Wheal Drea engine house, St. Just in Penwith, Cornwall
Archaeological watching brief during structural repairs

Cornwall Archaeological Unit

Report No: 2016R077

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Report author	**Adam Sharpe**
Checked by	**Dr. Andy Jones**
Approved by	**Dr. Andy Jones**

Cornwall Archaeological Unit
Cornwall Council
Fal Building, County Hall, Treyew Road, Truro, Cornwall, TR1 3AY
Tel: (01872) 323603
Email: enquiries@cau.org.uk Web: www.cau.org.uk

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This study was commissioned by Peter Bee, Regional Building Surveyor, the National Trust and was carried out by Cornwall Archaeological Unit, Cornwall Council. The works on site were carried out by Roger Maclean and Darren Dayus and were supervised by Mark Gendall of pdp Green Consulting Ltd. The lightning protection system was installed by St. Ives Steeplejacks and the related trenching was undertaken by John Williams.

The Project Manager was Dr Andy Jones.

The views and recommendations expressed in this report are those of Cornwall Archaeological Unit and are presented in good faith on the basis of professional judgement and on information currently available.

Freedom of Information Act

As Cornwall Council is a public authority it is subject to the terms of the Freedom of Information Act 2000, which came into effect from 1st January 2005.

Cornwall Archaeological Unit is a Registered Organisation with the Chartered Institute for Archaeologists

Cover illustration

Work in progress on the repairs to Wheal Drea engine house chimney in December 2016.

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Abbreviations

AONB	Area of Outstanding Natural Beauty
CAU	Cornwall Archaeological Unit
CIfA	Chartered Institute for Archaeologists
OS	Ordnance Survey

1 Summary

Wheal Drea whim engine house near Kenidjack Hamlet, St. Just was acquired by the National Trust in 1995 and partly conserved by the organisation in 1998 as part of its West Penwith Project. In March 2014 the engine house was struck by lightning, resulting in significant damage to the upper section of the chimney. A programme of repair works was drawn up by the Regional Building Surveyor for the National Trust in 2014. The repairs to the chimney were undertaken by Roger Maclean of Carnyorth in late November and early December 2016, during which a lightning protection system was installed by St. Ives Steeplejacks. Cornwall Archaeological Unit undertook an archaeological watching brief and building recording during the works, which were managed by pdp Green Consulting Ltd. of Truro.

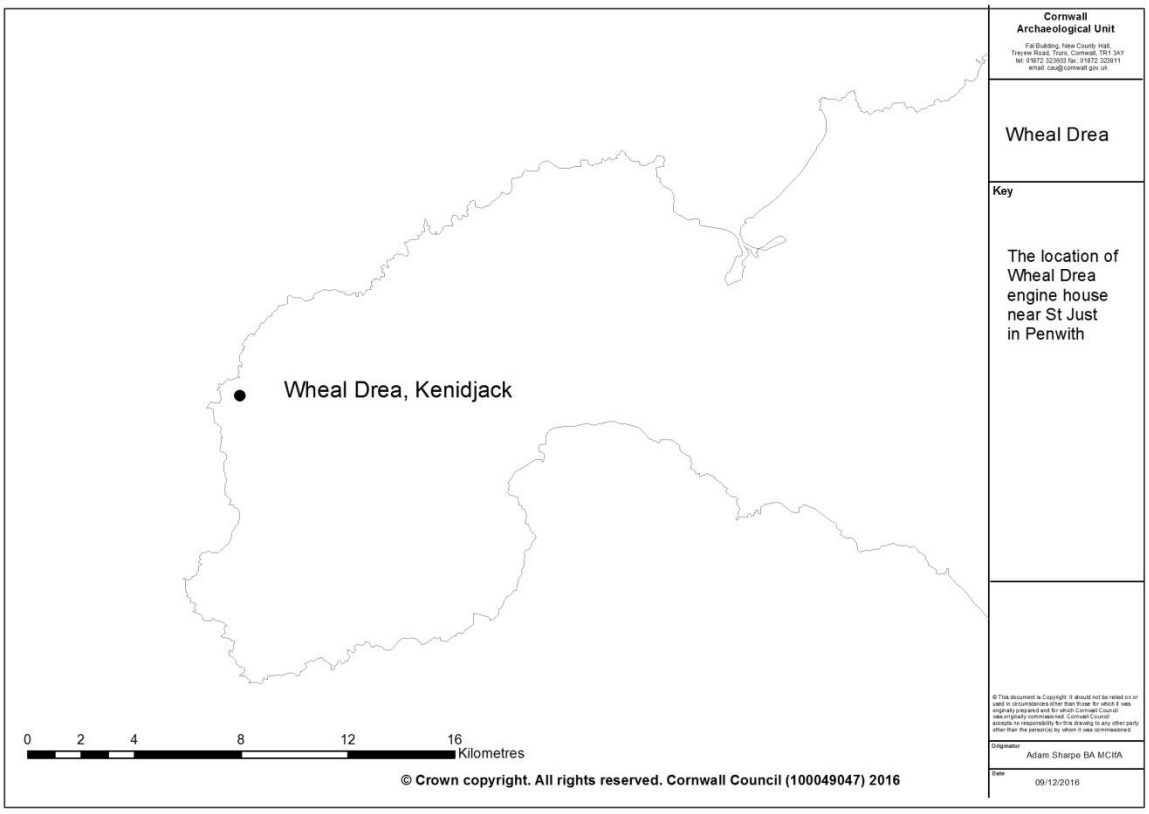

Fig 1. The location of Wheal Drea, Kenidjack, St. Just in Penwith.

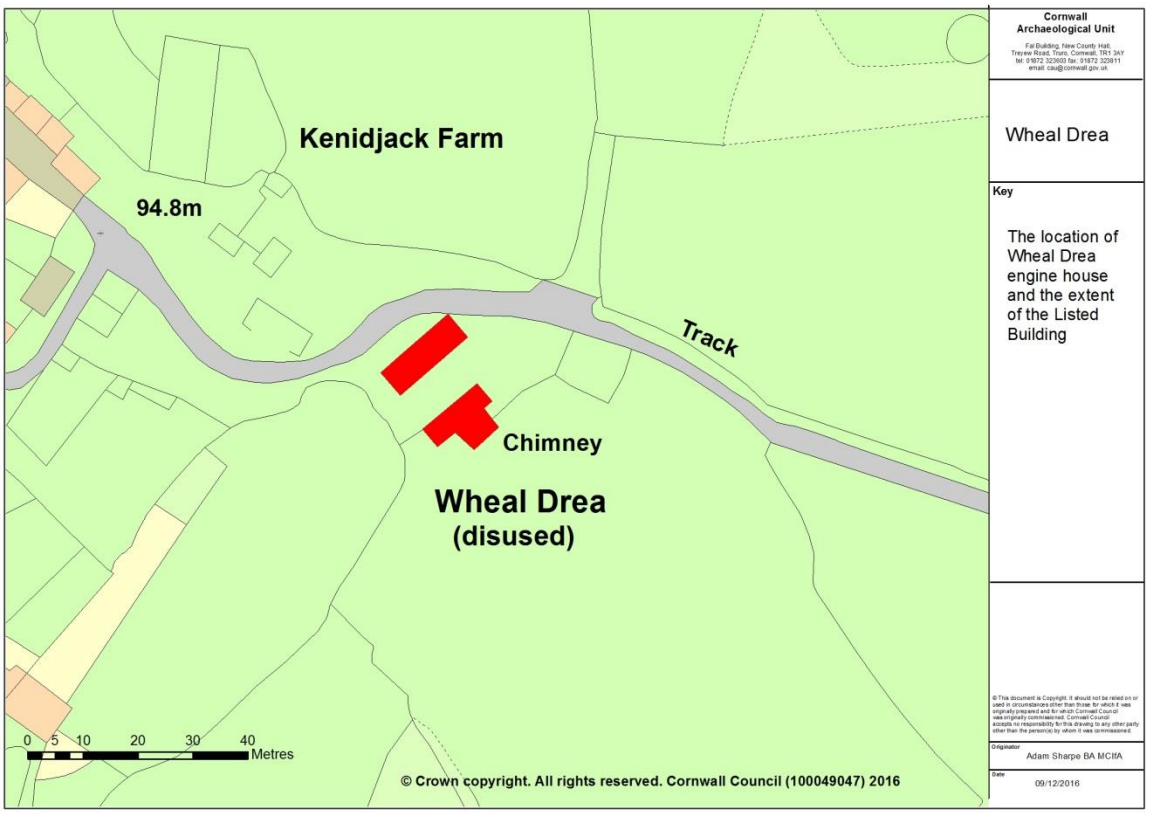

Fig 2. The location of Wheal Drea engine house.

2 Introduction

2.1 Project background

In March 2014, Wheal Drea engine house was struck by lightning during a severe storm, resulting in significant damage to the brickwork section of its chimney. The National Trust commissioned pdp Green Consulting Ltd. of Truro to carry out a structural assessment of the engine house and to produce a schedule of the repairs which would be required to restore structural integrity to the building (Gendall 2014). An application for Listed Building Consent to carry out the necessary works was submitted to Cornwall Council. Consent was granted subject to a number of conditions (PA14/07449 approved on 20/8/2014 and PA15/04829 for partial discharge of conditions approved on 26/5/2015 apply). Condition 3 of the Listed Building Consent reads:

No development to which this permission relates shall commence until an appropriate programme of historic building recording and analysis has been secured and implemented in accordance with a written scheme of investigation which has been submitted to and approved in writing by the local planning authority. The development shall be carried out at all times in strict accordance with the approved scheme.

Reason: To ensure that provision is made to record finds of historical interest in accordance with the aims and intentions of paragraph 141 of the National Planning Policy Framework 2012.

Roger Maclean of Carnyorth was appointed to carry out the works and following the approval of a method statement, CAU were appointed to undertake a watching brief and provide on-site building consultancy during the repair programme. It was originally intended that the work would be undertaken in the autumn of 2014.

However, despite the unstable condition of the upper section of the chimney, the start to the works was significantly delayed – initially by the requirement of the Conservation Officer for suitable bricks for the repair to be approved. A number of sample brick types were submitted for approval; eventually a source of reclaimed 19th century bricks was identified by Roger Maclean – these were approved as a good match with those from which the chimney had originally been constructed and were thus suitable for use. However, Natural England further delayed the commencement of the works with their concerns that the chimney might be in use as a Chough nesting site. Although observation of the structure by National Trust Rangers indicated that this was not the case, no works were permitted on the structure during spring, summer and early autumn months. The works eventually got underway on 14 November 2016, being completed on 9 December 2016.

2.2 Aims

The principal aim of the project was for the site archaeologist to provide on-site advice to the building contractors during the works, to amend and update the building survey prepared in 2014 by pdp Green to provide an accurate record of the damage to the structure prior to works and the repairs undertaken in 2016, to undertake a watching brief during the repair works and during trenching to install a lightning conductor earthing system and to produce an report on the works programme (this report).

Further project objectives were to prepare an archive of project materials for the National Trust and to produce an entry to the Historic England OASIS ADS-Online database of archaeological projects.

2.3 Methods

2.3.1 Desk–based assessment

No desk-based assessment was required for this project, as the engine house and its context were researched and reported on in 1992, 1997 and 1999 (see Section 9.2).

2.3.2 Fieldwork

An archaeological watching brief and building conservation consultancy was provided by CAU during the repairs programme and during trenching for the lightning conductor earthing mats.

2.3.3 Post-fieldwork

All project materials were archived with the National Trust.

3 Location and setting

See Figures 1 and 2.

Wheal Drea engine house is located at SW 36557 32342 just to the east of the former farming and mining hamlet of Kenidjack, just under a mile to the north of St. Just in Penwith, Cornwall. Its boiler house is attached to the north-west of the engine house whilst the former miner's dry is a few metres to the north-west again. Wheal Drea Shaft is located on the edge of the valley floor 110m to the south-south-west of the engine house, whilst Greenland's Shaft (the principal shaft from which the engine house wound) is 110m to its north-north-east.

4 Designations

See Figure 2.

Wheal Drea engine house is Listed Grade II (National ID No 351298, first Listed in 1994). The site is within the Cornwall AONB and Area A(i) of the Cornwall and West Devon Mining Landscapes World Heritage Site.

The List Description reads:

Beam engine house of former tin mine. c1859. Granite rubble, with dressed granite to bob wall. Rectangular plan of approx. 7.6 x 5.2 metres, standing to 12 metres high, with walls surviving from original boiler house of approx. 11.5 x 3 metres to north west. Square-headed openings with twin lintels of granite (to exterior) and timber (to interior). Upper section of rear wall has collapsed. NW corner stack finished in brick. A substantially complete example of a beam engine house with its original boiler house, a rare surviving example. This constitutes a significant surviving group with the former miners' dry (qv) to the north west. (Cornish [sic] *Archaeological Unit, "St Just: An Archaeological Survey of the Mining District", 1992, pp. 188-92).*

Wheal Drea lies within an area of Heritage Coast, and was within an area identified in the former Cornwall Structure Plan as an Area of Great Heritage Value (AGHV) and an Area of Great Scientific Value (AGSV).

5 Site history

The Cornwall and Isles of Scilly SMR contains no reference to Wheal Drea, which was centred around Kenidjack hamlet, the main shafts during the later 19th century being at SW 36511 32243 (Wheal Drea Shaft) and at SW 36652 32410 (Greenland's Shaft) (Sharpe 1997). Little could be discovered about the early history of the mine, though Noall (1973, 132) mentions this area in quoting the lease of a sett by the Lords of Kenidjack to John Thomas of St. Just in 1795, the area granted being as far south as: '*… the road leading from Kenidjack to Henry Boyens' Smith Shop except twenty fathoms to the North of the said Road on Kins-an-drea Load which is already in grant to the adventurers in Kinsandrea Tin Mine, and so far East as to adjoin with the several tin bounds called Kenidjack Cliff Bounds and Wheal Edward Bounds'*. Noall also mentions (1973, 133) an alternative name for the Wheal Drea main lode - *Cercendry* - almost certainly a variant of *Kinsandrea*, whilst the Colonel Oates collection mentions a mine called Polandrea – probably sited near the pool now spanned by the clapper bridge below the hamlet. It seems probable from Moody's map of 1778 that the mine reworked as Wheal Gendall was the earlier (and later) Wheal Drea. The late reworking of the mine during the second half of the 19th century was from a new shaft and to far greater depth, and there is little evidence that the earlier shafts to the south-west and

west of the hamlet were reused.

The mine was incorporated into the Wheal Owles group in about 1859, having worked independently for some years during the earlier part of the 19th century. According to Noall (1973, 138) the engine shaft at Wheal Drea was being deepened during 1871, when it was discovered that it intersected three lodes at the 160 fathom level. Three years later, parts of the Wheal Owles sett were suspended and allowed to fill with water, but work continued in Wheal Drea. It seems probable that it was at Wheal Drea in 1881 that the Champion rock drill was introduced to the Wheal Owles mines, the compressor being powered by an old waterwheel on the Boscean side of the stream. In 1882, the Wheal Drea miners holed into Boscean workings - an indication (had the implications of this event been realised) that the underground survey was erroneous. In 1884, the Wheal Drea section was abandoned. On 11th January 1893, the West Wheal Owles miners developing lodes there south-eastwards holed into the enormous mass of water which had filled Wheal Drea to surface. According to Jim Polglase (pers. comm.) air pressure resulting from the inrush of water caused a run of ground on the outcrop of Huel an Vor Lode, a feature which is now covered by the agricultural tip on the hillside to the west of Kenidjack hamlet. Another run of ground is supposed to have been visible until a few years ago on the Boscean side of the stream near the Poor House.

The few visible remains of the mid-19th century mine are clustered within a small area to the east and south-east of Kenidjack hamlet. The shaft has a galvanized steel grille within its massive drystone collar for security and stands atop a high dump. Richard Jenkin suggested (letter of 26.9.88) that the reason for this tall dump is that "*the group of mining venturers, who exploited a very rich lode of tin in a very restricted area, were at loggerheads with their neighbours who were also mining venturers. Being without space to stack their deads (waste stone) they extended the collar around their shaft to a height above ground of more than 25ft with dressed granite and tipped their waste stone around it as the work proceeded. This abortion now exists close by the very old village of Kenidjack*".

The shaft dump is an impressive feature above the Kenidjack road. Its upper surface has been extensively dug into by mineral collectors, who have displaced rock down the dump sides, creating a number of deep, unstable and dangerous excavations on its surface. A large quantity of material has been dug away from the foot of the dump for roadstone over the years.

The shaft is open to some depth. On its northern side are the remains of a stonework feature which appears to be part of a (buried) balance bob pit. A horse whim may have also have been sited on this side of the shaft, which was evidently used for winding, as the *circa* 1878 OS 25" mapping shows a tramway leading from this shaft to the dressing floors at the Grouse site further up the valley. Martin Mount (pers. comm.) reported a small stone-lined shallow adit opening onto the Kenidjack Stream a short distance downstream from the bridge. Moody's map of 1778 shows this exiting to the stream at SW 36272 32413.

The engine house which survives to the north of the shaft primarily wound from Greenland Shaft, though Ken Brown has suggested (pers. comm.) that it may have pumped via flatrods in Wheal Drea Shaft. The 1893 accident report specifically mentions 8" pumps with an 8 foot 6 inch stroke in this shaft, apparently confirming this suggestion.

6 Wheal Drea engine house

The engine house is in good condition having been conserved in 1998, and still retains substantial portions of its boiler house walls, which lie on the western side of the house.

A plain and sturdy rotative beam engine house measuring 7.6m x 5.2m in plan, and standing to 12.0m high, this deceptively standard looking building was constructed of granite throughout. The stonework of the bob wall is of squared blocks, but the other walls are of rubble masonry, shaped stone being confined to quoins and the framings of

the wall openings. No tie bars were installed. All wall openings are square headed, granite being used for the external lintels, timber for the internal lintels (except above the boiler house door, where granite was used for both). The tall plug doorway (4.35m high x 1.05m wide) in the bob wall is flanked on the offside by a cut-out for the flywheel. At the base of this is a small opening through the wall. It is unclear whether this engine was double acting as there are no traces of the anchorages for the additional bolts securing the beam trunnion, nor of a link motion opening through the wall.

There are windows in the offside wall on the ground and middle floors - the lower window being set just behind the bob wall, the middle floor window at the centre of the elevation. The nearside wall is windowless - the boiler house door is set just behind the bob wall rear face; just above the level of its lintel, and set to its rear is the steam pipe entry. The upper section of the rear wall has collapsed. At its base is a granite-lintelled cylinder door (1.8m high x 0.95m wide). The positions of the windows in this wall are unclear, though it is likely that there would have been a middle floor light. The stonework at the head of the wall was thought by Ken Brown (pers. comm.) to be consistent with this house having been intended to have a back bob opening (evinced by the lack of any gable stonework, which is not an effect of the collapse of parts of this wall, the edge of a faced opening on the offside of the upper part of the wall, and the greater thickness of this wall over the side walls). Photographs dating to the 1960's made available to the National Trust by Bill North, a local mining historian, show two elongated square-headed windows in this facade, whilst excavations behind the engine house found no trace of a shaft. There are no surviving traces of the spring beam openings. A further curiosity about this house is that there appears to have been no main girder - there are no pockets or openings in the walls whatsoever for this feature. At the base of the rear wall is a small tunnel giving access to the bottoms of the cylinder bed bolts.

Inside the house, other oddities were found. The locations of the longitudinal bearers for both upper floors could be seen on the rear wall, but on the face of the bob wall, only two middle floor joist pockets (rather than the four in the rear wall) could be seen - one adjacent to the plug door opening on the offside, one flush with the nearside wall. There appear to have been quite massive lateral timbers spanning the cataract pit. Brick-infilled putlog holes are visible in two rows on the face of the nearside wall only. The bedstone is a single granite slab bearing four bolt holes, and has a central slot running from the middle of the block to its front face, presumably to accommodate an eduction pipe.

Some of the structure of the boiler house, which was constructed onto the nearside of the engine house, survives. Although the rear end of this structure (which projects to the rear of the engine house) has until 1999 been in use as an agricultural shed, the forward end of the building has been demolished. The rear walls contain three unusual slit openings, unlike any other boiler house recorded by CAU; these probably represent flue openings. The boiler house appears to have been 11.5m long x 3m wide, and where it is intact, stands to 2m high. At its rear end it was constructed on top of a revetted plinth. The engine pond is sited a little way to the north-east of the engine house. Now a small paddock (the wall has been breached for a gateway) it measures about 12m square, and has enclosing banks 1.2m high.

The chimney is built into the nearside rear corner of the engine house and was constructed in the usual Cornish fashion with a stone lower section and a brick top, the two materials being separated by a stepped five course brick drip ring.

The remains of the loadings extend to the front of the house on the south-eastern side of the plug door. These consist of a line of large granite blocks about five metres long bearing a number of bolt holes; to the south-east again is the partially infilled flywheel pit. The ground to the south-east of these again is occupied by a small grass-grown dump of material on which can be seen a small rectangular concrete machine base and some small iron bolts, suggesting that an upright axle whim cage was mounted here.

At the rear (south-west) of the engine house, where Sharpe (1992) suggested that a weed-grown hollow might indicate the site of a shallow pumping shaft, archaeological investigations in October 1997 in advance of building conservation works revealed a backfilled 0.65m wide trench cut into rab. This was interpreted as a drain serving both

the condenser pit and the flywheel pit, and must have been cut at an early stage in the construction of the house. There were no signs of timber or stone lining, nor of any capping material, and it may be that the trench originally contained an iron pipe which was removed on the closure of the mine. The course of the trench indicated that it drained into the field to the east some way downslope.

The consolidation works carried out to the engine house in 1998 consisted of the replacement of the timber lintels over the inner face of the plug door, the boiler house door, the steam pipe entry opening and both openings on the eastern wall. In the rear wall granite lintels were reinstated at first floor level where they had been lost and a section of masonry was rebuilt over them. All decayed pointing on the engine house was replaced (with the exception of that covered by ivy on the south side of the chimney); the chimney brickwork was re-bedded where the original mortar was found to be failing.

7 Archaeological watching brief results

See Figures 3 to 23.

An initial inspection from temporary scaffolding had been made by pdp Green Consulting in 2014, allowing a record of the structure to be made and specifications for the works to be drawn up.

The scaffolding for the 2016 works was erected in the week commencing 14 November and was available for access at the beginning of the following week. A site meeting was undertaken by Mark Gendall (pdp Green Consulting), Roger Maclean and Darren Dayus (contractors) and Adam Sharpe (Cornwall Archaeological Unit) to inspect the structure and fine tune the detailing of the work.

The brickwork section of the chimney had 49 complete courses of header bricks, each roughly hand-cut to a taper and one incomplete course; it was 3.5m high. At the junction of the brickwork and stonework sections of the chimney was a five course thick stepped drip ring (corbel). The lowest metre of the brickwork section of the chimney had an additional internal skin of brickwork bonded to the outer face.

It was clear that the 2014 lightning strike had hit the top of the chimney on its northern side, completely destroying a V-shaped section of brickwork 500mm wide and 500mm deep at the top of the chimney (Fig 3). Fragments of brick littered around the base of the engine house, on the cylinder plat and in the cockpit are assumed to have derived from the damage to this area. The strike had then travelled down the northern side of the brickwork section of the chimney unzipping the brickwork and tearing the chimney open, leaving a gap averaging 250mm wide (Fig 5). The sections of the chimney on either side of the line of the strike had been forced apart, breaking a number of bedding joints down to the base of the five course drip ring. Three full height cracks on the southern side of the chimney showed where the two sections of the chimney had hinged apart, these cracks being significantly wider on the inside of the chimney than on the outer face. The additional thickness of the lowest section of the brickwork had probably given it additional strength, and this had probably prevented the whole of the upper section of the chimney collapsing as a result of the strike. Nevertheless, the brickwork section of the chimney was in a poor state overall. Its eastern half was leaning outwards by several inches at its head, whilst its western half was leaning inwards slightly (Fig 18).

The force of the strike had additionally destroyed all lichen covering on the brickwork and pointing for 250mm on either side of the crack, broken bed and side joint pointing in much of the chimney brickwork and cracked bricks near the strike line on the southern face of the chimney.

The strike subsequently travelled 1.4m down through the uppermost section of chimney stonework, opening up a full-depth crack and displacing masonry along this line (Fig 6). Below this point, the force of the lightning appears to have dissipated, the strike probably travelling over the surface of the structure – the outer faces of some sections of pointing could be seen to have been blown off as a result.

The levels of damage to the chimney were considerable, though unsurprising considering that a lightning strike can induce localised temperature rises of over 30,000 degrees Centigrade in a fraction of a second – a strike travels at 1 x 10^8 metres per second. Any moisture within areas travelled across by the strike will be instantaneously vaporised, the resultant steam pressure literally blowing bricks and other materials apart with explosive force. In the case of the Wheal Drea chimney it can be seen that sufficient force was exerted to not only split the chimney but to bodily move the resultant two halves apart, as well as exploding the brickwork into small fragments at its initial point of contact.

During the 2014 inspection it had been concluded that the lightning had destroyed brickwork down the strike line on the southern side of the chimney over a width of around 250mm, and the remedial proposals had been based on these assumptions. However, the 2016 site inspection showed that the brickwork had in fact been unzipped by the strike and that the damage was far more widespread than had originally been thought to be the case. On the basis of the observations made at the site meeting it was concluded that the best approach to the repair of the chimney would be to dismantle the whole of the brickwork section of the chimney and to rebuild it using a mixture of original and reclaimed brick. However, it was concluded that the project budget would not cover such an approach and that it would be difficult to source a sufficient number of suitable reclaimed bricks, as it was assumed that many bricks would be incapable of reuse.

It was therefore decided to limit the repairs to the damaged areas of the brickwork and stonework and to keep any dismantling of the chimney to the minimum (Figs 19 and 22).

Given the precarious state of the chimney brickwork, the conservation masons enclosed it with a series of heavy-duty ratchet straps which were progressively tightened until they held the two halves of the chimney together firmly (Fig 4). These were left in place until the bulk of the repair works had been completed. They had the additional effect of drawing the two halves of the chimney together to some degree and assisted considerably in the re-setting of the displaced stonework, whose joints were subsequently deeply packed with lime mortar.

With the structural stability of the chimney enhanced to some degree by these means, a small number of loose bricks on the edges of the main part of the crack were removed and repairs were undertaken to the drip ring and the lower courses of the chimney to tie these together. Five courses of brick were dismantled at the head of the chimney and the northern crack was infilled with a mixture of original and reclaimed brick, laid in courses to match the original work. Where reclaimed bricks were used these were hand cut to a taper. All repaired sections of the chimney were kept wrapped in a tarpaulin during periods of cold weather and overnight to prevent any danger of frost damage to the mortar as it cured, and to ensure that curing did not take place too quickly owing to wind exposure (Fig 9).

Once all courses up to the truncated head of the chimney had been repaired, an annular stainless steel reinforcing rod was bedded into the mortar five courses from the intended top of the chimney to provide additional structural strength; a similar annular reinforcing rod was installed two courses above this. The top of the chimney was finished with a complete course of bricks to strengthen this and facilitate the installation of the lightning conductor crown ring. Given the nature of the damage to the chimney brickwork, its final shape (as repaired) was sub-oval, though this is not evident from ground level (Figs 11 and 12). It may well have been the case that this odd shape is also in part the result of differential drying rates in the bedding mortar due to the effects of the prevailing wind when the chimney was originally constructed.

It had initially been proposed to install stainless steel helicoil bedjoint reinforcement into the stonework joints on the southern side of the chimney, but once this area had been rebuilt it was felt that it would be more appropriate to stitch reinforce the three

full height vertical cracks on the southern side of the brickwork section, as daylight could be seen through some of these and they clearly weakened the structure as a whole.

Five bed joints at four course spacings were cut out across the three cracks and extending beyond them on both sides for a minimum of 350mm (Fig 13). The helicoil reinforcement was bent to shape and installed using a proprietary grout; small wooden wedges were used to hold the reinforcement in place until the grout had cured (Fig 14). Two additional half-length sections of reinforcement were installed to further tie together lower sections of these cracks. On the northern side of the chimney two other cracks above the drip ring were also tied together using helicoil reinforcement, again set in grout.

The mortar mix used for the 1998 pointing work had been made up to an experimental recipe devised by Dave Rickard of the National Trust Cornwall Region Building Department, the aim being to provide a good match for the original pointing on the Wheal Owles engine houses in terms of colour and texture (Sharpe 1999). The mix was follows:

- 1 part Castle an Dinas 8mm to dust
- 5 parts site-won sieved rab
- 4 parts Gwithian dark sand
- 1 part sieved mine waste sourced from the West Wheal Owles mine dump
- 1 part Portland cement
- 0.5 parts putty lime

It is now recognised that the inclusion of Portland cement within a lime-based pointing mix negatively affects the performance of the mortar. The inclusion of the sieved rab (to provide texture) and the sieved mine waste (to achieve the desired colour) is also likely to have introduced clay particles into the mix, which could have prevented the lime from fully adhering to the aggregate. It can also be seen that the mix was a fairly weak one; although it eventually achieved a good set, this took many years.

The brick and stone bedding mix used in 2016 was a 2.5:1 mix of an off-white builders' sand and NHL5 hydraulic lime. This was made up in daily batches and knocked up again in the mixer before use to ensure its workability. All joints were cleaned out using a leaf blower and wetted up before the mortar was applied using appropriately dimensioned trowels.

The use of pointing mixes with suitable textures and colours was a condition of the Listed Building Consent. Two test panels were therefore set up before the repaired sections of the chimney were repointed. On the stonework a 2.5:1 mix of Moor Gate Quarry dark sand and NHL5 hydraulic lime was used (Fig 8). This was tended to produce slightly recessed joints within which the aggregate was visible, though not prominent, and dried to a light buff colour. For the brickwork pointing a 2.5:1 mix of an off-white locally-sourced sand and NHL5 hydraulic lime was used and was again tamped up and allowed to dry (Fig 7). Photographs of the finished test panels were emailed by Mark Gendall of pdp Green Consulting to the Conservation Officer, who approved them by phone.

All repaired areas of the brickwork and stonework were repointed. The joints were cleaned out using a leaf blower and wetted up before repointing took place. Once the applied mix had achieved an initial set it was brush tamped to ensure that it adhered to the arrases of the brick and stone and to reveal the aggregate in the surface of the pointing. Where other brick bed and vertical joints had been significantly damaged by the lightning strike these were cut out, filled and repointed. In the case of the wider vertical joints brick slips were used as gallets during the repair works (Fig 15).

A visual inspection had shown that the brick joints on the interior face of the chimney were, in many cases fairly open, having lost their filling mortar either to weathering or as a result of the lightning strike, particularly on the north side where the two sides of the chimney brickwork had hinged. Working off an abseil rope, wearing a full climbing

harness and standing on a scaffold plank cut to size so that it fitted snugly on top of the internal step in the chimney, the conservation mason filled all significant voids in the brick joints back to the inner face of the chimney (Fig 17). This will greatly strengthen the upper section of the chimney in the future.

A lightning protection system was installed in the chimney by St. Ives Steeplejacks on 1 December 2016. A copper crown ring was fixed to the upper surface of the chimney brickwork with stainless steel screws (Fig 12); twin down tapes were attached to this and led down the interior of the chimney, being clipped to its inner face at intervals. The masons had cleared out the flue entry at the base of the chimney on its southern side at its base, allowing the earthing tapes to be led out here. On 8 December 2016 John Williams of Pendeen machine excavated a narrow trench from the base of the chimney out into the adjacent field (Fig 20). This was 350mm wide, between 400mm and 600mm deep (down to the surface of the rab) and 10.5m long. At its northern end an original doorway in the flue running round the outside of the boiler house was cleared of rubble to allow the earth tape to be brought out from the flue entry at the base of the chimney. Along the western side of the field John Williams excavated a trench 8m long, 1.2m wide and 1m deep to accommodate the earthing tape and mats (Fig 21). The trench was again excavated down to rab; all of the material above this consisted of clean topsoil with some large stones. The trenches were excavated under archaeological supervision; no artefacts were recovered or structures exposed.

St. Ives Steeplejacks returned to site on 9 December 2016 to install the remainder of the lightning conductor earthing system, this consisting of four copper earth mats clipped to the tape at one and a half metre intervals (Figs 20, 21 and 23). The trenches were backfilled and consolidated by John Williams on the same day. The following week St. Ives Steeplejacks returned to site to install a resistance test box just outside the flue opening. This was disguised with stones to help to prevent theft of sections of the tape. A recommendation was made by CAU to the National Trust that a galvanised steel grille should be fitted to the flue opening to prevent unauthorised entry to the chimney.

8 Conclusions and recommendations

The repair works to the engine house chimney at Wheal Drea should ensure the survival of this structure for many years, whilst the installation of the lightning protection system should prevent any future lightning strikes from damaging this locally-prominent building. The remainder of the building appeared to be in good condition with the exception of the section of chimney pointing which had, until recently, been covered by ivy. Considerable mortar loss was noted on this area of the building and it is recommended that its re-pointing is undertaken in the medium term. Given budget constraints, it was not possible to dig out and repoint all of the cracked brickwork joints on the Wheal Drea engine house chimney, although the worst of these were treated. The building should be visually inspected from ground level on an annual basis to check that significant deterioration is not taking place as a result of water infiltration through these partially open joints, or through their weathering.

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9.3 Websites

http://www.heritagegateway.org.uk/gateway/ Online database of Sites and Monuments Records, and Listed Buildings

10 Project archive

The CAU project number is **146486**

The project's documentary, digital, photographic and drawn archive is maintained by Cornwall Archaeological Unit

Electronic data is stored in the following locations:

Project admin: \\Sites\Sites W\Wheal Drea chimney repairs 2016

Digital photographs: \\Historic Environment (Images)\SITES.U-Z\Wheal Drea chimney repairs 2016

Electronic drawings: \\Historic Environment (CAD)\CAD Archive\Sites W\Wheal Drea chimney repairs 2016

Historic England/ADS OASIS online reference: cornwall2-270321

Fig 3. The chimney shortly after the lightning strike.

Fig 4. The top of the chimney, ratchet strapped to secure it at an early stage in the works.

Fig 5. The unzipped lower section of brickwork and drip ring.

Fig 6. The displaced upper section of the stonework below the drip ring.

Fig 7. The sample pointing on the brickwork.

Fig 8. The sample pointing on the stone section of the chimney.

Fig 9. Rebuilding the chimney brickwork. The tarpaulin was used to protect the mortar from the effects of the winter weather.

Fig 10. The original brickwork courses were far from level. Not so their replacements.

Fig 11. As can be seen the chimney was far from circular in plan, partly as a result of the lightning damage.

Fig 12. The lightning protection crown ring and twin down tapes.

Fig 13. Brick joints cut out across the southern cracks in preparation for the installation of the helicoil bedjoint reinforcement.

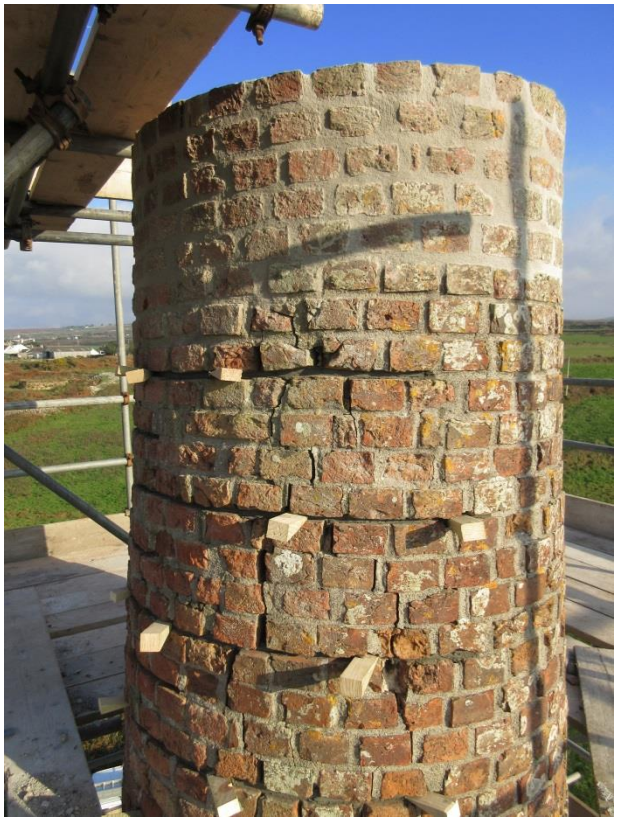

Fig 14. The helicoil reinforcement grouted into place. The wedges held the reinforcing in place until the grout had set.

Fig 15. Repointing a stepped crack near the base of the chimney brickwork. The open vertical joints were infilled with brick gallets.

Fig 16. The lower section of the repaired brickwork at the location of the original major cracks. The mortar had yet to be tended to bring up its texture.

Fig 17. Filling the inner faces of the brickwork joints, which had lost most of their original pointing mortar.

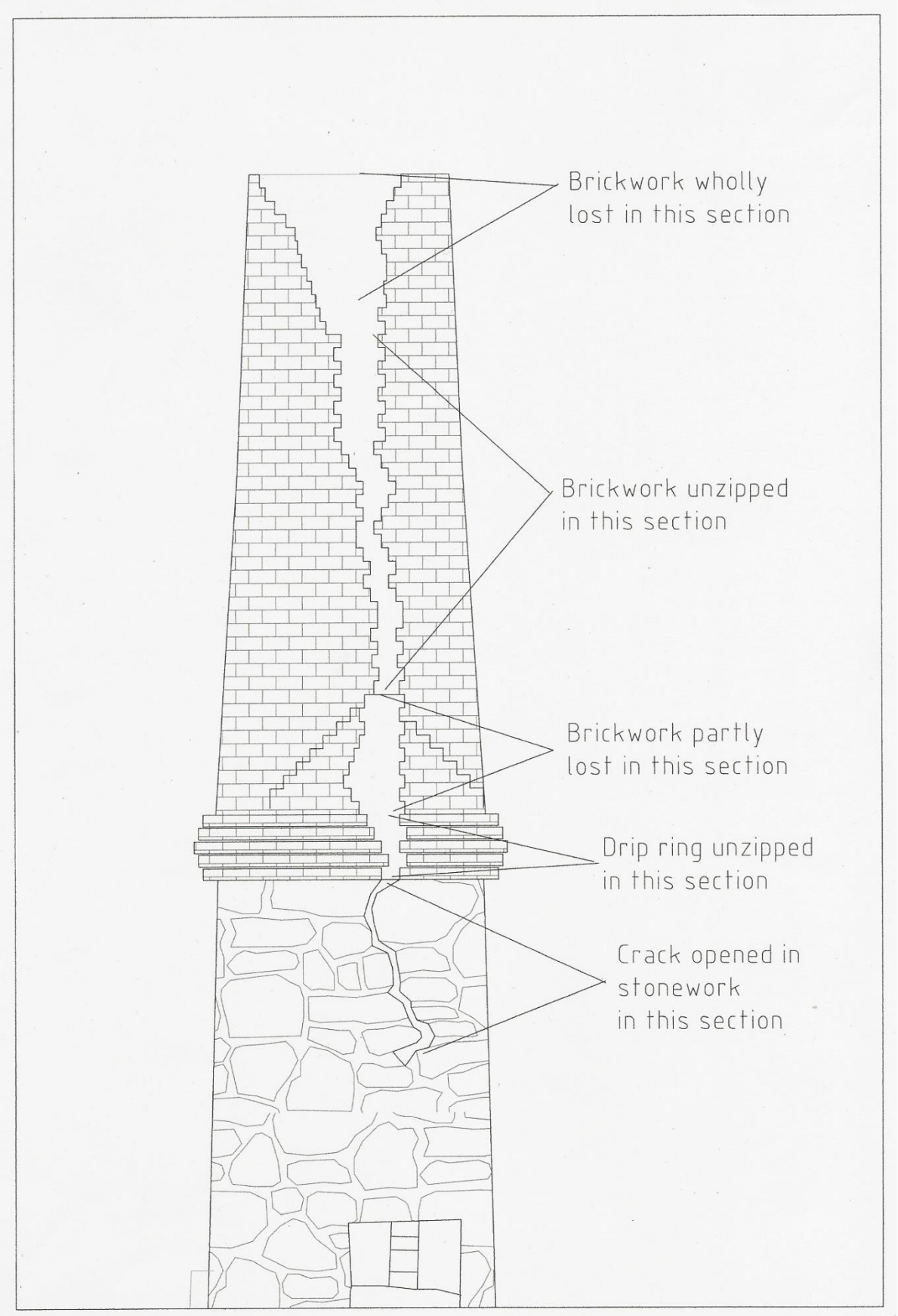

Fig 18. An annotated copy of the pdp Green Consulting drawing of the chimney showing the extent of the damage caused by the lightning strike.

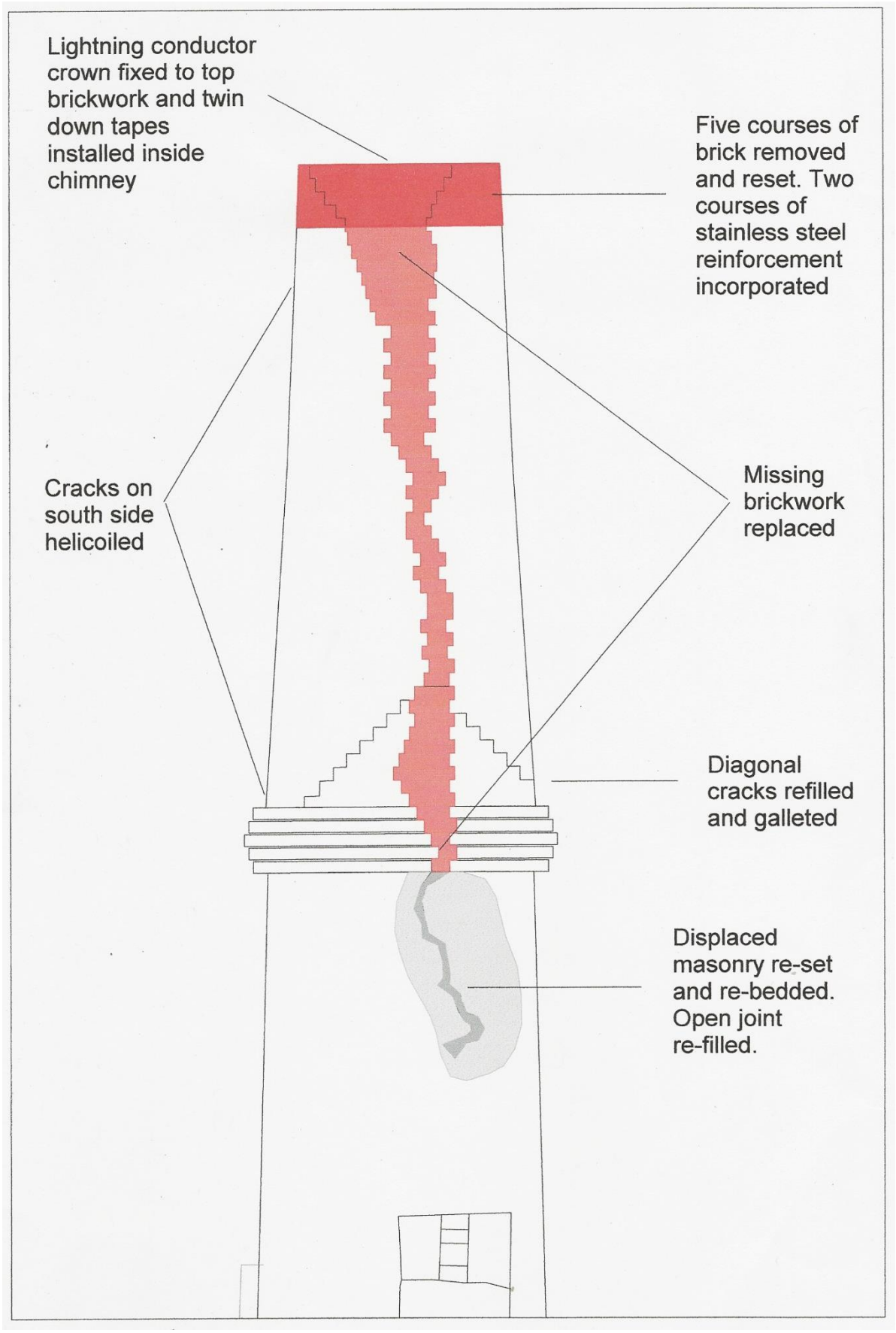

Fig 19. A summary of the repair works undertaken to Wheal Drea engine house chimney in 2016.

Fig 20. The trench excavated for the earth protection system showing the doorway into the flue and flue opening in the chimney.

Fig 21. The earth mats installed in the trench.

Fig 22. The repaired chimney viewed from the north.

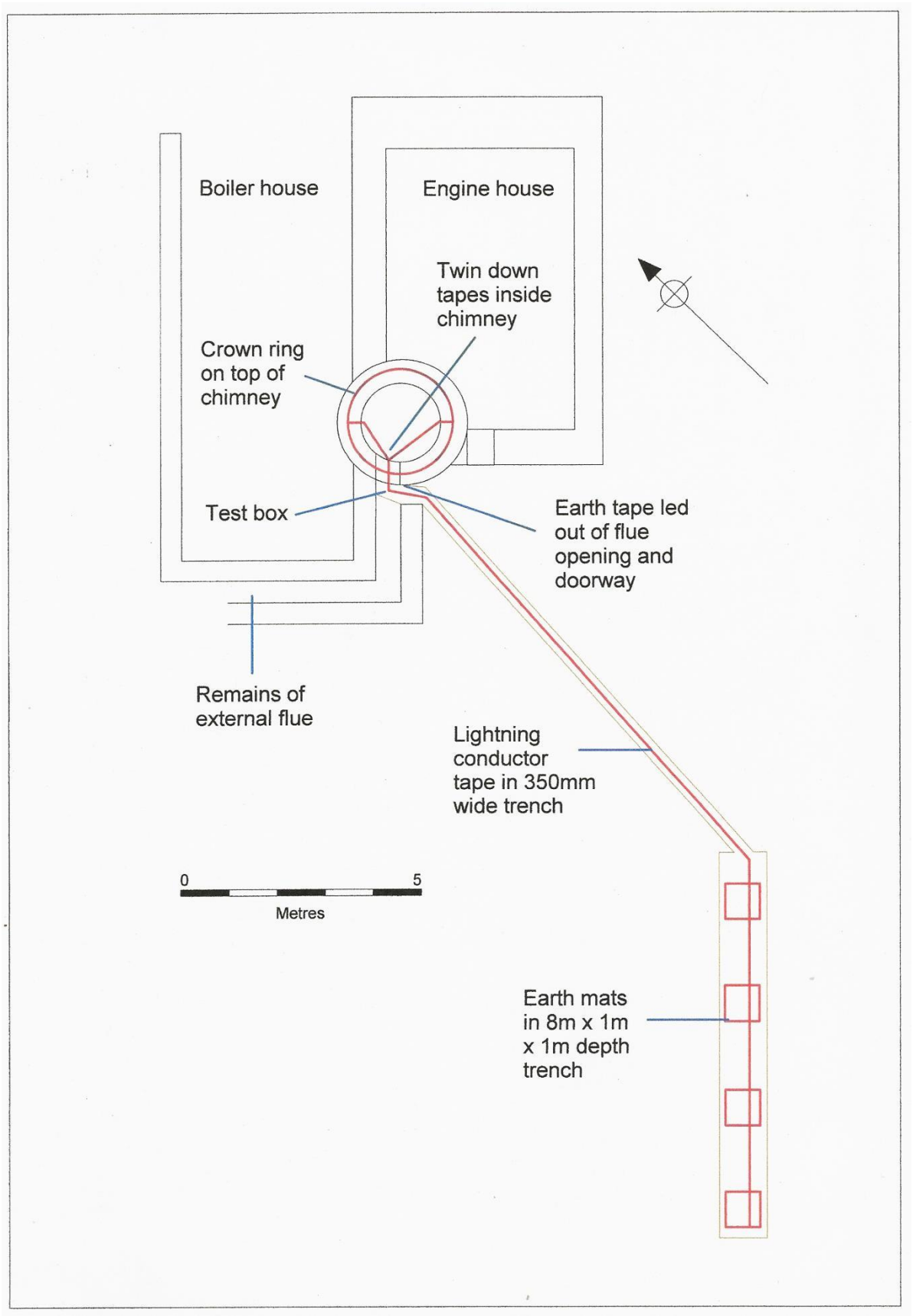

Fig 23. A plan of the earth protection system installed by St. Ives Steeplejacks.

Cornwall Archaeological Unit

Fal Building, County Hall, Treyew Road, Truro, Cornwall,
TR1 3AY

(01872) 323603
enquiries@cau.org.uk
www.cau.org.uk