undertaking, allowing for freely sharing data, ongoing commentaries, images and video.

All these technical discussions aside, Turf to Tools was (and remains) a project examining a complex progression : from resources out of the natural landscape,

processing these into basic raw materials, then converting those materials into finished objects. At every step, limits may be imposed and choices are determined by availability, knowledge, skill, and design, all of which may then channel back into each other. The influence of ancient, traditional, modern, (even conceptual) realities also shape the possibilities. As a consideration of Experiment, there were many individual components undertaken, any of which may be worthy of further examination in detail.
Over all lays the understanding that man has, and continues to, modify the physical world around him. Even in ancient times, it is clear that any activity directed towards one desired goal may have massive impacts on others, known or unknown.

Acknowledgements :

The working teams :
Prototype A : Eden Jolly, Thomas Stackhouse
Prototype B : Darrell Markewitz, Neil Peterson, Dr. Ron Ross, Kelly Probyn-Smith
Phase 1 core team : Darrell Markewitz, Eden Jolly, Thomas Stackhouse, Kelly Probyn-Smith, James McCarthy
Smelt 1.2 : plus Emma Harrison, Phil Chaplin
Smelt 1.3 : plus Dirk Sporleder, Emma Harrison, Richard White
Phase 2 core team : Darrell Markewitz, Eden Jolly, Uist Corrigan, Kelly Probyn-Smith, Llyr Davies
Smelt 2.1 : plus Katie Spragg, Andrew Dunlap

Eden Jolly – For welcoming me into his workshop facility, and treating me like a fellow technical staff member. Eden embraced the project with enthusiasm and without his assistance (and continuing friendship) this work would not have been possible.
Nuno Sacramento – For having the vision that framed Turf to Tools, and especially for providing the support that funded this project, especially making my participation possible by covering the (considerable) travel costs involved.
Dr. Gordon Noble – For being so free with his knowledge of the archaeology at Rhynie, and being willing to engage in open discussions relating artifacts to working methods. Plus being willing to pick up the hammer himself to further his own personal understanding of blacksmithing techniques.

Ross Murray – For sharing some of his own unpublished photographs of the Culduthel furnaces, and patiently answering questions and clearing up details from his field reports.
Canada Council for the Arts – For generously granting funding that assisted with travel expenses during Phase 1.
Beth Bidwell – For opening her home at Point of Sleet, which allowed for the final deposit to conclude the project

figure 22 : Posing as the Rhynie Man in 2014 (iv)

The axe used here is the Early Viking Age replica discussed above.
In the image it has been modified (along the top edge only) to more closely resemble the carving. The handle length here is 66 cm.

Image Credits :

Note : In preparing this report, much use was made of modifying images via Photoshop to alter scale and proportion. Available images were re-sized to life to allow for more consistent measurements and to serve as a close comparison during the making process. Apologies are given for the poor quality resulting from this method. Certainly considerable care must be taken with this kind of data generation method. (Obviously first hand examination of actual artifacts would be ideal, but in this case was not physically possible.)

a) Ross Murray (?) 2006, '*Culduthel: An Iron Age smelting site near Inverness',* in *Historical Metallurgy Society*, Winter 2006-7 pg 64, altered image, used without permission

b)Unknown / Visit Aberdeenshire, (date?), '*The Rhynie Man, Aberdeenshire Scotland*', (web page), used without permission : https://www.visitabdn.com/listing/the-rhynie-man

c) Angela Care Evens (?) 1986, '*The Sutton Hoo Ship Burial*', pg 42 (modified), used without permission
(A portion of the original excavation report, by Rupert Bruce-Mitford, was also available as a reference here.)

d) PETERSEN, J., 1919, '*De Norske Vikingesverd',* via internet source (direct download of portion of document scanned as pdf), used without permission http://forum.blankvaapen.org/showthread.php?t=744

e) Gordon Noble, 2014 (?) 'Rhynie Axe Pendant for scanning and replication', Power Point presentation delivered at T2T-1, artifact & X-ray images, used without permission

i -iv) Kelly Probyn-Smith, 2014, 2023, used with permission

Footnotes :

1) The author's experimental team has done full smelt sequences using a number of different variations of the slightly later Norse 'twin bellows' equipment. For an experiment directly comparing a hypothetical smelting sized twin bellows to an electric blower. See Markewitz, 2021

2) A long sequence of experimental development is behind this functional design and the general method described. See Markewitz, 2012a

3) Past experience with use of rigid forms to aid in furnace builds had shown that working with exterior placed forms can be quite difficult, if the intent is to create a cylindrical shape much taller than about 55 cm. This because of the typical finger to arm pit arm length of most people of 50 – 60 cm.

4) For the purposes of ease, duplication, and low cost, standard ceramic kiln support tubes are used as tuyeres. These have an ID of 2 cm, OD of 4.5 cm, wall thickness of 1.25 cm, normally purchased as 30 cm long. These are rated for 1250 – 1300 C (cone 10). See :
https://psh.ca/collections/kiln-posts/products/12-t175-round-post-305-mm

5) Starting in 2008, the author's team developed an analog to mimic a natural primary bog iron ore (unavailable anywhere close to the workshop site in South Central Ontario.) This is composed of 'Spanish Red' Fe_2O_3 oxide (at about 70 iron oxide %) with 10% whole wheat flour (added as a binder). Although specific batches can vary, the average iron content is roughly 52%. See :
www.warehamforge.ca/ironsmelting/ironsmelting/ores.html

6) Taken from the description : Mineral Data Publishing, 2001, '*Macaulayite*', which further references : Wilson, M.J., Russell, J.D., Tait, J.M, Clark, D.R., Fraser, A.R ., & Stephen,I.,1981, '*A swelling hematite/layer-silicate complex in weathered granite*' in *Clay Minerals* 16, pg 261-278.

7) This tuyere was created in April of 2012, and had become the standard equipment for experimental smelts after that date. At the time of T2T-2 it had been used 8 times with no noticeable damage (at time of writing, the same tuyere has been used over 35 times). Ceramic tuyeres are found in archaeology, the evidence for copper is limited to rare finds of distinctive slag ring encasements. See Markewitz, 2012b

8) The Lecht Mine was originally exploited for iron ore in a short period from 1745, then abandoned. It was re-opened in 1841 – 47 to extract manganese. For more details see : https://canmore.org.uk/site/74949/lecht-ironstone-mine

9) This process was complicated by the very rough nature of the limited forging equipment available at SSW. An unexpected problem was the amazingly poor quality of the available coal fuel which both had an extremely high sulphur and ash content.

On further investigation, this coal was actually imported from Poland, and was simply the worst fuel I had ever had to work with. It also proved impossible to purchase the borax flux normally used for hammer welding (in North America). Taken together, this made the process of fusing together the spongy bloom pieces extremely difficult.

10) A traditional measurement, 'one hand' (commonly used to measure the shoulder height of horses) was considered to be 4 inches = 10 cm.

11) " The francisca (or francesca) was a throwing axe used as a weapon during the Early Middle Ages by the Franks, among whom it was a characteristic national weapon at the time of the Merovingians (about 500 to 750 AD). It is known to have been used during the reign of Charlemagne (768–814). Although generally associated with the Franks, it was also used by other Germanic peoples of the period, including the Anglo-Saxons; several examples have been found in England. " (Wikipedia, ND)

12) Initial estimates were generated by making modelling clay replicas, then determining the volume and multiplying by density. Historic wrought iron will be somewhat less dense than pure iron (at 7.87 gm/cc), so a multiple of 7.8 gm/cc has been used. (Data from '*The Material Property Database*' : www.matweb.com)

13) It is worth remembering that the ancient blacksmiths who made the artifacts would have been working on small iron anvils, generally in the range 10 cm on a side (from a single bloom) or even flat block of stone. Forges would have been ground mounted and fired charcoal, which would be more difficult to generate high welding temperatures over large objects like axe heads.

14) The following commentaries had been prepared 2014 - 2016 (but never finalized)

Maxime Hourani : *On double exposure: a landscape in suspension*

Darrell Markewitz : *Turf to Tools : A View from an Artisan Maker*
Turf to Tools : A Project Overview
Interpreting the Rhynie Man Axe
Rhynie as Bogie : What is the Rhynie Man?

Deirdre O'Mahony : *From Turf To Tools: Fieldwork Through Practice.*

References :

Futher detailed information on many aspects of the Turf 2 Tools project by the author can be found via the internet :
Blog - '*Hammered Out Bits*' :
http://warehamforgeblog.blogspot.com/
Web Site Documentation – '*Experimental Iron Smelting*' :
http://www.warehamforge.ca/ironsmelting/index.html
Direct links to the data for individual experiments can be found in Appendix A

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Appendix A : Links to Individual Smelt Data

Further descriptions are available via the web site '*Experimental Iron Smelting*' by the author. (www.warehamforge.ca/ironsmelting)

Turf 2 Tools Project Documentation

Experiment, Archaeology & Art - The Turf to Tools Project :
http://www.warehamforge.ca/ironsmelting/turf2tools/index.html
Replication of the Rhynie Man Axe (duplication of section in main paper) :
http://www.warehamforge.ca/ironsmelting/turf2tools/Rhynie-axe/index.html
Who, or What is the Rhynie Man :
http://www.warehamforge.ca/ironsmelting/turf2tools/bogie.html
Turf to Tools – An Artisan's View :
http://www.warehamforge.ca/ironsmelting/turf2tools/Artisans-View.html
Bloom to Axe (photo essay)
http://www.warehamforge.ca/ironsmelting/turf2tools/bloom-bar-axe.html

Individual Iron Smelt Experiments

Prototype B - June 14, 2014
Description : http://warehamforgeblog.blogspot.ca/2014/06/pictish-late-iron-age-smelt-overview.html
Sequence : http://www.warehamforge.ca/ironsmelting/iron2014/6-14/6-14data.htm
Layout : http://www.warehamforge.ca/ironsmelting/iron2014/6-14/June14-layout.jpeg

Smelt 1.1- August 12, 2014
Description : http://warehamforgeblog.blogspot.ca/2014/08/first-iron-smelt-for-turf-to-tools.html
Sequence : http://www.warehamforge.ca/ironsmelting/iron2014/SSW-A/T2T1-data.jpeg
Layout : http://www.warehamforge.ca/ironsmelting/iron2014/SSW-A/T2T1A-layout.jpeg

Smelt 1.2 – August 16, 2014
Sequence : http://www.warehamforge.ca/ironsmelting/iron2014/SSW-B/T2T2data.jpeg

Smelt 1.3 - August, 2014
Sequence : http://www.warehamforge.ca/ironsmelting/iron2014/SSW-C/T2T3-data.jpeg
Layout : http://www.warehamforge.ca/ironsmelting/iron2014/SSW-C/TtT3-layout.jpg

Experiment 1.3A – August, 2014
Sequence : http://www.warehamforge.ca/ironsmelting/iron2014/SSW-peat/T2T-peat-data.jpeg

Smelt 2.1- September 16, 2016
Description : https://warehamforgeblog.blogspot.com/2016/10/turf-to-tools-two-project-iron-smelts.html

Sequence : http://www.warehamforge.ca/ironsmelting/iron2016/SSW-A/T2T-2-A-Data.htm
Layout : http://www.warehamforge.ca/ironsmelting/iron2016/SSW-A/T2T2-A%20layout.jpeg

Smelt 2.2 – September 24, 2016
Description : https://warehamforgeblog.blogspot.com/2016/10/turf-to-tools-two-smelt-b.html
Sequence : http://www.warehamforge.ca/ironsmelting/iron2016/SSW-B/Experiment%20Data.htm

Smelt 2.3 – September 27, 2016
Description : https://warehamforgeblog.blogspot.com/2016/10/turf-to-tools-2-smelt-3.html
Sequence : http://www.warehamforge.ca/ironsmelting/iron2016/SSW-C/T2T-2-C%20Data.htm

General commentaries and photo essays (blog postings)

Turf to Tools - Project Outline : http://warehamforgeblog.blogspot.ca/2014/07/turf-to-tools-outline.html
A Scottish Late Iron Age Smelt : http://warehamforgeblog.blogspot.ca/2014/06/scottish-dark-ages-iron-smelt.html
Some Considerations for Iron Ore : http://warehamforgeblog.blogspot.ca/2014/05/some-considerations-on-iron-ore-for.html
Pictish Iron - Bloom to Bar : http://warehamforgeblog.blogspot.ca/2014/07/pictish-iron-bloom-to-bar.html