EITRM116871: D2.3 Geoscientific evaluation of pilots

1 September 2022

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Contents

Table of Figures

List of Abbreviations

EDM Empresa de Desenvolvimento Mineiro, S.A
EMET Ecton Mine Educational Trust
GUE Global Underwater Explorers
INESC TEC Institute for Systems and Computer Engineering, Technology and Science
ROV Remotely Operated Underwater Vehicle
TBD To Be Done

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

UGR UNEXMIN GeoRobotics
UNIM University of Miskolc
WCU Water Chemistry Unit

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1. Introduction

This document contains a geoscientific evaluation for each of the pilot sites. It states all the data gathered and analysed for each trial.

This deliverable will be updated after each pilot test. This document will be reviewed, adapted or modified as required during the course of the project's implementation, upon approval of the consortium.
Trials conducted in 2022 were:

1. South Crofty Mine (United Kingdom)
2. Ecton Mine (United Kingdom)
3. …

Of these sites, only Ecton has significant amounts of geological data, as at other sites the robot has remained within the confines of the shaft and tunnels where little to no exposure to rock was available. For the sites lacking geological exposures this report will focus on the available data and post-processing thereof where it could be used for geological assessments. However, full geological reporting remains impossible.

This report overlaps and complements D2.5: Mission Field Manuals.

2. First pilot – South Crofty, United Kingdom

In March 2022, the UNEXMIN Georobotics Ltd. performed exploration dives in the New Cooks Kitchen shaft of the South Crofty mine. The aim of the work was to explore as detailed as possible the "195 fm pumping station" which is located approximately 350 m from the surface and to obtain visual information of the shaft section between the water surface and the "195 fm pumping station" using robotic technology.

After preliminary dives on 17th March, the principal dive to 292m depth was performed on 18th March, the intended purpose being to obtain a 3-dimension model and images showing the condition of the pumping station adjacent to the shaft at that depth.

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2.1. The site description

Geology and mineralogy

The mine is geologically situated in the south-west England section of the Hercynian orogenic belt (Figure 1), and exploits hydrothermal Sn/W/Cu vein mineralisation in a granitic batholithic intrusion and overlying Devonian meta-sediments.

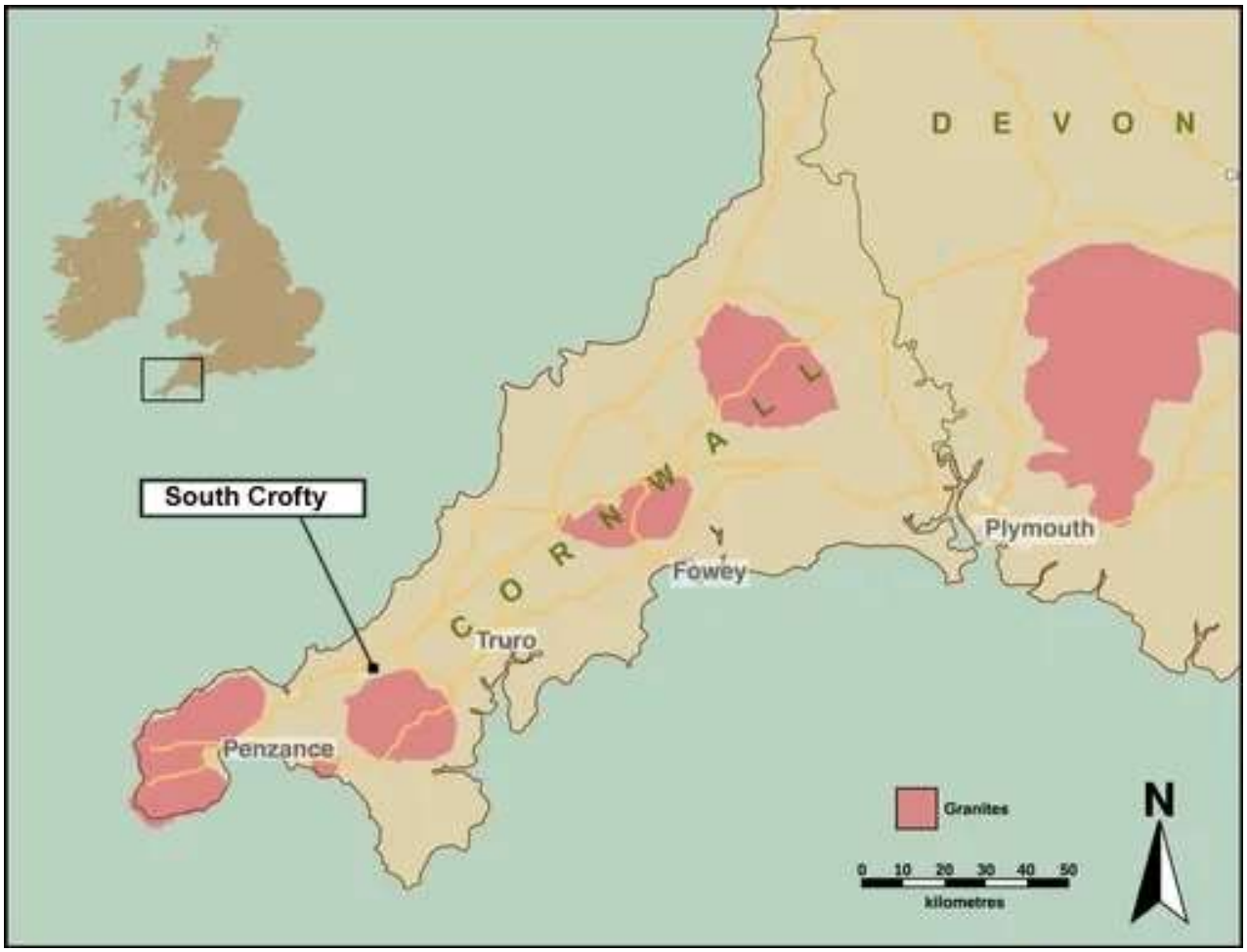

Figure 1 Location of South Crofty Mine

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2.2. Observations

Within 3 working days one full dive was performed up to the pumping station. In total 1.01 TB of mission data was collected that include all the point clouds, scientific measurements and 37.13 GB of video footage.

The collected data were provided to the South Crofty mine after the mission in the following link:

https://drive.google.com/drive/folders/1vhwk4matPYiwTr2qXKNSeWFKRJSYEXux?usp=sharing

All the raw data were collected in ROS bag format with a maximum of 100 GB packages.

2.3. Conclusions

Full description of the mission and its results are given in Appendix 1.

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3. Second pilot – Ecton Mine, United Kingdom

3.1. The site description

Ecton Mine is a copper/lead/zinc mine in central England, flooded to river level since 1858. It was the site of a series of dives during the UNEXMIN project, and was visited again in March 2022 as one of the principal UNEXUP project pilot missions. Dives were carried out in the two main shafts – one in the pumping shaft and two in the winding shaft, both accessed from the Deep Ecton adit at river level, and test dives using the BlueROV2 commercial submersible in the North Winze, an exploratory shaft just over 19m deep, to a boulder choke. The first dive in the winding shaft was cut short by entanglement of the robot in a 2mm nylon line that became caught in the thrusters. There was a second dive, which passed through a gap (identified from data obtained in the UNEXMIN mission in 2019) into the main pipe working.

3.2. Geology and archaeology

Ecton Mine exploited polymetallic ore deposits within the Lower Carboniferous limestones in the Peak District national park in central England. The main production period was the second half of the 18th century, and all production below river level ceased by 1854 when the mine was allowed to flood. During the last decades of operation, most equipment and infrastructure such as staging, ladderways, and props were removed, and the mine workings were stripped back to unmineralised host rock. Archaeological investigations include exmaination of remaining timbers and fixed items such as iron pegs and stacked waste rock. The geology and archaeology are described in detail in Annex 2.

3.3. Conclusions

A number of new archaeological and geological discoveries were made, including survey of the northern part of the pipe working which had not been visited in 2019, and identification of the geological structure which had controlled much of the mineralisation.

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Annex 1: South Crofty report

This is the report prepared by UNEXMIN Geo Robotics Ltd for the client South Crofty Mines Ltd.

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Report
South Crofty mine UX-1Neo robotic exploration

Content

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1. Summary

In March 2022, the UNEXMIN Georobotics Ltd. performed exploration dives in the New Cooks Kitchen shaft of the South Crofty mine. The aim of the work was to explore as detailed as possible the “195 fm pumping station” which is located approximately 350 m from the surface and to obtain visual information of the shaft section between the water surface and the “195 fm pumping station” using robotic technology.

2. Mission details

Within 3 working days one full dive was performed up to the pumping station. In total 1.01 TB of mission data was collected that include all the point clouds, scientific measurements and 37.13 GB of video footage.
The collected data were provided to the South Crofty mine after the mission in the following link:
https://drive.google.com/drive/folders/1vhwk4matPYiwTr2qXKNSeWFKRJSYEXux?usp=sharing
All the raw data were collected in ROS bag format with a maximum of 100 GB packages.

3. Technical background

The UX-NEO includes 6 cameras that register images in the visible range (RGB images). They are also the cameras used for recording the laser scans (SLS). Due to this dependence on the visible range the SLS systems are sensitive to clarity of the water. Obstructions like floaters, objects and murkiness of the water will reduce their performance.
In addition, the Multibeam sonar system (M3) produces point clouds from sound waves. For calibration the sound propagation velocity in water is used. It is therefore sensitive to large changes in sound propagation changes due to different composition of the water. M3 data is not affected much by little obstructions like floaters in the water.

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The UX-NEO has an on-board pressure sensor that is used for estimating the depth. An increase of 1 Bar of pressure equals an increase of 10m in depth.
For precise navigation additional military grade DVL and IMU (gyroscope) are also built into the robot. These devices are designed to refine laser and sonar information and track robot movement, however, in very narrow spaces (less than 1.5 x 1.5 m) these devices also accumulate error.
Collisions during the robot's dive due to the opacity of the water and the high amount of floaters in the water also increase the inaccuracy of the data collected, resulting in discrepancies in the final 3D point cloud.

4. Diving conditions

At the New Cooks Kitchen Shaft, a checkerboard was placed 12 m above the water surface to provide accurate georeferenced coordinates for the UX-1Neo robot (**Figure 1**). Before and after each dive, this table was identified in order to collect as accurate data as possible.

2. Figure - The view of the checkerboard on the surface with the right camera

The waterbody was completely opaque to the cameras of the robot from the depth of 0 m. The maximum field of view was approximately 5 cm.

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The opacity did not disappear in the deeper layers either (Figure 2), the sediment from the side wall of the shaft, corroded metal pieces, dust and other floating particles did not allow the visual survey of the parts of the shaft farther from the robot.

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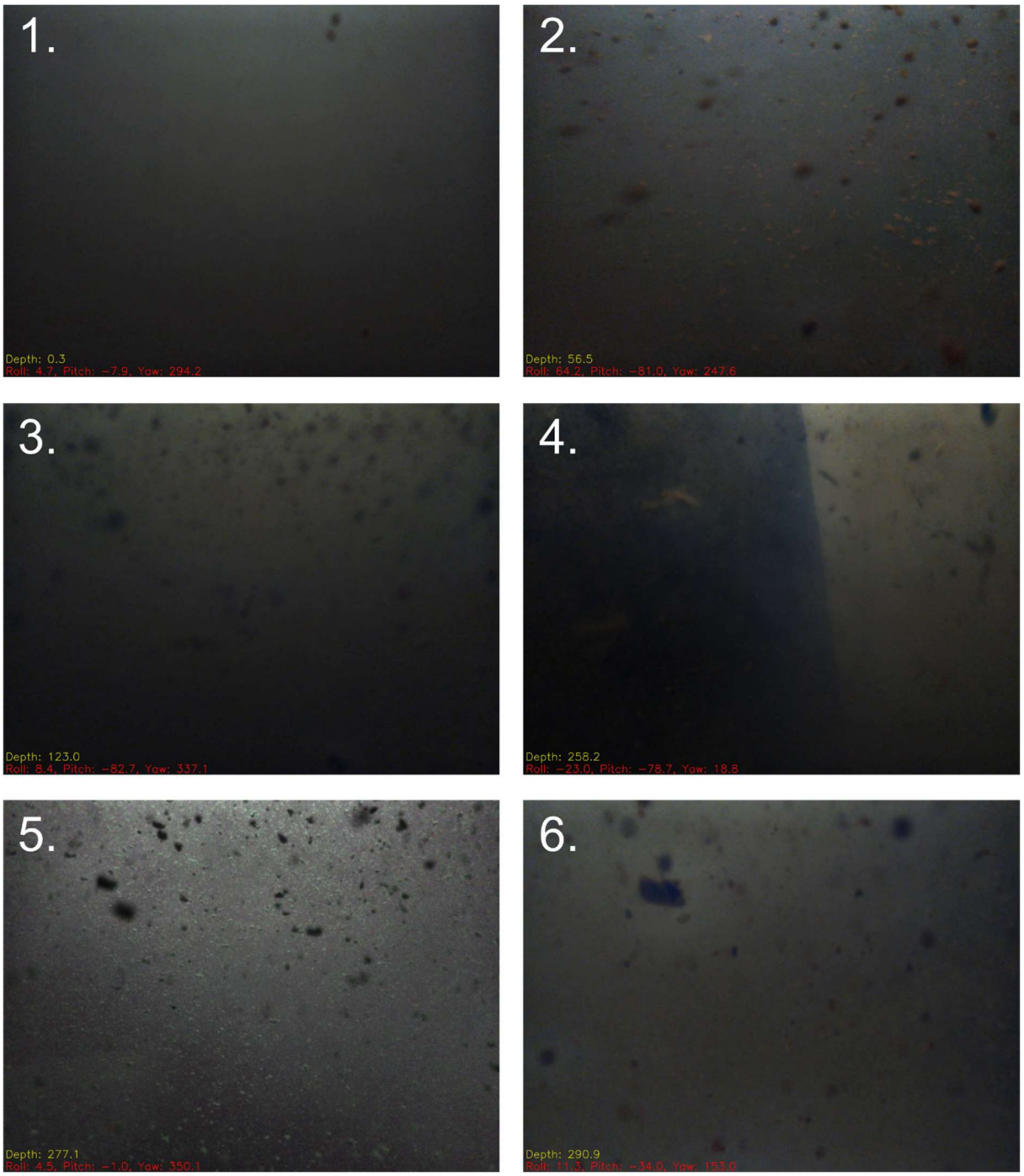

3. Figure - The opacity of the water.
1. Depth: 0.3 m; 2. Depth: 56.5 m; 3. Depth: 123.0 m; 4. Depth: 258.2 m; 5. Depth: 277.1 m; 6. Depth: 290.9 m

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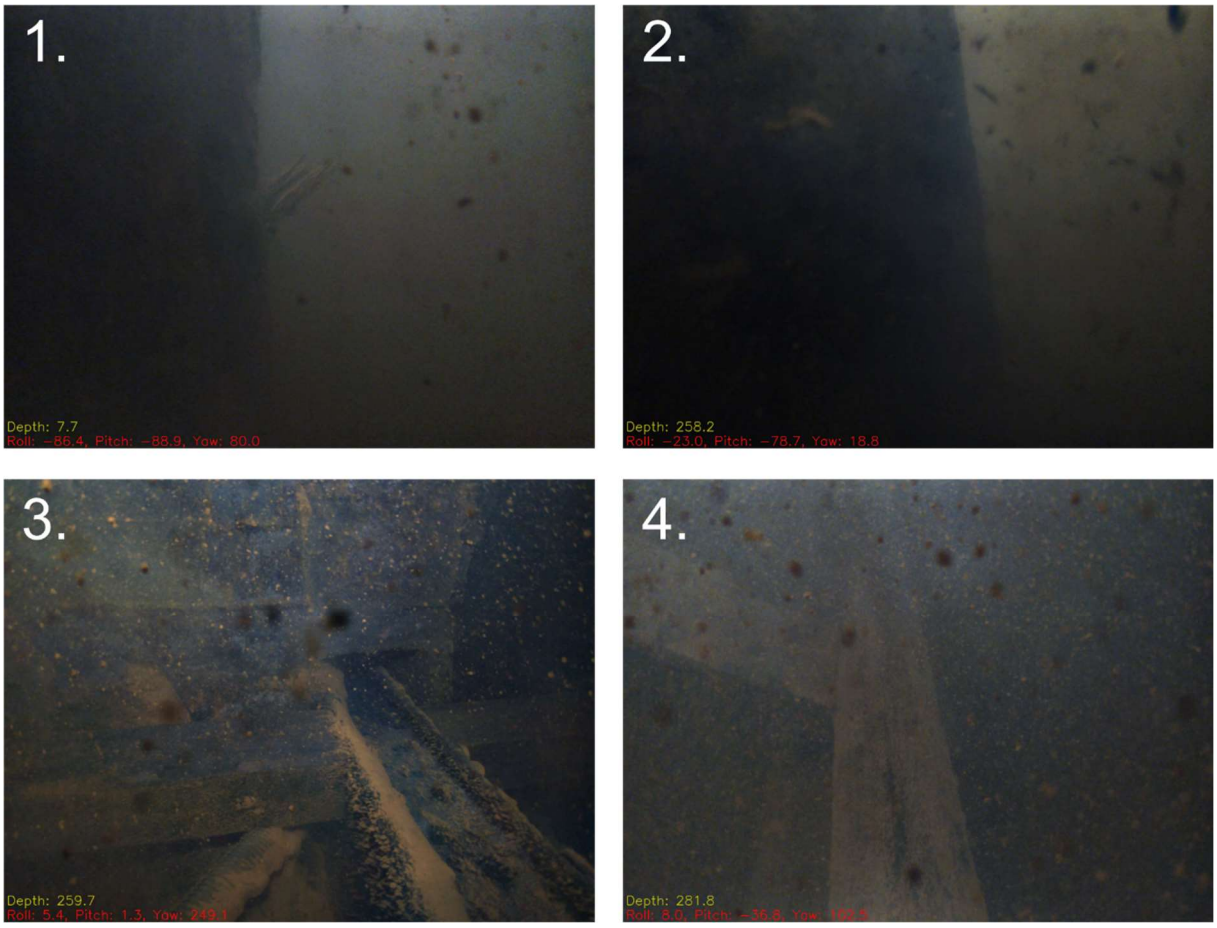
5. Interpretations

5.1. Videos

Due to the opacity of the water, the visual material collected during the dive can only be partially used for the evaluation.
The wooden bar, placed in the middle of the shaft is visible in most cases up to the level of the “195 fm pumping station” (Figure 3). With the help of other information collected during the dive, it can be stated that the wooden beam can be found up to the examined depth, it is not broken and has no missing parts.



4. Figure - The view of the wooden bar in different depths.
1. The wooden bar at 7.7 m depth; 2. The wooden bar at 258.2 m; 3. The wooden bar and other metal workings at 259.7 m (left camera); The wooden bar at 281.1 m depth

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Access to the level to be tested was not possible, so visual observation of the pump station could not be performed. The entrance to the level of the pump station was examined by the robot for more than 30 minutes at the request of the mine, so that the most accurate point cloud possible under the given conditions was collected (see Chapter 5.2).

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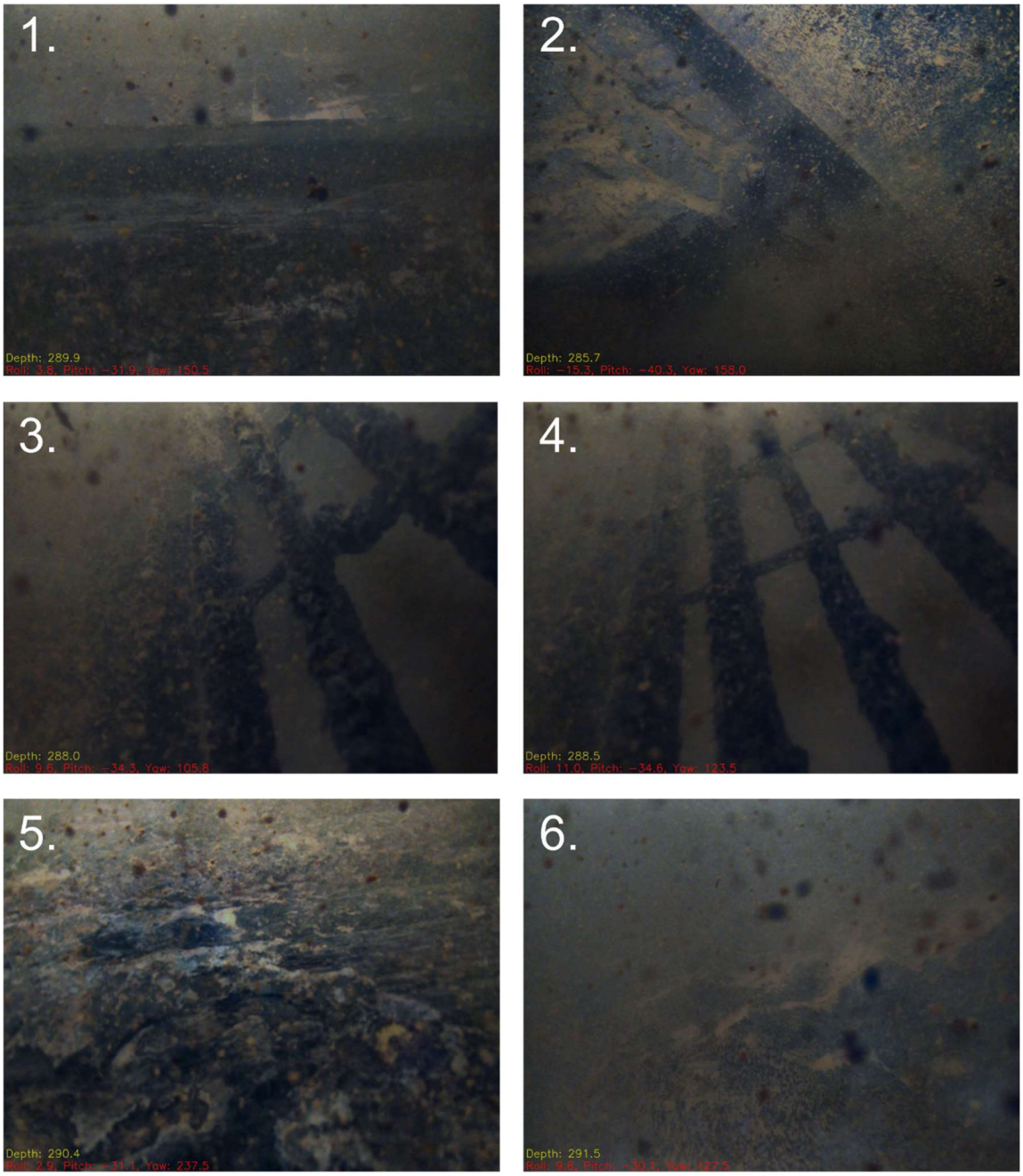
During the time spent near the entrance, the transparency of the water improved somewhat, but was never greater than 30 cm. The cameras were used to identify the concrete, metal and other elements



5. Figure - The view of the entrance of the "195 fm pumping station"
1-2. Concrete, metal and rock material around the entrance; 3-4. The closed metal gate; 5-6. The granite of the shaft.

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around the side tunnel (Figure 4/1-2) (and potential entrance) and the rock that forms the structure of the passage. The iron gate closing the entrance can also be seen in the recordings (Figure 4/3-4). In the latter, the material of the local granite is clearly visible (Figure 4/5-6).

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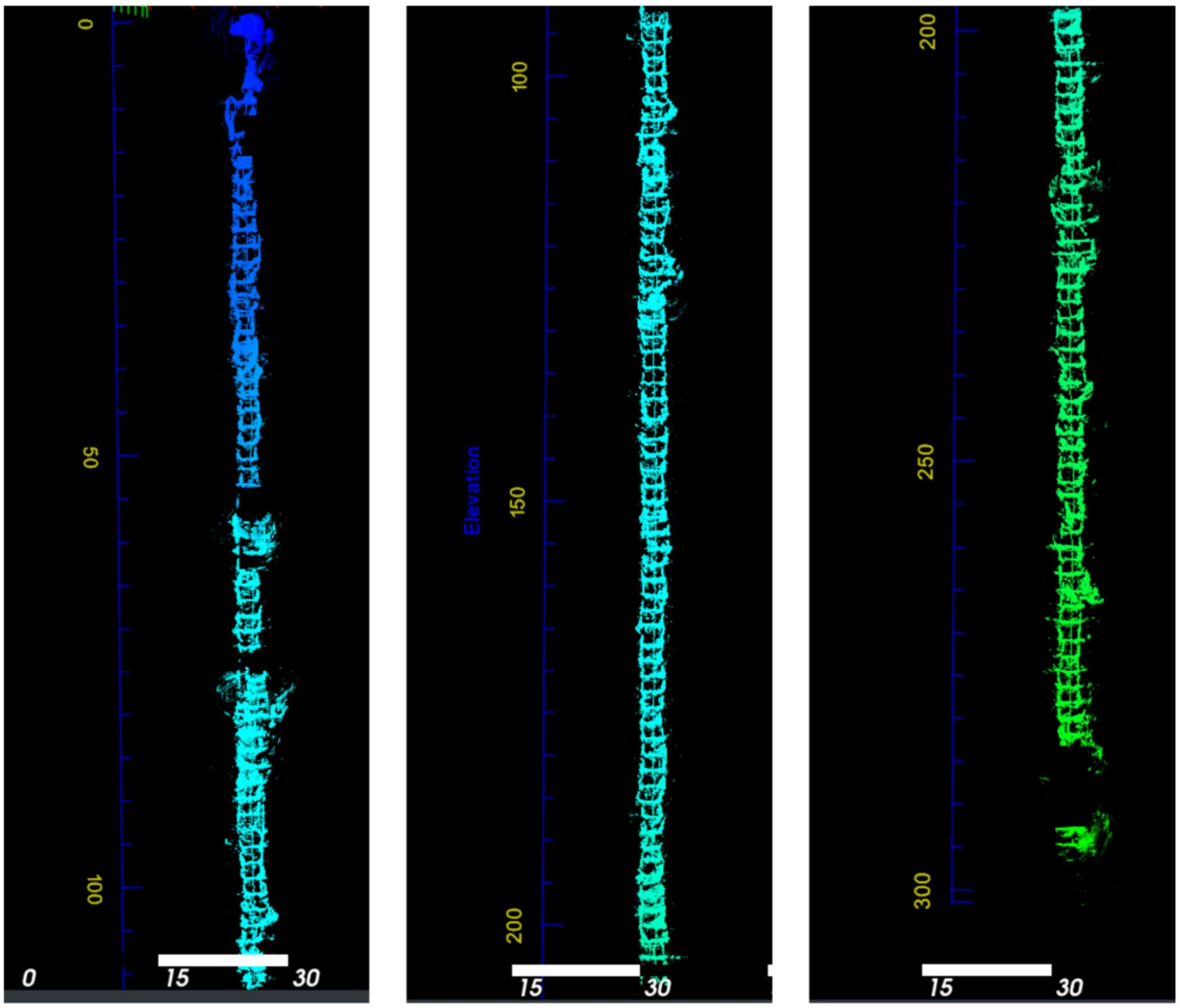
5.2. Point cloud

In the New Cooks Kitchen Shaft, in the section between the water surface and the pump station, a continuous 3D scan was performed using the M3 sonar (Figure 5). Due to the opacity of the water, the robotic lasers (SLS) did not provide usable data, so the use of lasers was avoided, thus reducing the amount of data collected for easier handling.



6. Figure - Continuous M3 sonar measurement in the New Cooks Kitchen Shaft

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Since the M3 sonar is mounted on the front of the UX-1Neo robot and only records at a certain angle of view, it is not suitable for full 360-degree mapping during a dive without continuously rotating the robot.

7. Figure - The point cloud of the entrance of the „195 fm pumping station" in between 288–292 m. The green curvy line represents the rout of the robot.

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During the time spent in the water, at the request of the mine – and because the continuous rotation in the shaft would cause serious and critical damage for the robot –, we focused on to create the most accurate model possible of the “195 fm pumping station” (Figure 6).

To fulfil this requirement, the robot spent more time at the entrance to the level, at a depth of 288–292 m, but due to the reduced visibility, the robot collided countless times with the shaft wall, the gate, and all the other objects that were nearby. The error accumulated due to collisions occurs as a deviation in the point cloud when returning to the surface.

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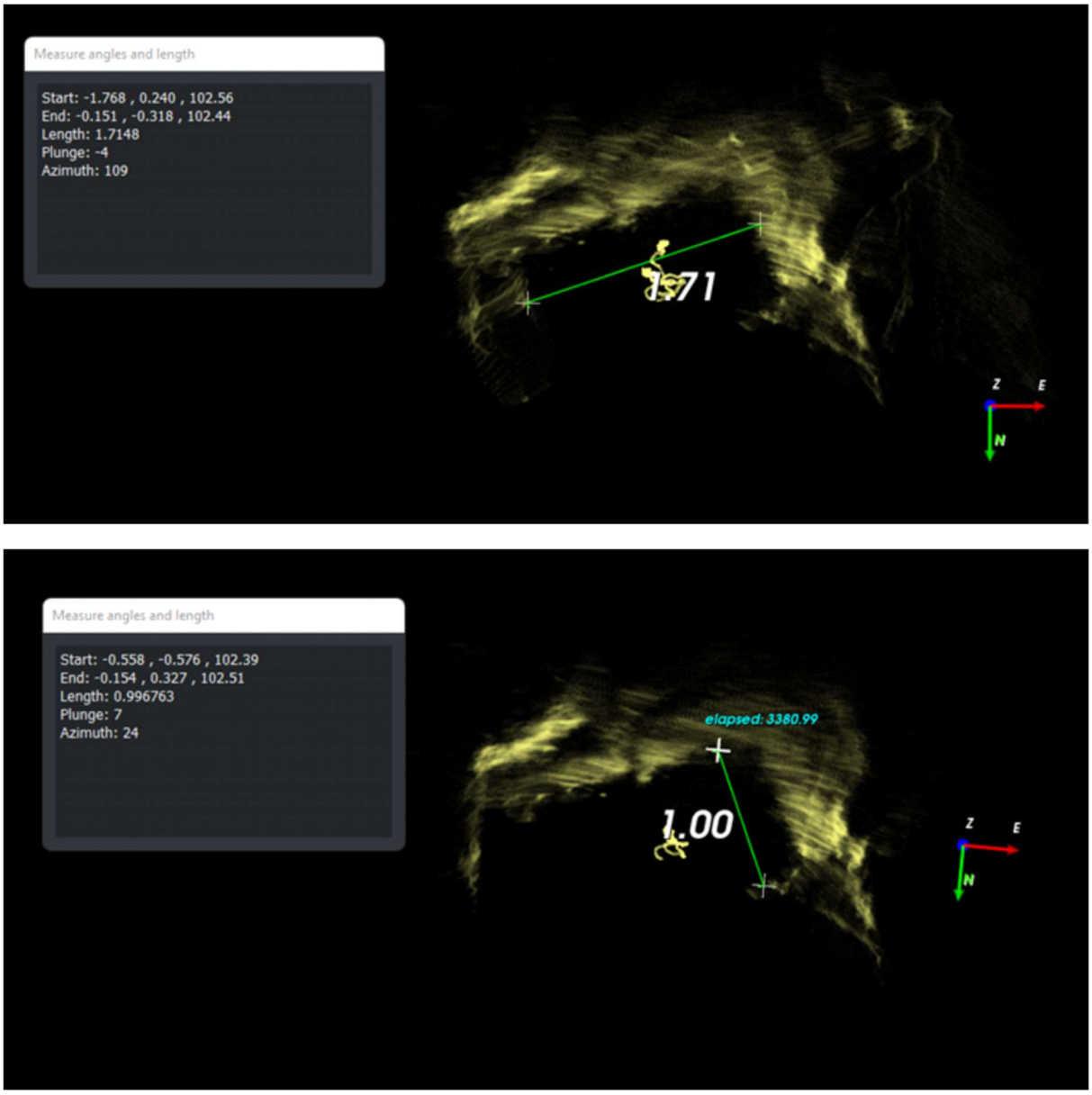
5.2.1. Results

The **Figures** *7–9* show that the dimensions of the shaft did not change during the dive. This also confirmed that the shaft structure was not damaged up to a water depth of 292 m.



8. Figure - The dimensions of the shaft (in metre) at ~100 m water depth

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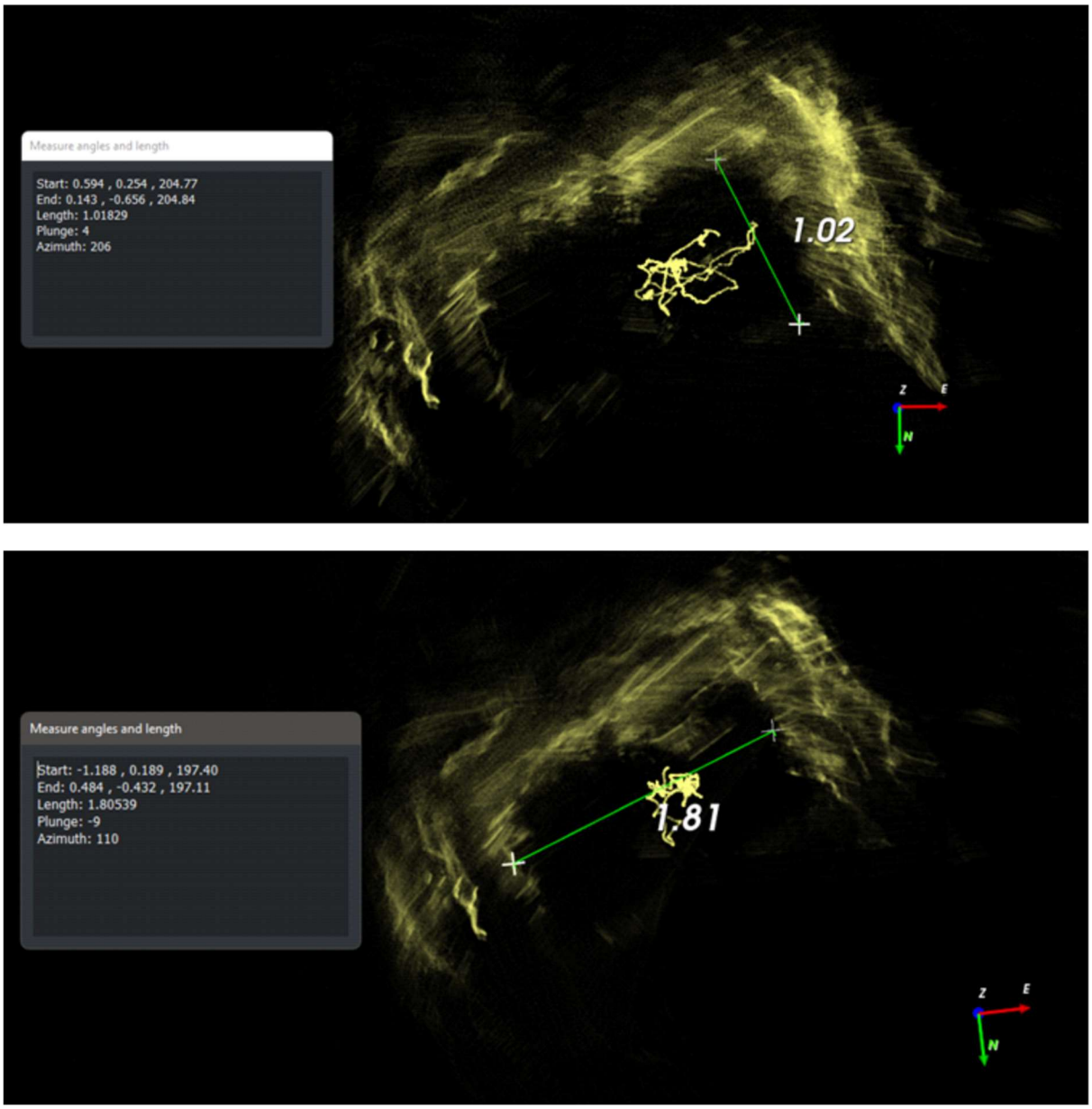

9. Figure - The dimensions of the shaft (in metre) at ~200 m water depth

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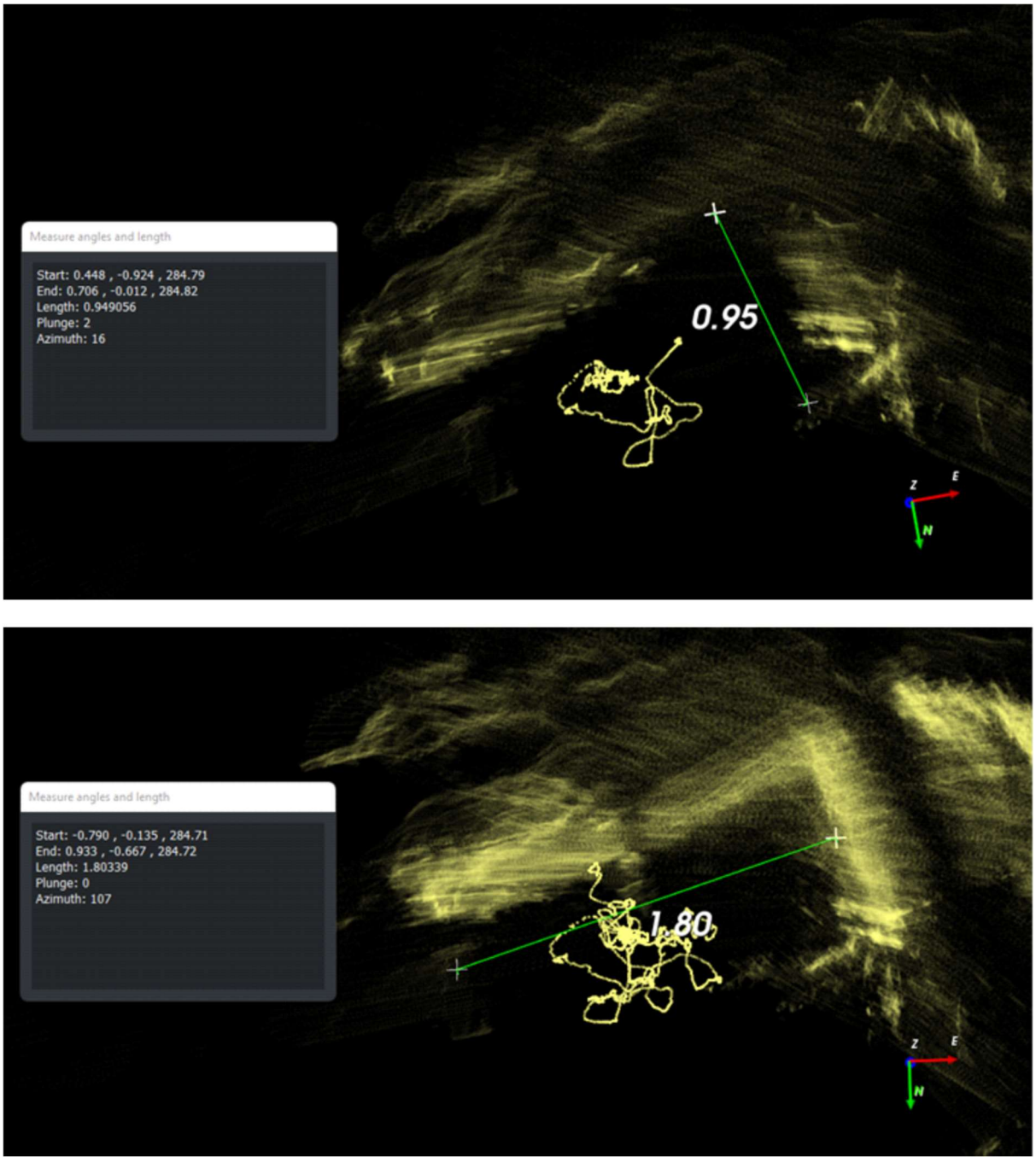

10. Figure - The dimensions of the shaft (in metre) at ~285 m water depth

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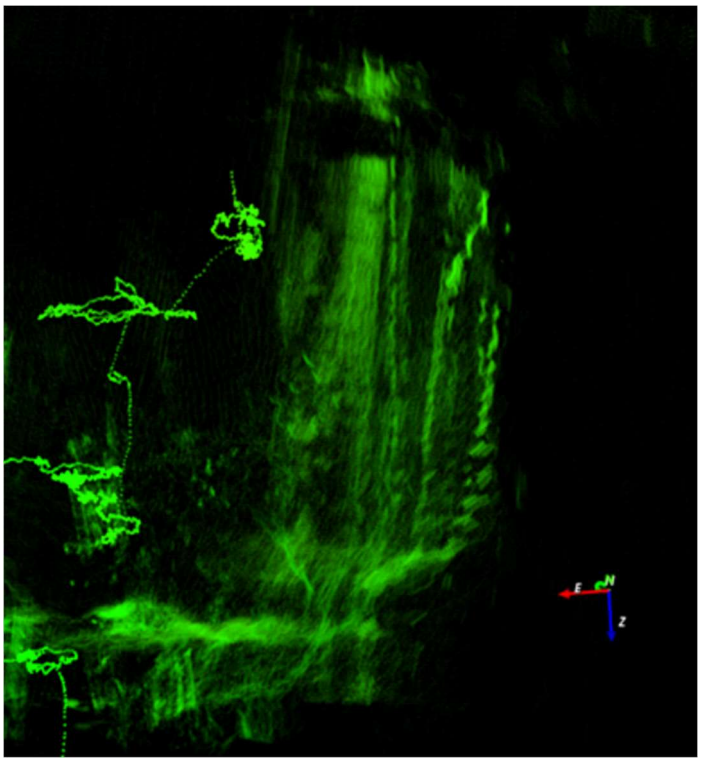
The closed gate and the dimension of it also can be seen on the sonar images (**Figures 10–13**).



11. Figure - The view of the gate at an angle

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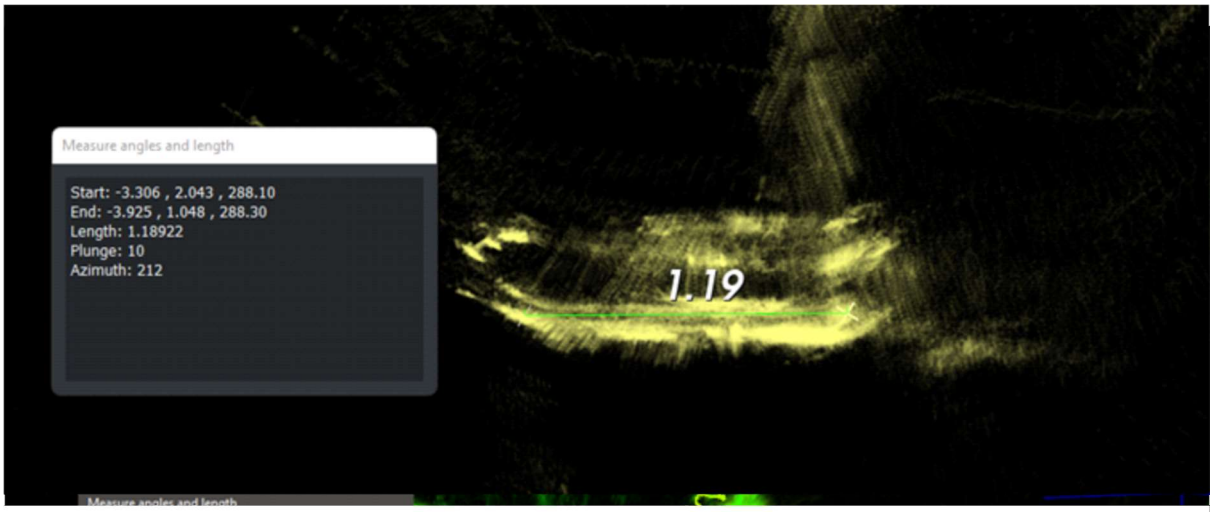
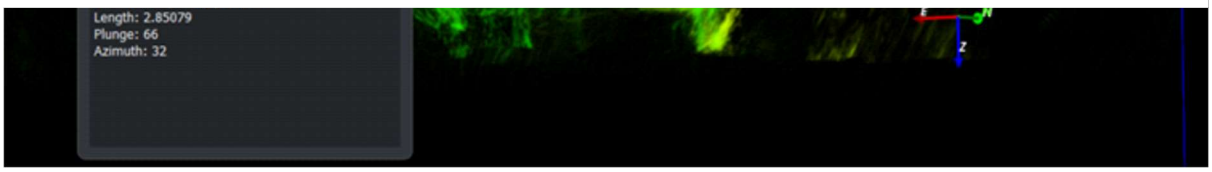


13. Figure - Measurement of the approximate width of the gate in metre - top view



12. Figure - The estimated height of the gate in metre

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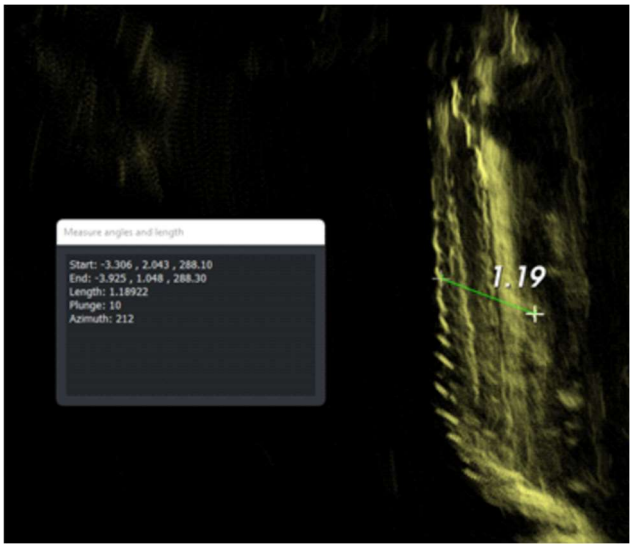

14. Figure - Measurement of the approximate width of the gate in metre - angle view

5.3. Water parameter measurements

Continuous water parameter measurements were taken during the dive. The water parameter measuring sensor collected data on temperature, pH, depth and electrical conductivity every second. The collected raw data and the calculated electrical conductivity values (in μS/cm) are also uploaded.

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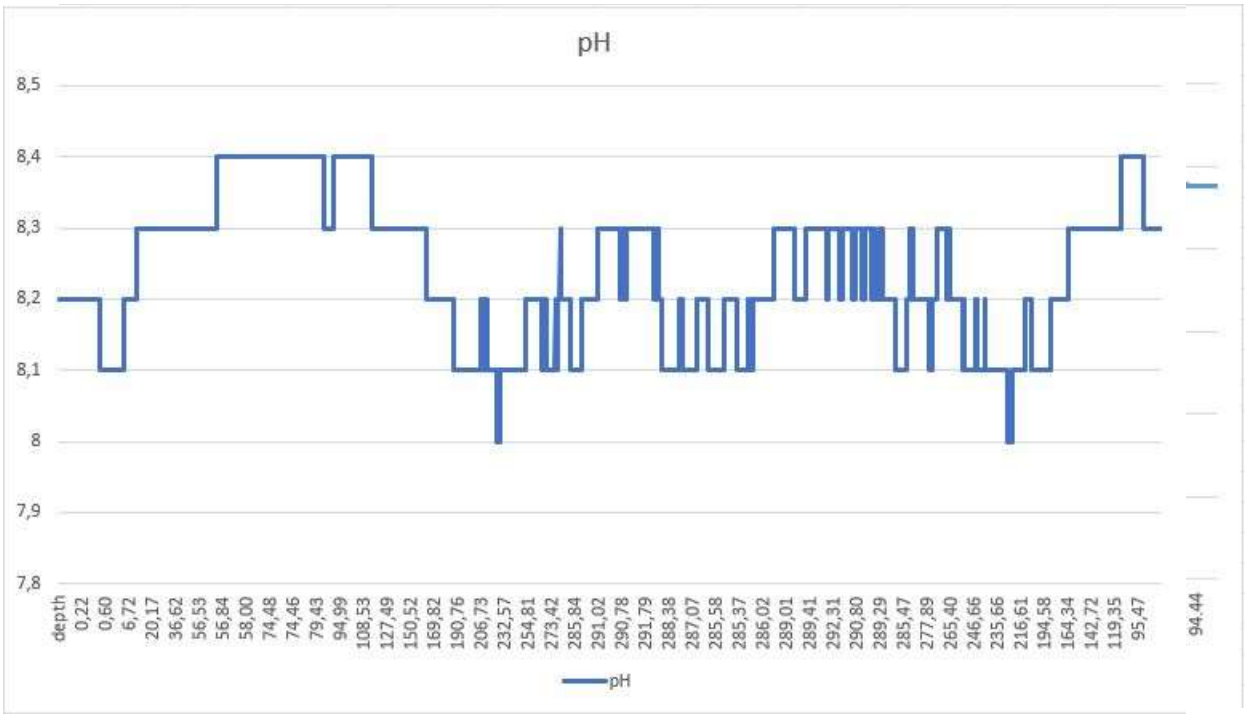
The results of the measurement can be seen on Figures 14–17.



16. Figure - Graph of the pH of the water during the dive

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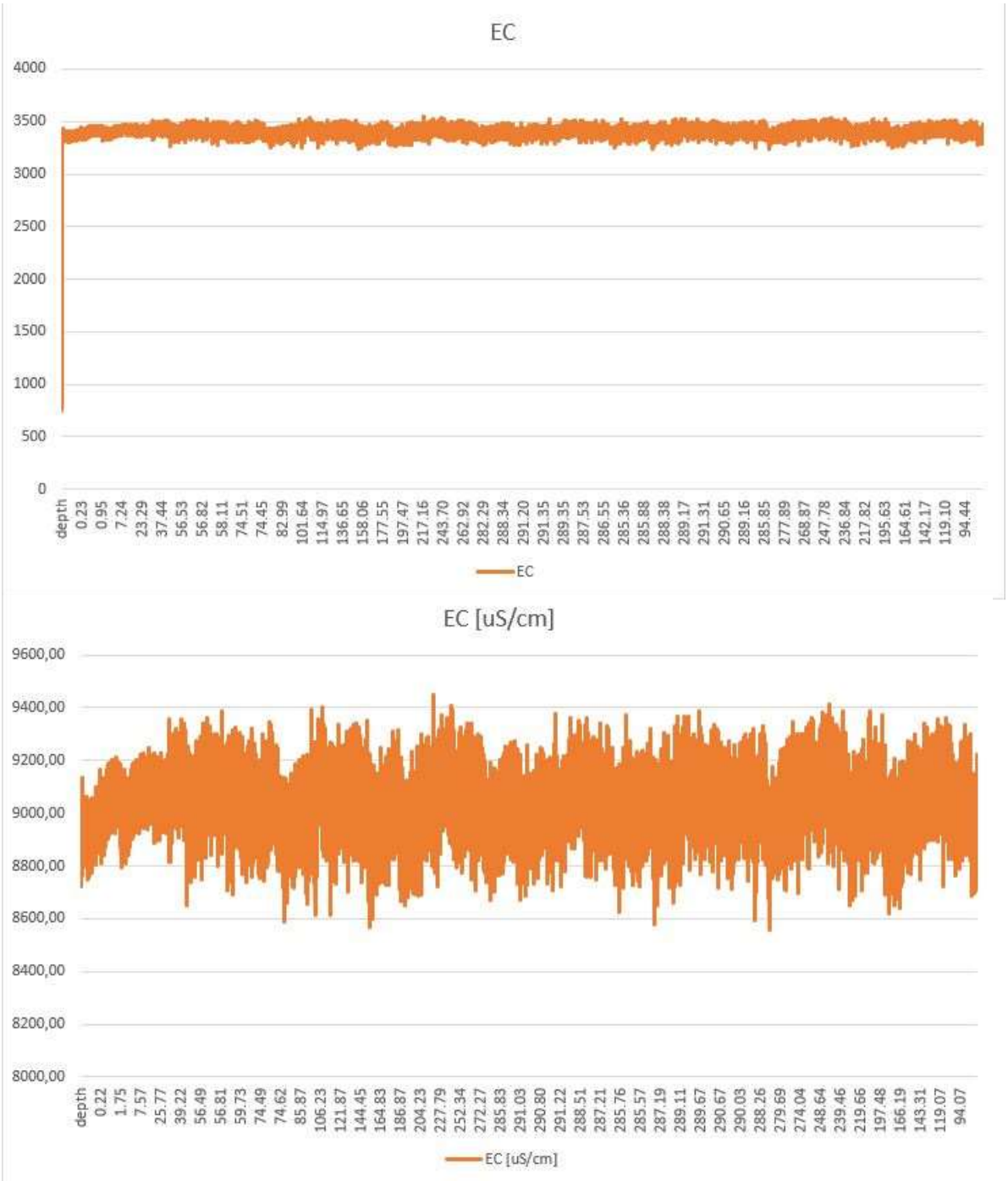

17. Figure – The change of the electrical conductivity (in µS/cm) during the dive (without the first value)

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The statistical values of the measurement can be seen on the Table 1:

1. Table - The statistical values of the water parameter measurements

	Min	Max	Average	Median
pH	8	8.4	8.24	8.2
EC [µS/cm]	1452.2	9447.4	9038.6	9043.2
Temp	19.34	24.34	23.96	23.97

The water parameter data show that the chemical parameters remained constant during the dive. Only the data measured on the water surface show different values for electrical conductivity as well as temperature. This may be due to the large amount of water flowing in from the surface.

6. Conclusion

As a result of the robotic exploration at the South Crofty mine, the primary objective of the mission was reached and the New Cooks Kitchen shaft was examined up to 292 m water depth. During the dives, the entire structure of the shaft and the wooden beam inside were intact. The sonar survey in the shaft and its analysis show the dimensions of the shaft were the same up to the examined depth of 292 m, with noticeable deviation.

With the help of the UX-1Neo robot, the “195 fm pumping station” was surveyed according to local conditions. Access to the level of the pumping station is not possible because the metal gate at the entrance is closed. In order to collect as much data as possible, the robot was used to explore the entrance and its immediate surroundings. Photographs and sonar images taken of the gate and the results of other measurements are included in this report.

During the robotic exploration, continuous water parameter measurements were performed. The pH, electrical conductivity and temperature of the mine water have been recorded, the results of them are also included in this report.

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Annex 2: Ecton Mine geology and archaeology

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Diving to Depth at Deep Ecton Mine: The Flooded Workings Revisited in 2021-22

John Barnatt, Steve Henley and Richard Shaw

Summary

In May 2019 there were explorations at depth in the Deep Ecton Mine's 300m deep flooded workings using prototype robots designed by the European UNEXMIN project team for exploration of flooded mines; the results were included in the project's online technical report and reported in Mining History. UNEXUP, a follow-on project designed to develop a new version of the robot for commercial use, is now in its third and final year and in March 2022 two new dives were undertaken at Ecton.

The team was in Britain to carry out a commercial dive for a mining company in Cornwall and this allowed them to come to Ecton before returning home. These dives, as well as testing a new robot based on the lessons learnt from testing the first prototypes, allowed uncertainties over the orientations of features recorded at Ecton in 2019 to be resolved, which had resulted from limitations in the reliability of the original navigation instrumentation. Also, the dives were undertaken using the robot in nose-down mode; this had not been possible in 2019 because a leak in the hull let in water at depth due to the pressure and being nose-down resulted in the shorting-out of electrics. Nose-down mode allowed the robot to be steered in a more refined way and thus shaft walls and obstacles such as timberwork could be more successfully avoided. Therefore very little sediment was disturbed and visibility at depth was transformed. We now had clear views of the passage walls rather than having to peering through the gloom in sometimes near-zero visibility. The downsides of exploring rapidly nose-down are that exact depth of features to the passage sides were harder to assess from the robot instrumentation and sometimes small features in the shaft corners were missed as they did not appear on the cameras. Also, it was not always easy to identify the direction of view, as the recorded orientation could change rapidly with only slight differences in pitch and roll angles.

The 2022 dives were still not without other technical limitations; the prime one being that the robot could still not be used in autonomous free-ranging mode and it was therefore still attached to an umbilicus to surface. Thus, as in 2019, only short horizontal stretches of passage could be explored without running the risk of fatal tangling of the cable around obstacles such as 18th and 19th century iron wall hooks and debris on floors. The result was that the 2022 UNEXUP dives for the most part consolidated what we learnt in 2019 rather than undertaking significant explorations that entered new parts of the old workings.

An unanticipated hazard was also encountered. In 2019 we had seen what we interpreted as a diver's line in the winding shaft remaining from a 1960s exploration when a diver died. This proved not to

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be the case and the 'line' was a *c.* 2mm diameter nylon fishing line that someone had presumably used to plumb the shaft depth from surface. While we encountered no problem with this line in 2019, in 2022 it got wrapped around three of the thrusters and the robot had to be hauled out manually to cut away the tangled mess before returning it to the water to complete the dive objectives.

One dive was undertaken in the main pumping shaft, the other, in the two halves just noted, was in the nearby winding shaft. The launch platform in the 'main pipe workings' was not used because analysis of the 2019 dive data discovered that one side opening in the winding shaft was a window at about -53m depth that led straight into the massive pipe-chamber that extended from about -22m to -58m below the '*Deep Ecton Level*' horizon; this provided an easier route to reach beyond the point where we had turned around previously. The passages were recorded by five cameras and sonar survey equipment, all built into the robot, and these allowed initial assessment and decision making as to where to go to be done in real time via monitors in the control room at the Ecton Education Centre. Videos made from the multitude of photographs, taken automatically by the cameras as the dives proceeded, allowed detailed assessment of the geology and archaeology.

In the pumping shaft three 'side pipe workings' in the *c.* 20m above the current blockage, the latter at about -127m down, were looked at properly for the first time as previously they had only been glimpsed in the gloom; we now know they are choked or in one case only small. Another 'side pipe working', at about -93m down the shaft that was entered in 2019, proved to be larger than previously thought, running away from the shaft for about 12m, with two potential links to unexplored workings at the top. Returning to near the bottom of the accessible part of the shaft a miner's 'inscription' was seen and this is the first we have found during dives and it comprised large number '2' picked into the shaft wall.

In the winding shaft two 'side pipe-workings' at depth were entered for a second time but with only new detail found rather than important discoveries made.

The main event during the UNEXUP dives was an exploration on 23 March 2022 of the massive pipe-working chamber first seen in 2019 where the original exploration ended at a walled hole in the floor going down to a 'cross cut' to the winding shaft with its floor at about -59m down, although upon analysis of the dive data it could be seen that the 'main pipe workings' continued northwards for some distance. This time we entered the 'main pipe workings' through the winding shaft window and continued the exploration northwards rather than go down to the 'cross cut'. We found that at the NNW end of the main chamber, not readily interpreted on the 2019 sonar data, there was a narrow but tall 'stope-like' passage going on to the north-west. This was followed for some distance before the dive team decided that discretion was needed because of the umbilicus and we left an open lead for when an autonomous free-ranging robot can be used. Also near this end of the main chamber there were 'side pipe workings' that linked back to the pumping shaft.

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Other dives have also been undertaken at Deep Ecton in 2021-22, led by Steve Henley of the Ecton Mine Educational Trust and Tim Rhodes of Highland Technology Services Ltd, using a small off-the-shelf, remotely operated vehicle (ROV), with a single forward-looking camera and umbilicus. These dives visited the upper part of the 'main pipe workings' in September 2021 and the North Winze in March 2022. In the upper part of the 'main pipe workings' one large 'stope-like' passage not entered previously was explored down to *c.* -27m at its WNW end and left as an open lead; various side passages were also explored. There was a NNW/SSE 'cross cut' running at roughly right angles near the end of the large 'pipe working' just mentioned. It originally crossed this 'pipe working' near its roof on what was probably a plank bridge at about -15m; one chain handrail and fittings for a second remain. This 'cross cut' came from roughly the direction of the South Winze in the striking chamber south of the 'main pipe workings', but the passage has not been explored in either direction; it may be part of a stepped ladderway, shown on an 1858 mine elevation, that went down to the '*Boat Level*' at -62m but this has yet to be confirmed. In the North Winze, a rubble floor was found at -19.5m depth, with very short trial 'levels' just above here leading off on the eastern and western sides. There were large timbers at the present shaft floor that had fallen from above and the rubble infill here prevents assessment of the original shaft depth.

Introduction

Deep Ecton Mine: This mine, near Warslow in the Peak District part of Staffordshire, was one of the most important copper mines in Britain in the 18th century. Today there are large flooded workings that extended down to about -320m below the river-level horizon by the 1850s; this a little over 100m below sea-level. Until 2019, these water filled passages had not been seen since the later 1850s after the mine pumps were stopped; the one exception was several decades ago, when a diver unfortunately got into difficulty and died. In 2019 very different dives in the 'main pipe workings', the pumping shaft and the winding shaft started exploring the underwater remains using an underwater robot (Fig. 1); further work has now been done using an new underwater robot, supplemented by further dives using a commercially available remotely operated vehicle (ROV) in 2021 and 2022; this included a dive in a fourth dive site at the North Winze. All dives were facilitated by the Ecton Mine Educational Trust, allowing exciting opportunities to safely go into workings.

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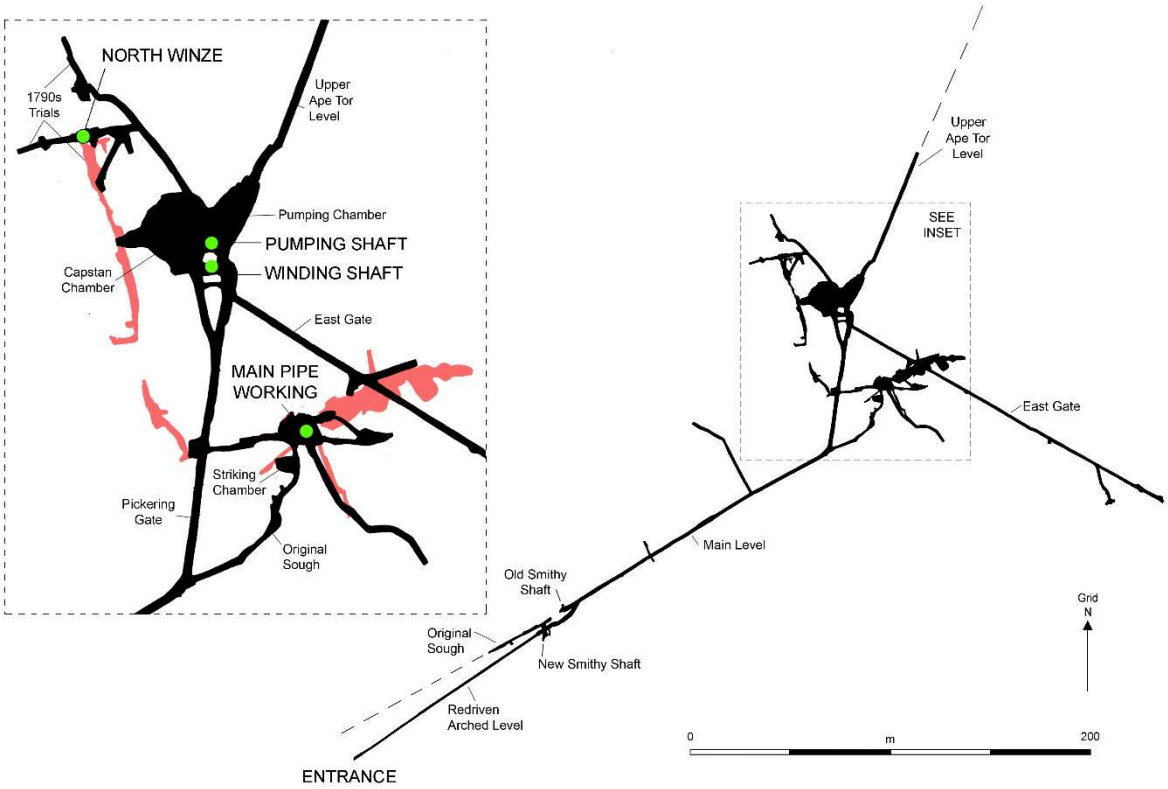

Figure 19 The Deep Ecton Mine workings at the river-level horizon (black) and those above up to but not including 'Salts Level' (red), with an inset showing the workings in the vicinity of the four submersible launch sites (green).

The 2019-22 Dives and Previous Reports: Details of the submersible robots used in 2019 for diving at Ecton and technical and logistical summaries have been published (UNEXMIN 2019; Shaw 2020). The geology, mineralisation and archaeology were covered in detail in the final UNEXMIN report (Shaw 2019; Barnatt 2019) and in Mining History (Shaw 2020; Barnatt 2020).

While the primary aim of the 2019 dives was to test the two prototype robots, we were also able to explore workings for which our prior detailed archaeological and geological knowledge was minimal. The most useful source of historical information on where now-flooded features were likely to lie was an 1858 detailed but schematic section through the workings (Fig. 2; Meads 1858). One thing that was obvious once the dives started, as long suspected, was that this 19th century drawing shows everything on the same plane but in fact there is a conflation of features that in reality are commonly in front of and behind each other. A classic example of this is the two main shafts, which are mostly sunk through bedrock close to but not within the 'main pipe workings'.

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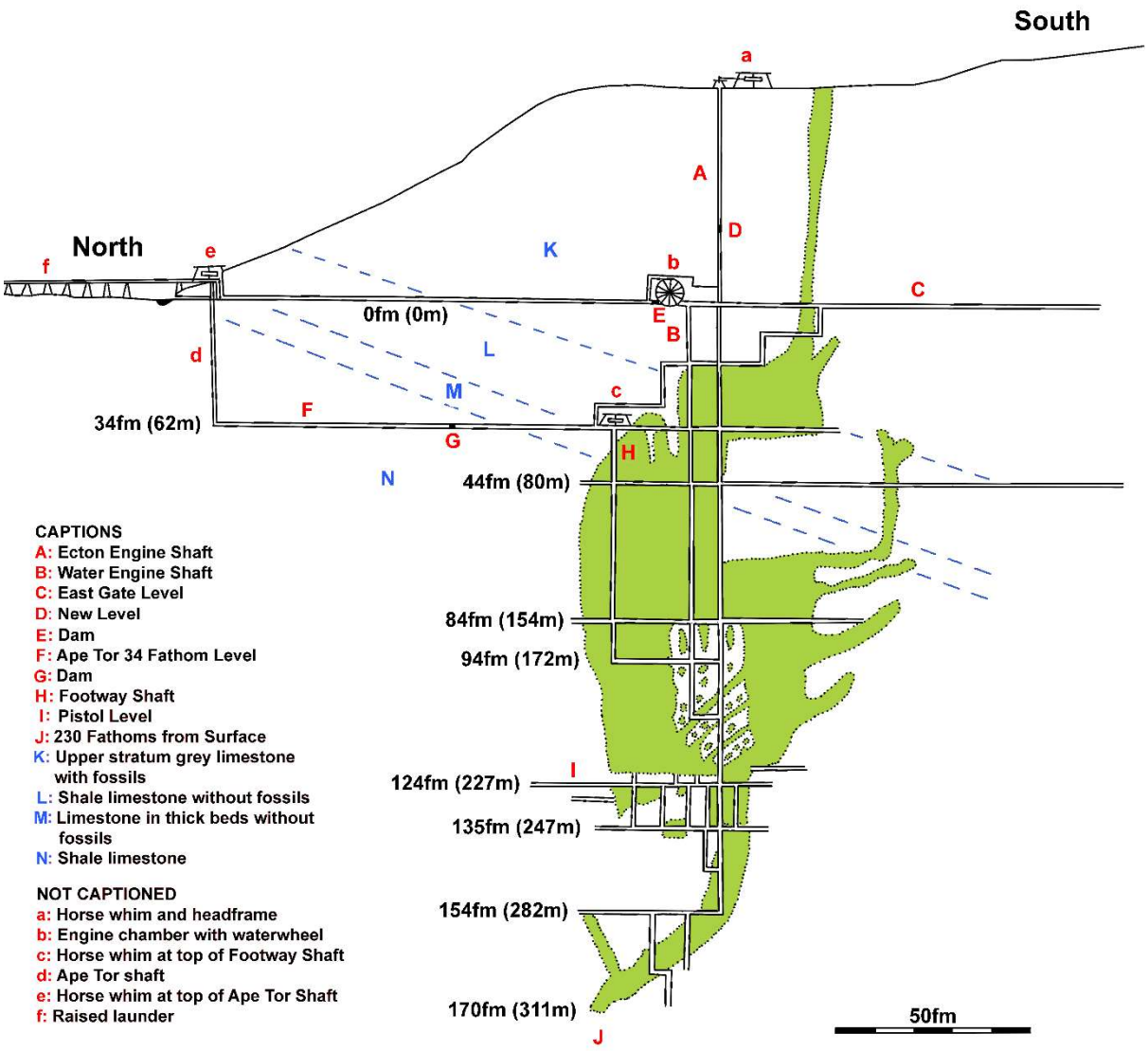

Figure 20 The detailed mine section of Deep Ecton Mine drawn by Meads in 1858, redrawn here for clarity; the shaft named the 'Ecton Engine Shaft' by Meads is what we refer to here as the winding shaft, while Meads' 'Water Shaft' is the pumping shaft.

During the ten dives undertaken in 2019 there was only time for less than 10% of the recorded workings to be entered (see Fig. 3). Explorations concentrated on the accessible part of the pumping shaft, while the winding shaft and the upper parts of the massive 'pipe workings' in the mineral deposit were also entered, with one dive at the former and two at the latter.

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Fifteen open leads were left in 2019 and some of these were explored in 2021-22. While important details were added to our knowledge in the most recent dives we have still not as yet entered vast mined '*opens*' at depth, Similarly, an underground 'canal level' at about -62m down with a third deep shaft going downwards from here have as yet proved elusive.

The three authors of the current report wrote this on behalf of the Ecton Mines Education Trust and the UNEXUP project.

The Documented History of the Now-Flooded Deep Ecton Workings (JB): The documented history of the Deep Ecton workings has been published previously (Robey and Porter 1972; Porter and Robey 2000; Barnatt 2013); mining on Ecton Hill in prehistory and the 17th century AD was all above the river-level horizon and is not discussed below. The development and extent of those parts that are now flooded was reviewed in detail after the 2019 dives (Barnatt 2020); this report should be consulted for a detailed appraisal of the character and development of the mine in the 18th and 19th centuries.

What follows is a brief historical summary to contextualise the 2021-22 dives reported here, with only those parts explored in 2019-22 given emphasis.

The 'Main Pipe Workings' in the 1740s to the 1820s

Post-medieval mining at Deep Ecton first took on great importance in the 1723-60 period when two successive companies of '*Adventurers*' developed the mine; previous work from the mid-17th onwards had been relatively small in scale and confined to the ridgetop. The '*adventurers*' eventually made exceptionally rich discoveries of ore. These were located around the river-level horizon and were probably first found in 1740-43. They continued to work downwards into the 1750s, with ore output increasing markedly again from 1752, perhaps reflecting work going northwards in the deposit for the first time in the area where a large chamber in the 'main pipe workings' was explored in 2019 and 2022. Here the mineral deposits reached huge proportions compared with what had already been found above, which in themselves were already large.

The workings in the Duke of Devonshire's Liberty, which primarily comprised Deep Ecton Mine, were taken in-house by the Fourth Duke late in 1760 after the '*Adventurers*' second lease expired. He chose not to renew this but to have the mines worked by his own miners, overseers and agents. Deep Ecton Mine made a massive amount of money for the Dukes of Devonshire from 1760 until 1790, but the mineralised 'pipe deposit' was noted as having '*failed*' at depth in the latter year.

By 1759, after work in the 1740s-50s, the 'main pipe working', which became significantly larger as it went down, had been worked to somewhere between about -30fm (-55m) and -35fm (-65m) below the river-level horizon. In the early-1770s the 'pipe workings' had reached about -80fm (-146m) below the river-level horizon. By 1790 the main 'pipe' mineralisation was found to be

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restricted in size from about -120fm (-220m) downwards. Trials below here from this date onwards failed to find sustainable economically-viable deposits.

Although much reduced compared with previously, from 1790 into the second decade of the 19th century, relatively large amounts of ore were still produced at Deep Ecton Mine (Porter and Robey 2000, p. 105). However, given the expense of raising this, eventually the mining here was running at an untenable loss and in 1825 the Sixth Duke wound up this Estate venture, presumably because they had run out of good leads to follow. As is often the case in mining, after the best was gone, they had made the mistake of spending large sums searching for further rich deposits around the next corner.

Pumping Shaft

Prior to the creation of this shaft in the 1780s water was brought out of the workings below the river-level horizon using hand-operated pumps to bring it up from the then sole of the mine. From the 1760s water ran along a 'canal level' at -34 fathoms (-62m) and from its end it was raised in barrels up a shaft using a horse-drawn '*whim*' engine at Apes Tor at the northern end of Ecton Hill. As the mine got deeper water would have been brought up to this 'level' using hand pumps and from c. 1780 an underground horse-operated whim engine was also used.

In 1780-84 they developed radically new mechanised pumping arrangements for water from the sole of the mine. They sank the '*Great Shaft*' from a new chamber at the river horizon deep under the ridgetop that was accessed via '*Deep Ecton Level*' at the river horizon; this is the shaft where dives took place in 2019 and 2022. The primary purpose of this pumping shaft was to house the pumps and their '*pump rods*', together with the '*rising main*' (water pipes) for bringing the water up to the river horizon; a water powered engine, or possibly two, were installed in a chamber here to operate the pumps below. As the mine continued downwards, the shaft was deepened three times between 1786 and 1795, and it was last used in the 1850s.

Winding Shaft

Prior to the creation of this shaft ore was brought out of the workings below the river-level horizon using hand-operated 'stowces' (windlasses) to bring it up from the then sole of the mine. In the 1760s and early 1770s it was also taken along a 'canal level' at -34 fathoms (-62m) to be raised in barrels using the horse-drawn '*whim*' engine at Apes Tor.

The main winding shaft, which comes down from surface high on the ridge top, was sunk to depth in 1767-73, to a point close to the then sole of the mine; this shaft was explored using submersible robots in 2019 and 2022. At first the winding was undertaken using a large horse-drawn '*whim*' engine at the ridge top but from late in 1788 there was a steam-powered winding engine operating here that was designed by James Watt and built by the Birmingham firm of Boulton and Watt. This shaft was the main winding shaft at the mine from 1773 and was used to bring ore from depth up to

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the river-level horizon. It was deepened twice between 1787 and 1791, and was last used below the river-level horizon in the 1850s.

The North Winze

Extensive trials in the Deep Ecton Mine in the 1790s, undertaken after the main ore deposit 'failed' at depth, including work at and below the river-level horizon that involved stripping back the sides of working; these did not find any large ore deposits. The 1790s trials also included work near the 'main ore workings', comprising the sinking of the poorly-documented North Winze from trial passages at river-level horizon and also possibly further exploratory passages at the bottom of this shaft.

The 'Main Pipe Workings' from the 1820s to the 1850s

The search for ore from the 1790s onwards by the Duke of Devonshire's miners came to nothing as new rich ore deposits in Deep Ecton Mine were just not there. In 1823, at a time when the Duke's miners were running down their activity, and in advance of letting the mine as a leasable concern, the old water-powered beam engine (or engines) at Deep Ecton Mine was replaced by a large waterwheel to operate the pumps below. The capstan/horse-drawn engine nearby, also located deep underground at the main pumping shaft 'collar', was probably also replaced with a new shorter-armed capstan.

The reputation Ecton Hill gained because of the 18th century success of Deep Ecton Mine attracted investment in speculative ventures across Ecton Hill throughout much of the 19th century from the mid-1820s into the 1880s. The investment was fuelled by past glories, with people hoping to make their fortunes when the fresh ore deposits that they thought were bound to be there were discovered. All private investors were to be disappointed and collectively they lost significant sums of money, although on the positive side the ventures kept miners in work.

Even though Deep Ecton Mine was no longer viable as a large producer, from 1826-27 to 1855 a series of mining companies worked here, using money from partners or shareholders who invested in the ventures. They worked at a much-reduced scale of operation than previously, with far fewer men. This included poorly documented work done deep down in the 'pipe workings', recovering metal ores from what must have been poorer ore deposits than worked previously. However, by the early 1850s all hope of profitable working in the old mine at depth must have been given up. In 1855, after they had failed to find investors to work here, the Ducal Estate finally turned off the pumps and let the workings flood.

The 2019 Deep Ecton Mine Dives: Discoveries and Observations

This section reviews what was learnt in 2019 and how this added-to, altered or confirmed previous interpretations of Deep Ecton Mine. The locations of the passages entered are given on Fig. 3.

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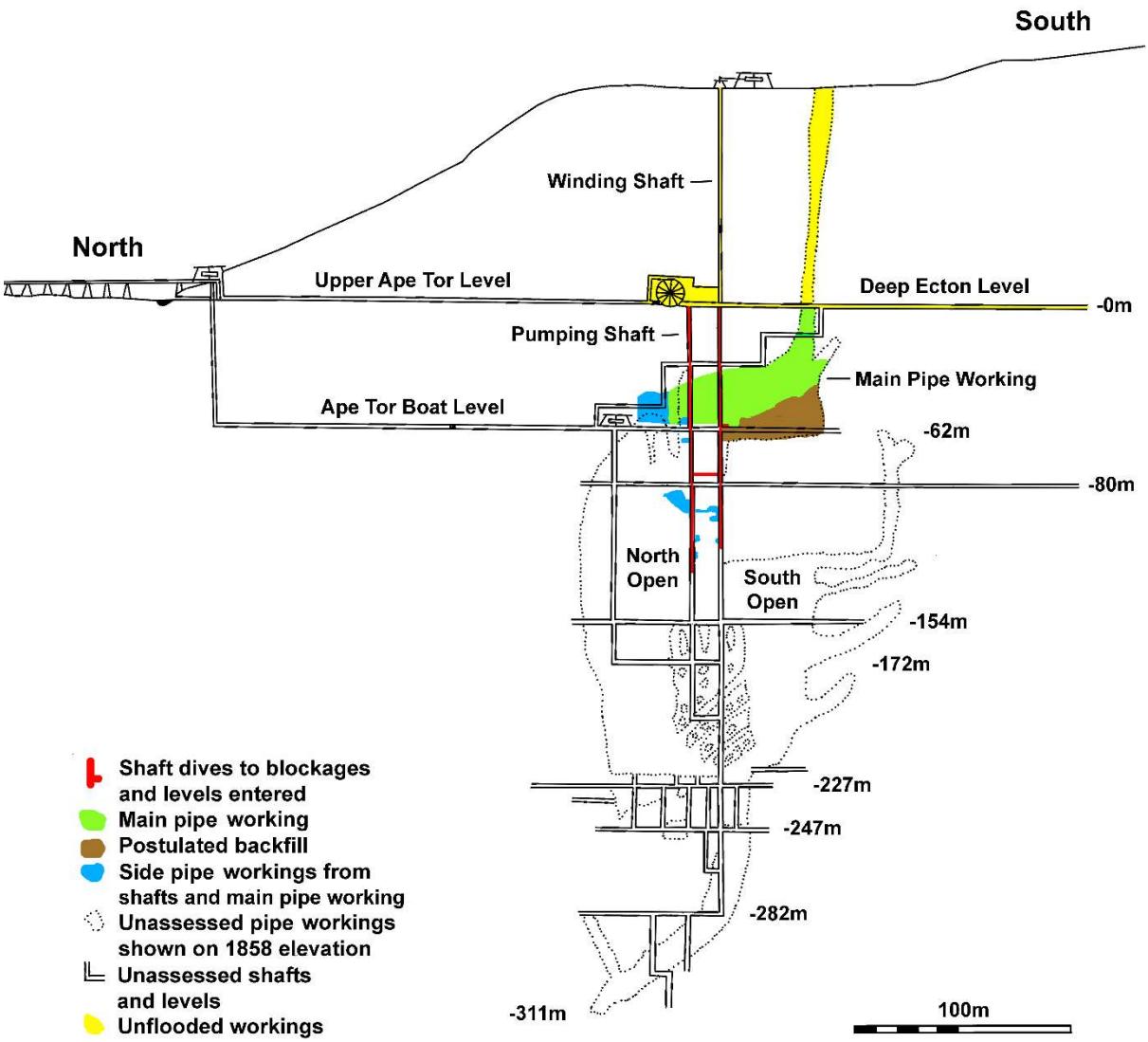

Figure 21 The approximate extent of passages explored and/or plotted by the sonar survey during the 2019 dives at Deep Ecton Mine (with the depiction of the 'side pipe workings' revised from the 2000 report to match the 2022 discoveries). These are superimposed on the schematic 1858 mine section drawn by Meads, with feature names, recorded depths of 'levels' and a metric scale added.

The main pumping shaft was explored down to a blockage at *c.* -124m to -127m, while the winding shaft was choked at *c.* -112.5 to -113.5m. These shafts are sunk through contorted bedrock, where the bedding was often near-vertical, but with the tops and bottoms of folds also seen. Both shafts had horizontal miners' 'levels' leading off their sides at various depths, some as 'cross cuts'

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connecting the two shafts, others going elsewhere. The two shafts also accessed complex groups of irregular mined cavities termed here 'side pipe workings' found at two broad horizons. In the pumping shaft there were various substantial timbers, thought to be for helping retain the now-removed 'pump rods' and 'pump pipes', entrances to 'levels' and perhaps also ladders. Also at the pumping shaft there is a passage with a walled 'dam' at its entrance that looks to have been designed to hold back water.

In the 'main pipe working', entered in 2019 from a launch site in a chamber at the river-level horizon, a route through convoluted passages led vertically downwards to a second and larger chamber with highly irregular sides starting from about -22m, where the robot descended straight down to a little under -40m. This chamber was massive towards the bottom, measuring roughly 20m across, with the roof of this 'pipe working' extending NNW beyond where the cavity came from above. Below -40m this working, at its SSE end were the robot came down, had been backfilled with mine waste. However, a route on, starting above this fill and going NNW, led diagonally down via three low retaining walls holding back stone dumps. The second and third walls lined a large pit. Here, at its bottom, a short 'cross cut' with a floor at -58.5m was entered that led to the main winding shaft. The large 'pipe working' chamber continued NNW beyond the pit, as shown by the sonar plots, but was not explored until 2022.

No intact miners' timber working-platforms remained in the 'main pipe workings', but on the rubble floors there were scattered displaced timbers. There were also such items as moved iron tramway rails. It is thought that after the mineral deposit failed at depth, from about 1790, the miners systematically stripped back the 'pipe working' walls searching for missed ore deposits leading off. It seems they worked their way upwards from the bottom, dropping the material being removed into workings already searched. Thus, they smashed timber working platforms below as they went, and partially backfilled the old workings, hence the massive heap of material encountered below -40m depth in the second explored chamber where the backfill is probably over 25m deep at the SSE end.

Geology (RS)

What we knew by the end of 2019: The 2019 UNEXMIN explorer dives at the Deep Ecton Mine provided a significant amount of information on the geology of the flooded mine workings (Shaw 2020b). This includes observations on the stratigraphy, structure and mineralization of the ore deposit and surrounding host rocks.

The main findings of the 2019 exploration were:

- The 'main pipe working' greatly increases in size a short distance below current water-level horizon;
- Where of large size the 'main pipe working' appears to have developed in more thickly bedded limestones, probably mainly reef knoll facies, of the Milldale Limestones that may

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be one of the main controlling factors in the development of the ore deposit because they provided a favourable host rock for mineralisation.

- There is extensive development of least two and sometimes more than three phases of early, pre-main phases of ore mineralisation, each comprising hydraulic fractures filled with white calcite in proximity to the 'pipe deposit', which are likely to be precursor events to the main pipe mineralisation development and infilling.
- The structural geology of the mine is complex especially in the core of the Ecton Hill Anticline in which the pipe mineralisation is developed.

Questions still to be addressed: Three main geological uncertainties remained following the 2019 dives:

1. It is known that the copper values in the ore deposit significantly decreased in the deepest parts of the mine. While only schematic the cross section of the workings produced by Meads in 1858 suggest that the 'pipe deposit' was reducing in size and perhaps splitting into several branches towards the bottom of the mine (the same happened at about the same depth in the adjacent Clayton Mine where they worked similar 'pipe deposits'). While it is unlikely that the beds below the Milldale Limestones were reached by the workings it is possible that more thinly bedded, perhaps more shaly, limestones are present at depth which did not provide as good a host for mineralisation. The 2022 dives did not reach greater depths than the 2019 dives and this question remains unanswered.
2. The distribution of mineralisation within the 'pipe deposit' is not well understood. Only small amounts of mineralisation can be observed in the un-flooded mine workings and the 2019 and 2022 dives demonstrate that the miners thoroughly removed almost all of the mineralisation from the 'pipe deposit'. While 18th century mineral collections provide an indication of the mineralisation they are of mineral specimens collected because they were 'pretty' or unusual and do not provide a representative sample of the ore deposit within the 'pipe workings'. The 2022 dives, where visibility was better, have confirmed the thorough removal of mineralisation within the workings and details of the mineralisation within the 'pipe deposit' remain uncertain.
3. Both the Ecton and Clayton Pipes are located close to the axis of the Ecton Hill Anticline (Shaw 2022b). This is a complex asymmetric anticline that plunges to the north with a steeply dipping eastern limb and a more gently dipping western limb. The core area of the anticline comprises of numerous minor folds, for example those well exposed in the cliffs at Apes Tor just to the north of the mine, that often have an element of axial faulting associated with the concertina folding. There are also a number of minor faults exposed in the Deep Ecton workings with at least two faults present in the main 'pipe deposit' where intersected by '*Deep Ecton Level*' and a further two in the winding shaft striking chamber at the same horizon. All these faults are of small throw and their influence on the development of the deposit is uncertain.

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Archaeology (JB)

What we knew by the end of 2019: After the first set of dives were finished both main shafts had been entered but unfortunately the pumping shaft was found to be choked at *c.* -124m to -127m, while the winding shaft was choked at *c.* -112.5 to -113.5m. The 'main pipe workings' were explored down to a depth of -58.5m, and this included entry into a chamber from *c.* -22m downwards, that became massive at *c.* -35m, with a large dump of mining waste on its floor. There was a short 'level' linking the chamber to the winding shaft with a floor at -58.5m and a hole above where the shaft wall had been breached at *c.* -52m to -54m.

In the shafts there were 8-12 'side pipe workings' of various sizes (4-8 in the pumping shaft, 4 in the winding shaft). Some of these workings were earlier than the shafts, at least one was later. Similarly, there were 10-16 'levels' and 'cross cuts' leading off the shafts (5-10 in the pumping shaft, 5-6 in the winding shaft), including one explored that went between these two main shafts at *c.* -79m to -82m, with another at *c.* -26m to -27m that was suspected but not entered. In the pumping shaft there was a passage at *c.* -62m to -65m that had a stone-built dam at the shaft side that had originally retained water behind. Many of the side openings had iron pins, hooks and eyes near their entrances that may well originally have been used for fixing ropes or chains. In the pumping shaft there was timberwork associated with the support of the pumping '*pitwork*', for a postulated '*ladderway*', and for providing supports that retained the entrances to two 'levels'. Artefacts associated with the mining were rare except for displaced timberwork and tramway rails.

The bullet points that follow summarise what we had learnt about the interpretation of the Deep Ecton Mine flooded workings by the end of 2019 and are taken from the report produced at that time (Barnatt 2020, pp. 35-63). This is given here in slightly modified form to remove several specific details that were misleading as these have now been reinterpreted, with these details given below in the section on the 2021-22 dives. The dive videos, in combination with the sonar point-cloud data, allow the general layout of the two main shafts in relation to the 'main pipe workings' to be assessed, with the latter lying east of the former at depth. These relationships and the extent of areas explored are presented here as a schematic drawing using the mine section drawn by Meads in 1858 (see Figs. 3, 6).

<u>General Interpretation</u>

- As long suspected, the 1858 mine section drawn by Meads, while detailed, is in some ways schematic, especially with regard to drawing the workings in one plane rather than in three dimensions. The two main shafts were found in 2019 to be mostly sunk through bedrock and these lie to the west of the 'main pipe workings'. The same type of displacement may well apply within the 'main pipe workings' where different galleries are conflated by Meads as they lie in front of or behind each other. 'Side-pipe working' may have been ignored by Meads, or more probably were subsumed within the general depiction of the workings.

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- Once the problem of overlapping features is taken into account, there is a general approximate correlation between what Meads depicted in 1858 and what was explored in 2019. This has important implications for trusting the general configuration of 'pipe workings' shown in 1858 that have not yet been entered.
- Reappraisal after the 2019 dives of the historic documentation related to the 1760s '*34 Fathom Boat Level*' and the associated '*Deep Level*' at -62m, and their relationship with the two main pumping and winding shafts of the 1770s-80s, has led to revised interpretation. It has now been realised that the '*Deep Level*' certainly was never linked with the winding shaft, even via a 'cross cut', and this may also be the case with the pumping shaft. The 1767-1773 winding shaft was created to 'replace' the Ape Tor ore removal route, while the pumping shaft was created after the 'canal level' had fallen out of use as the main route for transporting ore to surface. Water removed via the canal after the main pumping shaft had been sunk to depth may have been just from springs within workings local to it. One implication of this re-interpretation for future explorations is that we may well need to find another way to access this important feature. This is especially so because it could be that the southern part of the -62m '*Deep Level*' was backfilled or became choked in the 1790s when the lower chamber in the 'main pipe workings' above was partially backfilled, thus a route entering it further north may well need to be sought.
- The observations made above have led to a more nuanced understanding of how and even if 'levels' and shafts throughout the mine were ever interlinked; in this respect the Meads' 1858 mine section may be downright misleading if taken at face value.
- Archaeological details previously recorded above the river-level horizon include a variety of iron pins, hooks and eyes at shafts and 'pipe workings'. Similar iron fittings were found in 2019 below the river horizon at the entrances to 'cross cuts' and other 'levels', and also at 'pipe workings'. These fittings relate to the use of these passages by miners, although just how they were employed is often unclear. Possibilities include attachment points for ropes, chains and ladders, or as handholds to facilitate entry or exit to these passages. In other cases iron pins were used to help keep structural timbers in place.
- Displaced narrow gauge iron tramway rails found in the parts of 'main pipe working' and the winding shaft that were entered, both created in the 18th century, are of 19th century date. Their presence possibly indicates a continuing presence by miners in the workings between -0.0m and -58.5m up until 1855 when the mine below the river-level horizon was abandoned. However, it is more likely that they fell from above, or they were dumped from old workings being trialled at and above the river-level horizon, thus they cannot be used as dating indicators in the workings explored in 2019.

<u>The Pumping Shaft</u>

A great deal was learnt in 2019 about the shaft itself down to the blockage at *c.* -124m to -126m (in 2022 the latter revised to -127m), the disposition of passages that lead off from the shaft, and details of the infrastructure installed in the shaft itself. The following points summarise what was known by the end of 2019:

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- The part of the shaft entered in 2019 was created in 1781-83 and the bottom of the initial sinking was only *c.* 2m below the present blockage; here there was '*a lodge*', a '*striking house…betwixt the shafts*', a '*dam*', a '*cistern*' and a '*level*' leading off to the '*vein*'. These were in use until 1792 when the shaft was deepened. Perhaps a platform and some of the fixtures were left in place, with these contributing to the present blockage.
- From its top to the blockage point the shaft had been mostly sunk through bedrock and it was of the same basic character throughout, created as large sub-rectangular feature in plan with vertical sides going to depth. Irregularities in the shaft walls resulted from how individual beds fractured. In some cases the rock needed cutting back somewhat to reach a point of stability.
- The shaft intersected previously unknown 'side pipe workings' at two different horizons. These may well have been (for the most part) linked with the 'main pipe workings', which at this upper part of the flooded passages probably pre-date the sinking of the shaft, created in the three to four decades before the main pumping shaft as sunk. Within some of these 'side pipe workings' there are passages leading off in the right direction for the 'main pipe workings' and none are certainly isolated from these (one at -115m to -117.5m was identified in 2022).
- Two 'cross cuts' to the winding shaft, one certain the other probable, were found. Neither was documented before 2019, although the presence of 'cross cuts' at depths unknown was previously suspected. Those found are interpreted as air-ways created when the pumping shaft was being sunk in the early 1780s. However, the lower one is also documented as being used for transferring ore from the pumping shaft to the winding shaft in 1786-88, in a short period when the former shaft was deeper than the latter and hence the ore from the bottom of the mine could not be brought up in one lift.
- There were other 'levels' leading off the shaft, or from 'side pipe workings' here, going to currently unknown destinations (with one detailed in the next point). These presumably went to various places in the 'pipe workings' rather than going to unknown shafts and 'levels'. Some lead off towards the 'main pipe workings' to the east side.
- One of the possible 'levels', at -62.5m to -65.0m, is particularly interesting as it has been carefully walled off as if to originally retain water behind it. The interpretation of this dam is far from clear and three potential explanations are apparent; these are given under the section on the 2021-22 dives.
- Various sturdy horizontally-placed timbers, all sawn and of rectangular cross section and some forming platforms, were found in 2019 at the two shaft ends, located at irregular intervals down this. An underwater timber and notches for others have long been observed close to the shaft top and these were reported upon previously and interpreted as defining three compartments in the shaft (Barnatt 2012; 2013). The 2019 dives confirmed that matching shaft-end timbers, and sites of others where the notches in the shaft sides remain, continued down the shaft; interpretation of these is given under the section on the 2021-22 dives.

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- From their appearance, the surviving sawn timbers in the pumping shaft look to be of high quality pitch pine. This partially explains their better survival compared with other timberwork both here and elsewhere in the flooded workings.
- It may well be that much of the timberwork in the part of the shaft seen in 2019 dated to documented installation of '*bunding*' platforms and '*lacing*' partitions in 1783.
- The character and distribution of artefacts observed in the pumping shaft in 2019, comprising displaced timbers, suggests these derive from the collapse of structures further up the shaft, or from the removal of features in the shaft by miners after they became redundant, at a points in time when timbers from these were placed in passages that were already disused.
- It is strongly suspected that the shaft below the choke at *c.* -124m to -127m has not been fully backfilled. It is highly unlikely that the shaft was purposefully backfilled once redundant, as it was in use until the 1850s and only small scale work was undertaken above the river-level horizon after that date. Rather, the blockage comprises material that has fallen from above when rubble fills collapsed from small areas immediately adjacent to the shaft at passages leading off. The shaft fill seen today may have come to rest on an obstruction at *c.* -128m; the presence of 1773 structures here has been noted above. The shaft below the blockage may well still be open as the likely size of collapse-features above is far from sufficient to completely fill the shaft below *c.* -128m.

The Winding Shaft

Again a great deal was learnt in 2019 during only a single dive about the shaft itself down to the blockage at *c.* -112.5 to -113.5m and the disposition of passages that lead off it. The following points summarise what was known by the end of 2019:

- The part of the shaft entered in 2019 was created in 1770-73 and sinking at this time went down to *c.* -137m; it was subsequently deepened in 1787-91.
- From its top to the blockage point the shaft is mostly sunk through bedrock and it is of the same basic character throughout, created as a relatively small rectangular feature in plan with vertical sides going to depth. Irregularities in the shaft walls resulted from how individual beds fractured, where in some cases rock need cutting back somewhat to reach a point of stability.
- No places were found in the parts of the shaft accessible in 2019 that had chambers designed to load ore into 'kibbles' for transporting this up to the river-level horizon above. The historical documentation would suggest there were two of these loading points at greater depth, at about -128m and -137m and created respectively in 1784 and 1773; the 'pipe workings' above here were largely worked out before the shaft was sunk. No discoveries were made above the *c.* -112.5 to -113.5m blockage that would refute this. This said, it is documented that for a short period, in 1786-88, ore was loaded into 'kibbles' in the winding shaft at *c.* -81m after being brought via the 'cross cut' here from the pumping shaft; there is no 'striking house' here, demonstrating that recognizable archaeological structures need not be present for ore loading to have taken place.

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- The shaft intersects previously unknown ‘side pipe workings’ at two different horizons. These may well have been linked with the ‘main pipe workings’. This upper part of the flooded workings was created in the two to three decades before the main winding shaft was sunk; none of the passages are certainly isolated from other workings and they may all predate the winding shaft. One of the ‘side pipe workings’ intersected by the shaft has surviving timber working platforms and other timbers that held up part of the roof, while another working has probable collapsed remains of a further platform.
- Two ‘cross cuts’ to the winding shaft, one certain the other probable, were found, neither documented before 2019, and these are covered above under the pumping shaft heading above.
- In the winding shaft sides the uppermost ‘cross cut’ just noted has a rock-cut ‘garland’ channel above it that took water from here into this horizontal passage, with the ‘garland’ created to divert water running down the shaft walls in order to help keep the hemp winding ropes dry and thus reduce their weight.
- Another ‘level’ or ‘cross cut’ was identified that led to the ‘main pipe workings’ with a floor at -58.5m and there is also a breach in the shaft wall a short distance above, where the shaft clipped the side of a pre-existing ‘alcove’ in the ‘main pipe working’. Both are described under the ‘main pipe workings’ heading below.
- There were also other ‘levels’ that led from the shaft and ‘side pipe workings’ to currently unknown destinations, presumably at various points in the ‘pipe workings’ rather than going to unknown shafts and ‘levels’.
- In the lowermost part of the accessible shaft there were several lengths, some long, of small-diameter metal pipe, one with a flanged end; all have fallen from above. These may well have originally been parts of one long pipe and a possible interpretation is that they belong to the documented pipe that brought water up the winding shaft to the 1788 Boulton and Watt steam winding engine on the ridge top for use in its boiler.
- The character and distribution of other artefacts observed in the winding shaft in 2019, many comprising displaced 18th or 19th century timbers and 19th century tramway rails, suggests these derive from collapse of structures further up in the workings, probably above the river-level horizon. Other artefacts seen may well be modern, also dropped down the shaft from above, but with some or all probably coming from surface before the shaft was capped.
- It is strongly suspected that the shaft below *c.* -113.5m has not been fully backfilled. It is highly unlikely that the shaft was purposefully backfilled once redundant, because it was in use until the 1850s and only small scale work was undertaken above the river-level horizon after this date. The blockage may well comprise material that has fallen from above, when rubble fills collapsed from small areas immediately adjacent to the shaft at passages leading off, either in the flooded part of the shaft or from above river-level horizon. This rubble presumably came to rest here on an original platform or another obstruction a short distance below *c.* -113.5m; the shaft below the blockage may well still be open as the likely size of collapsed features above is far from sufficient to completely fill the shaft below.

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The ‘Main Pipe Workings’ and ‘Side Pipe Workings’

While much was learnt in 2019 in the explorations down to -58.5m during two dives, poor visibility in the large passages meant that it could have been that some features were missed altogether. The following points summarise what was known by the end of 2019:

- The core parts of the ‘main pipe workings’ entered in 2019 were probably created in the 1740s to 1760s, but these were significantly modified in the 1790s when the walls of the old working were stripped back to bedrock in a search for new ore deposits. Much of the ore initially mined from here is likely to have been taken to river-level horizon using hand windlasses as the workings at this horizon predate the main winding shaft.
- What is not clear in the 1769-70 accounts, nor on the Meads’ 1858 drawing, is that there is an area between the two chambers explored in 2019, between -11.5m and -22.0m, which comprises a convoluted section of ‘pipe workings’ with many interconnected passages where bedrock has been left *in-situ* between them. The 2019 sonar plots did not readily identify individual passages except for the way down that the robot took. This ‘overlapping’ of individual workings, when compared with the single passage shown by Meads, has implications for the ‘pipe workings’ at depth that have not yet been explored; there may well be other similar areas here.
- The dives of 2019 showed that in addition to the ‘main pipe working’ chambers there are a number of ‘side pipe workings’ at various depths that were not shown as separate workings by Meads in 1858. While we knew of one ‘side pipe workings’ above the river-level horizon, used in the 19th century (and today) as a ‘*ladderway*’ up to ‘Salts Level’, we now know these may have been common, if perhaps only at specific horizons, throughout the full depth of the flooded workings.
- It may well be that the ‘side pipe workings’ found when exploring the two main shafts in 2019 are all connected to the ‘main pipe workings’, although this still needed to be confirmed by exploration.
- The two horizons of ‘side pipe workings’ are above and within the top part of the massive ‘*North Open*’ that went to depth, in an area where Meads’ 1858 drawing hints at complexity. It may be that in 2019 we gained a first glimpse of a complex area of interlinked ‘main’ and ‘side’ workings. In contrast, a short distance further down, roughly –below -80m, several written historic sources suggest some or most passages presumably come together to form a large open space that is as yet un-accessed.
- The general implication of the last four points, namely the presence of a complex ‘main pipe workings’ in combination with the several ‘side pipe workings’ found in 2019 at various depths in the two main shafts, is that the workings are far more complex than the Meads’ drawing and the 18th century descriptions of the ‘pipe workings’ would suggest.
- There is a strong possibility that most of the ‘side pipe workings’ explored in 2019 predate the sinking of the main pumping and winding engine shafts, given that ‘pipe workings’ at this depth were being extensively mined in the 1740s-60s and the shafts date to the 1770s-80. Nothing was seen in 2019 to strongly indicate that any of these ‘pipe deposits’ were first discovered

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when the shafts were sunk and thus worked subsequently (in 2022 one small example was identified at depth in the pumping shaft).

- A comparison of the Meads' 1858 drawing of the large chamber still open today above -58.5m depth, with the partial filling of waste stone found in 2019, shows that at its southern end the second chamber down (PW4/6) had a fill likely to be over 25m deep. This may well be associated with the 1790s reworking of the 'main pipe working' sides, with rubble dropped by miners into workings below that they had already searched.
- There is no documentation of when working platforms and ladders were removed from the 'main pipe workings' down to -58.5m. Before the May 2019 dives it was assumed they would still be *in-situ* where not collapsed due to deterioration. In 2019 it became clear that many of them may well have been destroyed when the sides of the 'main pipe working' were reworked in the 1790s.
- While many of the working platforms and ladders between -0.0m and -58.5m seem to have been destroyed in the 1790s, historical documentation shows that some mining below the river-level horizon took place in the first half of the 19th century. However, given what we found in 2019 this is likely to have been mostly or entirely somewhere below *c.* -60m. It is documented that at least one exploratory 'level' was driven deeper down and platforms and ladders dating to the creation or reuse of passages in this period may still exist at depth.
- A passage leading from the top chamber in the 'main pipe workings' at its south-west end was postulated in 2019 to be a 'cross cut' to the small shaft in a small 'striking house' at the river-level horizon, which is located to the side of the original 'sough' passage close to the topmost chamber of the 'main pipe working'; this was demonstrated in 2021 to be untrue as the passage was only an alcove in the chamber side. Instead a far more viable candidate for a link with the striking house winze was found in the form of an unexplored 'cross cut' at -15m heading towards the striking house, which is a similar depth to the plumbed depth of the winze; in the opposite direction it heads NNW. This shaft, of pre-1760 date, together with the newly-seen 'cross cut' may be the uppermost parts of the postulated '*ladderway*', as shown but not named on the Meads' 1858 drawing. This had three short winzes between horizontal passages on the way down to the '*34 Fathom Boat Level'* at -62m.
- The 'cross cut' from the 'main pipe workings' to the winding shaft found in 2019 at -58.5m has no 'striking house' at the shaft, so this begs the question - was it used for loading ore into 'kibbles'? The winding shaft was not sunk until 1770-73 hence ore from early work in the 'main pipe working' was taken out via a different route. In the 1750s and earlier 1760s, when the main workings above the -58.5m horizon were being first created, all ore recovered from here is likely, as noted above, to have been taken up to river-level horizon with the help of hand windlasses using short lifts in the workings. In contrast, any ore found from workings in this depth range from the later 1760s into the 1770s is likely to have been taken along '*Deep Level*' to the -62m 'canal level' and then taken up the Ape Tor shaft. The main winding shaft that intersects the -58.5m 'cross cut' was only sunk below the river-level horizon in 1770-73 and much or all of the rich ore deposits above this 'cross cut' may well have been removed by this date.

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Therefore, the initial purpose of this passage may have been to access the 'side pipe workings' just beyond the winding shaft, and this 'cross cut' was driven before the shaft was created. This said, the 'cross cut' at -58.5m was purposefully kept open in the 1790s, with retaining walls around its entrance to protect it, presumably to allow for the possibility of ore removal via here once the -62m 'level' below had become choked with deads. However, given the lack of a 'striking house', it was perhaps never used in earnest for this, with the implication being that very little ore was found above when the 'pipe working' sides here were cut back. However, counter to this argument, the 'cross cut' at *c.* -81m in the pumping shaft is known to have been used in 1786-88, when for this short period ore was moved from one shaft to the other and there are no striking chambers here.

Questions still to be addressed: Of the fifteen research questions raised before the dives began the 2019 dives started to address many of them, but there was still much to learn:

1. The pumping shaft was confirmed in 2019 to have had three compartments, with those to the ends for the '*pitwork*', including the '*rising main*' water pipes and presumably '*pump rods*', and another at the other end postulated as holding a '*ladderway*'. The central space is known to have been designed for lowering and raising equipment using the adjacent 'capstan'. However, the evidence was not clear cut for the presence of a '*ladderway*'.
2. Similarly, while there are documented '*bunding*' platforms that were installed down the pumping shaft in 1783 and some of the timberwork found may well have been parts of these, the archaeological evidence to support their presence was inconclusive.
3. At the winding shaft no evidence was found for points where ore was delivered to it for haulage upwards; the choke in the shaft prevented access to the uppermost of those that had been documented in the 18th and 19th centuries.
4. The 2019 discoveries showed that there was certainly one and probably two 'cross cuts' between the two shafts above the blockages. However, while there were also 'levels' leading elsewhere, their destinations were still largely unknown, except for an explored one that came from the 'main pipe working' chamber.
5. It was found that while both shafts were for the most part sunk through bedrock they intersected 'side pipe workings'. There was still much to confirm regarding whether these pre-existed the shafts and thus connected to the 'main pipe workings'
6. The 'side pipe workings' were found in two zones down the shaft, but how they related to the 'main pipe workings' had still to be elucidated in detail.
7. It has long been thought that the 'pipe workings' will be far more complex than the pre-dive evidence in the form of an 1858 section drawing by Meads allows assessment of. This was proved in 2019 to be the case but exploration of the inter-connectedness of these works still needed appraisal because of the limitations imposed by using the submersible robot attached to an umbilicus.
8. The 'main pipe workings' were indeed large as reported when the mine was in work. However, the largest reported cavities, which started at *c.* -70m down had yet to be seen.

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9. In the ‘main pipe workings’ explored down to -58.5m all miners’ working platforms and ladders were found to have been removed, with this postulated to have taken place in the 1790s when they were stripping back the sides of the workings looking for more ore. What was not known is whether this is still the case at greater depth in the chambers yet to be explored.
10. The documented underground canal and stables nearby, both at about -62m, had yet to be entered and assessed.
11. Thus, we did not know whether anything remains of canal boats and the documented horse-operated winding engine and nearby stables that lay nearby.
12. A stepped-passage shown on the 1858 mine section, located between river-level horizon and the canal had still not been located, thus it was not known whether this was a ‘*ladderway*’ for accessing workings below (what was probably part of the top section of this passage was identified in 2021 and this was certainly used for miner access).
13. Similarly, several documented long ‘levels’ from -80m downwards and a deep third shaft *(‘Footway Shaft’)* with its collar at -62m, all shown on the 1858 mine section, had not yet been entered, hence their character and purpose were still not known.
14. Also, we did not yet know anything of the character and size of the lowermost workings below *c.* -220m where the main ‘ore deposit’ is documented as having ‘*failed*’.
15. In the areas explored in 2019 no important *in-situ* mining artefacts were identified, other than displaced timberwork and tramway rails, but it was not known if this was the case in passages yet to be entered.

The dives of 2021-22 for the most part comprised consolidation of what we knew by the end of 2019 rather than radically expanding our sphere of explorations; this was inevitable as the robot explorer was still operating with an umbilicus rather than being in autonomous free-ranging mode. A few passages were entered for the first time. Also, some places were inadequately recorded in 2019 because of poor visibility as a result of disturbed sediments during the first dives and these were re-examined. Orientations of known passages were checked and where necessary corrected because there were problems with the navigation instrumentation in 2019. Our knowledge at the end of 2022 was on a much firmer footing that at the end of 2019. This said there is still much of the mine we have still not yet entered so some of the points listed above still apply.

The 2021-22 Dives

Introduction (SH): The principal purpose of the dives in September 2021 and March 2022 was to evaluate the performance of the UX1-NEO robot by comparison with the UX1-NATA robot used at Ecton in 2019 within the previous UNEXMIN project and to assess the usefulness of the BlueROV2 ‘off-the-shelf’ submersible for the preliminary site assessment role for which it was acquired.

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The UX1-NEO (Plate 1) was built by members of the UNEXUP consortium. It is about the same size as the UX1-NATA used previously, slightly ellipsoidal in shape rather than truly spherical. Instead of using a single pressure hull, which was found to create serious difficulties in maintenance such as changing batteries and repairing instrumentation, it is modular in design, with each instrument, camera, or other major component housed in its own sealed unit, thus minimising any damage that might be caused by leaks. Neutral buoyancy is maintained by using foam blocks, which also provide shock absorption protection to sensitive internal components.

Plate 1: The UX1-NEO robot at Urgeiriça Mine, Portugal, 2021

The new robot was transported by road from Hungary for two missions in the UK: a semi-commercial mission at a flooded mine in Cornwall, followed by the test dives at Ecton Mine.

The UX1-NEO includes 6 cameras facing forward, left, right, up, down, and backwards, though the backward-facing camera was inoperative during the 2022 Ecton trials. It also includes instrumentation broadly similar to that included in the previous UX1-NATA robot: scanning and

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collision-avoidance sonar units, and a water chemistry unit to record temperature, conductivity, oxygen fugacity, and pH, and last but not least a navigation unit to record depth, direction, and orientation in three dimensions. Maximum dive depth is notionally 500 metres, though most of the instrumentation is rated for 1500m or greater depths.

The BlueROV2 is a commercially available ROV (Plate 2), supplied in kit form. It was assembled by Tim Rhodes of Highland Technology Services Ltd. in Aberdeenshire, and brought to Ecton in September 2021. Final configuration and testing were done at Rudyard Lake, Staffordshire, followed by shallow dives in the 'pipe workings' at Ecton Mine.

Plate 2: The BlueROV2 submersible being prepared for tests at Rudyard Lake in Staffordshire, 28 Sept. 2021

The BlueROV2 is configured as standard with one forward-facing camera and a navigation unit to record depth, direction, and orientation. However, in the March 2022 dives the depth sensor was inoperative. A makeshift fend-off bar had also been fitted to minimize collision with passage sides and resulting loss of visibility by disturbing sediments. Use of this bar has the added advantage that

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it lies partly within the field of view of the camera and can thus give a reliable scale estimate for features it touches. Maximum dive depth is 100 metres, and the ROV has 150 metres of umbilicus.

Both submersibles have on-board batteries allowing several hours of continuous operation, but are operated via a communications umbilicus that allows real-time video monitoring of their performance and thus the driving of the submersibles with precision as the dives proceed.

Both have automatically north-seeking navigation units. The UX1-NEO also has on-board software to determine an accurate position at the start of a dive, relative to a checkerboard panel that can be surveyed if required to within millimetre precision.

Zero depths for the dives at Ecton for both submersibles were taken to be the actual water surface, less than half a metre below the rock surrounds of the launch platforms

In the dives in 2019, there were serious uncertainties in the directional data due to both instrumental drift (a continuous but unpredictable rotation in reported directions) during a dive and automatic 'resets' after collisions with shaft walls. These problems had been resolved in UX1-NEO by the use of new instrumentation in 2022, giving directions that were much more consistent and reliable, and could also be checked visually in dives carried out in 'nose-down' mode.

New software has been acquired by Resources Computing International Ltd to provide additional capabilities, and this will be available for use by the Ecton Mine Educational Trust following completion of the UNEXUP project. This includes a video editing application that allows synchronised videos from the five operational cameras to be presented simultaneously in a pseudo-3D view, similar to the screen view that is displayed during a dive. There is also a photogrammetry application available, which it is proposed to use in further follow-up work to help in the interpretation of complex geological structure seen in the shafts. Another software package that has been acquired can carry out image enhancement by removal of speckling 'noise' that can obscure features in poorly illuminated areas, and has been used on some of the images presented in this paper.

Of crucial importance to the tests of hardware and software is the demonstration of useful results that cannot be achieved in any other way. At Ecton Mine this comprises the extraction and interpretation of data on the geology and archaeology of the mine: the word archaeology is used rather than history because most of the observed features are not documented at all, or only in the most general terms, in contemporaneous 18th and 9th century records.

In the 2019 dives during the UNEXMIN project, a large number of open questions regarding what was being viewed remained to be answered, largely as a result of murky water (because of sediment disturbance) or low confidence in the navigation. A number of these questions have now been given definitive answers, simply by improvement in both the robot hardware (such as a better

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configuration of thrusters) and in the mode of use, with continuous movement rather than the stop-start approach that led to much greater water disturbance.

On 22nd March 2022 there was a dive of UX1-NEO in the pumping shaft and two dives of the BlueROV2 in the North Winze. On 23rd March it was intended that there would be one dive of UX1-NEO in the winding shaft, to include also an exploration of the northern end of the 'pipe working'. However, during the dive, the robot snagged a length of 2mm nylon fishing line, and this needed to be disentangled from the thrusters before the mission could be completed in a second half of the dive.

Although there were only two new dives of UX1-NEO, one in two halves, these generated a large amount of information additional to what was obtained in ten dives in 2019. The last dive, from the winding shaft launch platform, actually entered the 'pipe working' through one of the openings discovered in 2019, and yielded completely new information on the northern part of the 'pipe workings' at this horizon that had not been entered previously.

On the 29-30 September 2021 a series of five dives of the BlueROV2 were carried out in the 'main pipe working' (Plate 3). The results of these are described in the sections on geology and archaeology below. The main objectives of these dives were to test the performance and manoeuvrability of this ROV, and to explore the shallower flooded parts of the 'pipe working' (to a maximum of 20m depth) without entering the labyrinth of passages that lead to the deeper parts of the 'pipe workings'.

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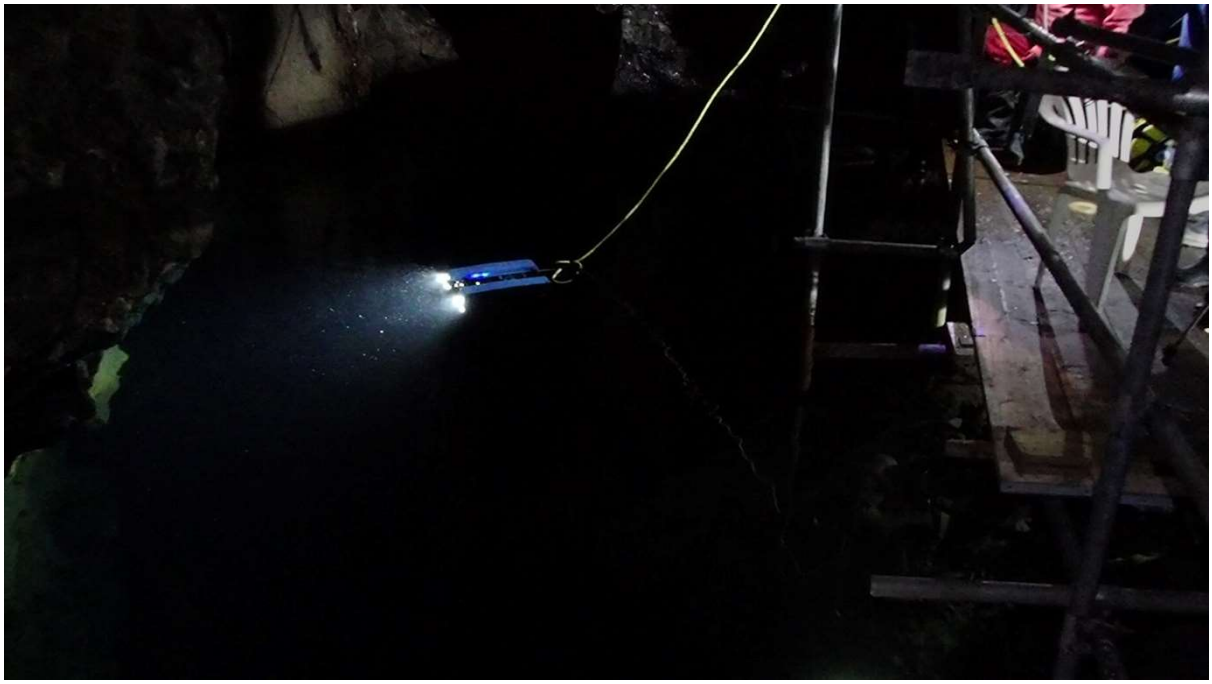

Plate 3: The BlueROV2 in the 'main pipe working' chamber just after its launch on 29 Sept 2021

On the 22-23 March 2022 three dives of UX1-NEO and two dives of the BlueROV2 ROV were carried out.

The UX1-NEO robot has more autonomy built into its control systems than the UX1-NATA robot developed in the UNEXMIN project and used at Ecton in 2019. This autonomy is sufficient to allow free-ranging operations, but the robot is still operated most of the time with an umbilicus, especially in 'exploration' dives where real-time human monitoring and decision-making are needed. In free-ranging mode no communication with operators at the surface is possible between launching and recovery of the robot. In the Ecton dives in March 2022, the robot was operated with umbilicus for all three dives.

During the three dives of the UX1-NEO robot, the primary objective was to resolve questions concerning open leads identified in the UNEXMIN project in 2019; it also allowed comparison with the 2019 data for all features.

In the pumping shaft dive on 22 March 2022, the robot descended to the known shaft blockage at -124m to -127m depth, and its ascent was paused for examination of each of the open leads. Improved visibility (by comparison with 2019 dives) was enabled by better configuration of thrusters allowing major reduction in disturbance of sediment and by careful driving of the robot in nose-down mode to avoid obstacles. This was combined with reliable orientation data and sonar scans (Figs 4-5) to

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provide additional information on the status of these leads, as documented in the archaeology section below and in Appendix 1 below.

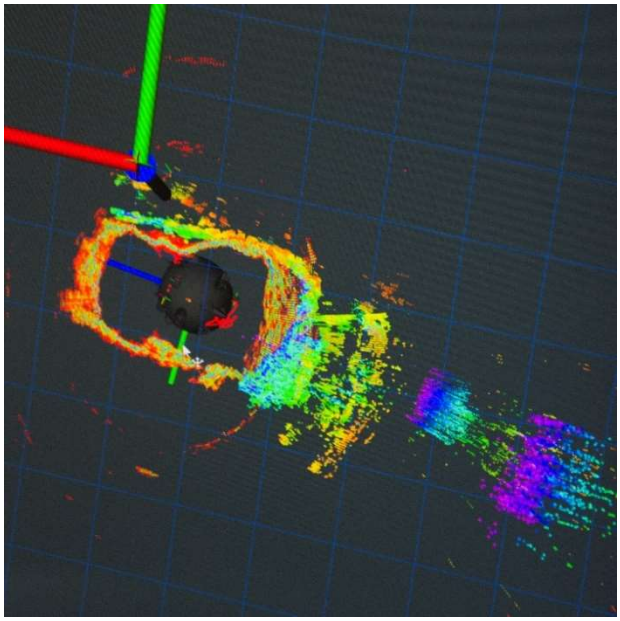

Figure 22 An example of sonar plotting at the winding shaft in 2022, photographed from a monitor in the control room during the dive

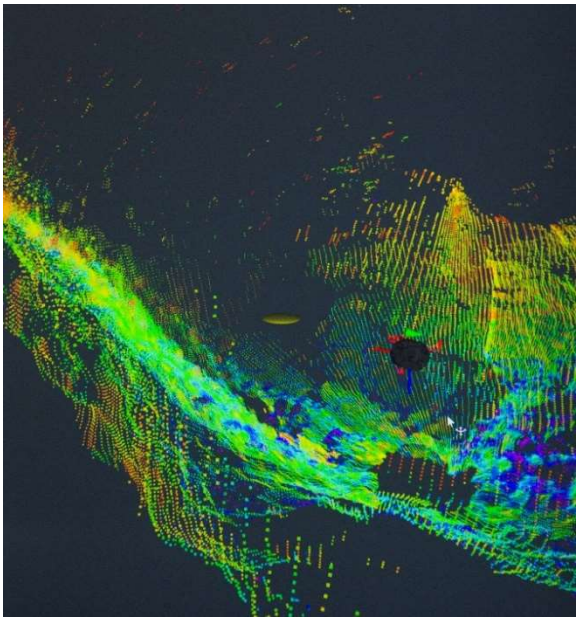

Figure 23 Sonar plotting in the 'main pipe workings' in 2022, photographed from a monitor in the control room during the dive

In the winding shaft dive on 23 March 2022, the same approach was followed, with rapid descent to the known shaft blockage at -112.5m to -113.5m depth, and examination paused at each of the open leads. Updated detailed information is documented in the archaeology section below and in Appendix 2. The ascent was interrupted before this task could be completed, as a result of entanglement with nylon fishing line. The robot was freed with difficulty at the launch site and the line disentangled from the thrusters.

A second part of the winding shaft dive was then carried out with the specific objective of passing through an opening discovered in the 2019 dives into the 'main pipe working', and exploring the northern part of this 'pipe working' that had not been visited before. This is documented in the archaeology section below and in Appendix 3. New open leads were discovered, requiring further exploratory dives at a future date to resolve. A hole in the western wall of the 'main pipe working' was found that connects directly with a 'side pipe working' accessed from the pumping shaft.

The BlueROV2 made two dives on 22 March 2022, in the North Winze (see Fig. 6, upper left) to gain a better understanding of what features lay below the water and to test postulated links at depth

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with other parts of the mine, as there is known to be hydraulic connectivity (the water-level changes with that in the main shafts and 'pipe workings'). The results of these dives are presented in the archaeology section below and in Appendix 4.

The Locations of Features Explored: Three figures are relevant throughout the rest of paper hence are they are placed here for convenience; they show the workings as we understand them after all the 2019-22 dives had taken place. Fig. 6 shows the 'main pipe workings' in plan down to *c.* -60m, demonstrating their relationship to the main shafts, 'cross cuts' and 'side pipe workings'. Figs 7 and 8 show all the explored workings in elevation on north/south and east/west planes.

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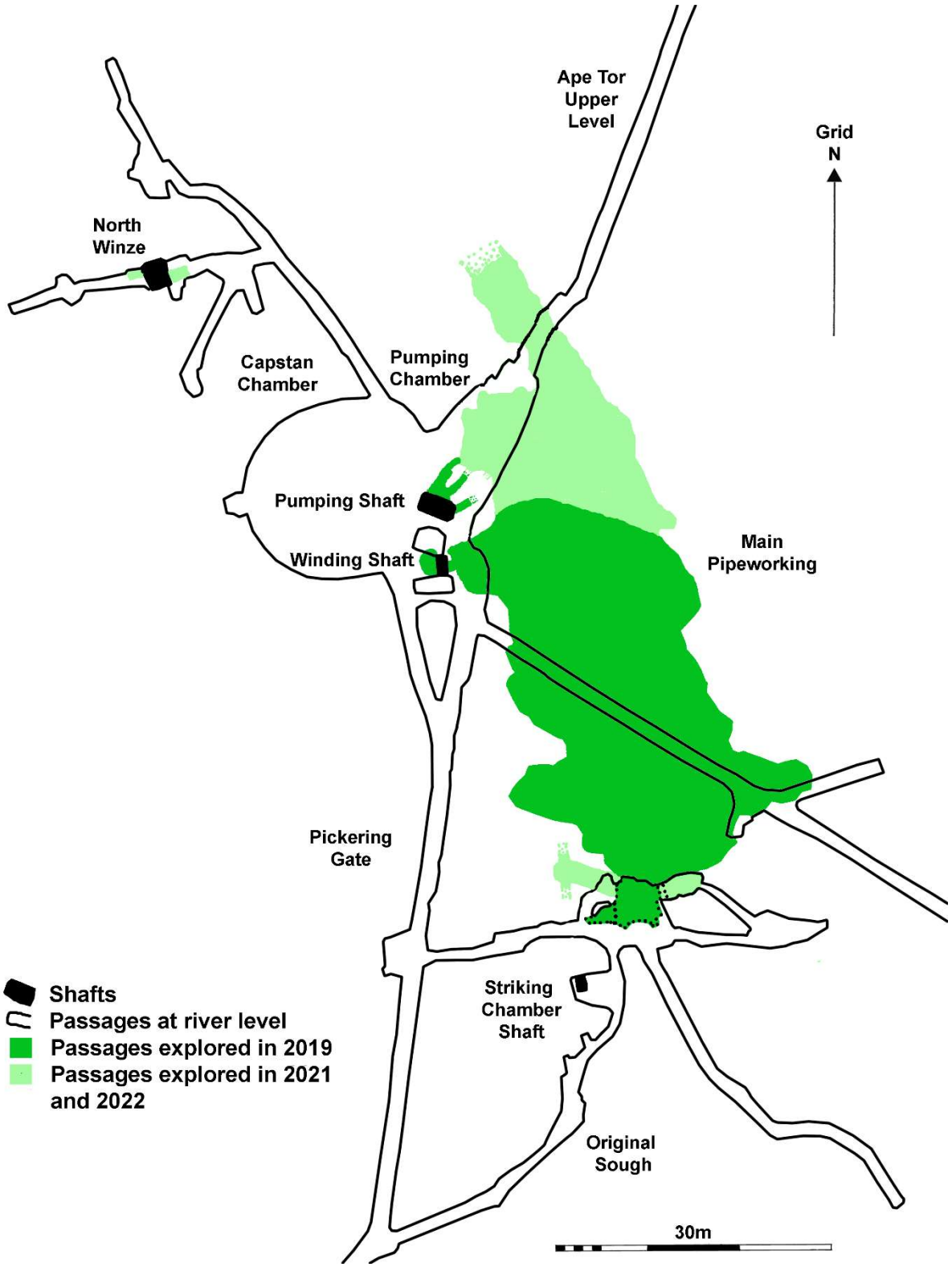

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Figure 24 Plan showing the new discoveries made under water in 2019 and 2021-22 down to about -60m, including those in the flooded 'main pipe workings', those at the 'side pipe workings' at PS8/9 and WS6, and those at the North Winze. The plan of the 'main pipe working' was generated from the sonar point-cloud plots. These workings are shown in relation to the pumping and winding shafts, the 'cross cut' WS7/PW10 at the base of the 'main pipe workings' that was explored in 2019 and the 'side pipe workings' at PS8/PS9 assessed in 2019 and 2022.

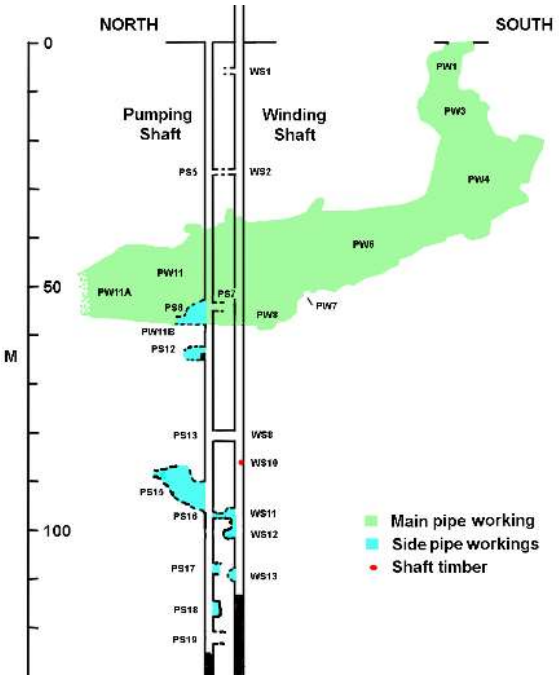

Figure 25 North-south schematic elevation through the explored workings drawn to include revisions made in 2022 after the new dives here. This shows the inter-relationship between shafts and the 'main pipe workings', with 'side pipe workings', 'cross cuts' and other 'levels' also shown (note: the orientation of the pumping shaft is skewed to show the shaft sides on the same axis as the other shaft)

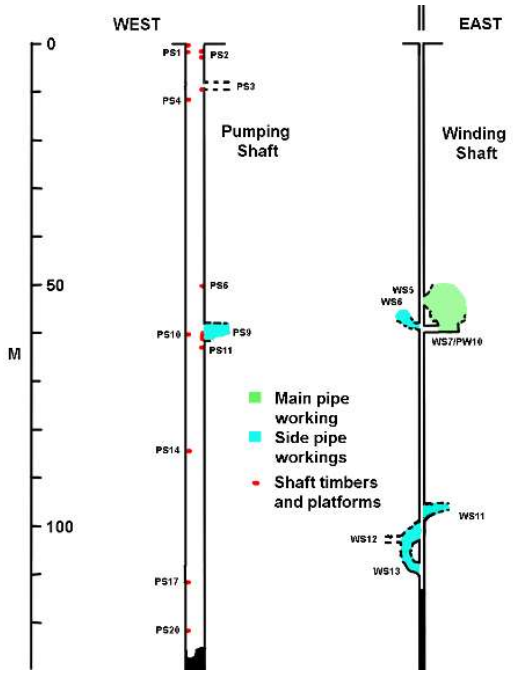

Figure 26 East/west schematic elevations through the pumping and winding shafts as two separate images, drawn to include revisions made in 2022 after the new dives here. This shows the explored 'pipe workings', 'cross cuts', 'levels', and shaft timbers (note: the orientation of the pumping shaft is skewed to show the shaft ends on the same axis as the other shaft)

Geology – The 'Main' and 'Side Pipe Workings' together with the Adjacent Shafts (RS): The UNEXUP dives into the Winding and Pumping Shafts in May 2022 have confirmed the geological summary provided by Shaw (2020b). The improved imagery has allowed some additional observations to be made and approximate orientations of features to be determined.

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The top part of the Pumping Shaft appears to be sunk through thick- bedded limestones, with near-vertical dip, from the water-level horizon to the first main pipe vein workings at a depth of about 50-55m (Plate 4). Individual beds can be followed over much of this distance. These beds strike approximately north-south. Below this depth the limestones are generally more thinly bedded with frequent evidence of folds or crumpled bedding and with more evidence of jointing and minor faults (as seen on Plates 5-9). For example there are synclines at depths of about -78.5m, -92.0m and -97.0m and anticlines at about -69.3m and -87.9m. These are acute and usually have an axial joint or minor fault. The folds have an approximately north-south trend but plunge, if any, has not been ascertained.

Plate 4 Thickly bedded limestone in the winding shaft at c. -36.5 down, with the dip near-vertical because of folding

New understanding has been found on the structural control of mineralisation. The 'stope-like' opening at the northern end of the 'main pipe working' was driven along the axial plane of an anticline (Plate 5), suggesting that there was significant structural control of mineralisation. This is part of an inferred larger structure, as there is an asymmetric syncline immediately to the west of

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this stope, and much of the western wall of the ‘pipe working’ is on the long eastward-dipping limb of this syncline. Although the geological structure is not easily seen, it is surmised that the opening (a ‘side pipe-working’ adjacent to the pumping shaft) trending approximately north-south, sub-parallel to the main pipe-working, also occupies another anticlinal axis. Fig. 9 shows a schematic W-E section through the postulated structure.

Plate 5 Composite image showing the vertical ‘stope-like’ passage at the NNW end of the large chamber in the ‘main pipe working’ that was entered for the first time in 2022. This passage occupies the axial plane of an asymmetric anticline.

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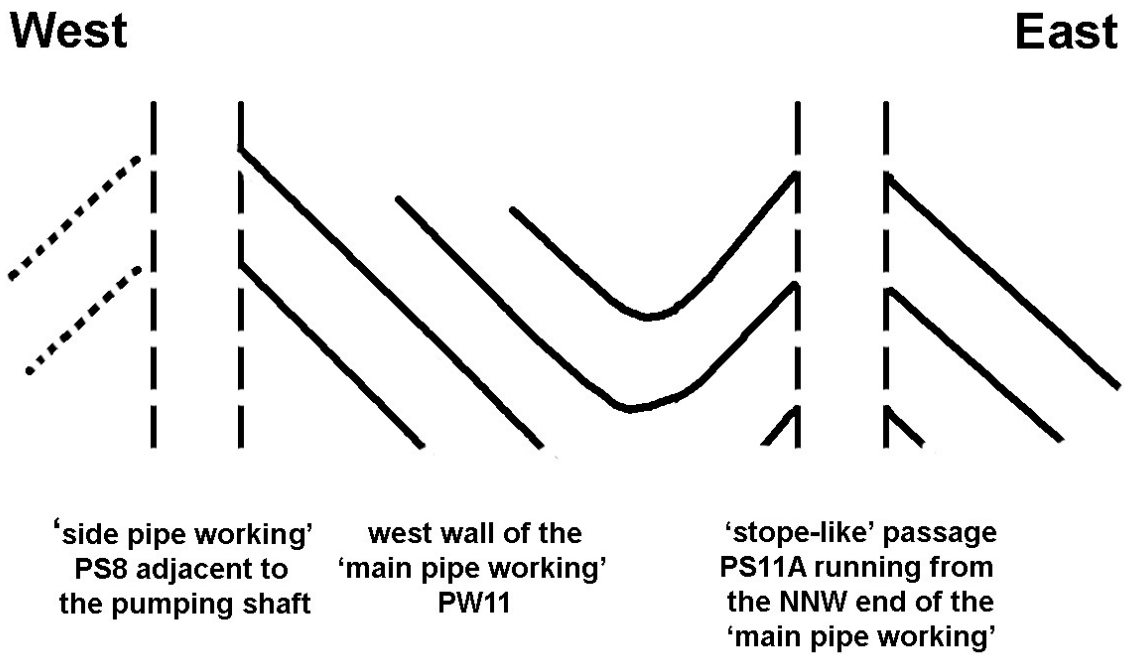

Figure 27 Schematic west/east section through the postulated structure at c. -55m depth in the 'stope-like' passage at the NNW end of the 'main pipe working', the west wall of the 'Main pipe working' and the 'side pipe workings' next to the pumping shaft

Axial plane fractures are a very common feature of the structural deformation at Ecton, as seen on a smaller scale in Plates 6 and 7, though in the more thinly bedded limestone layers, deformation also takes the form of disharmonic folding and crumple zones as in Plates 8 and 9. It should be noted that the features in Plates 6 to 9 are all within the same small area, just a few square metres in extent.

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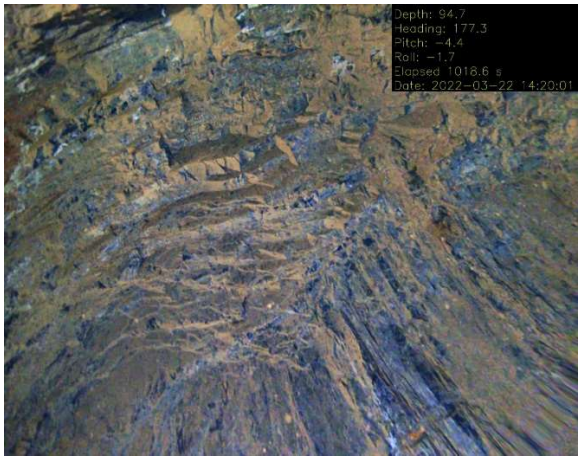

Plate 6: A fracture in the axial plane of a small-scale anticline in the wall of the pumping shaft at -94.7m depth

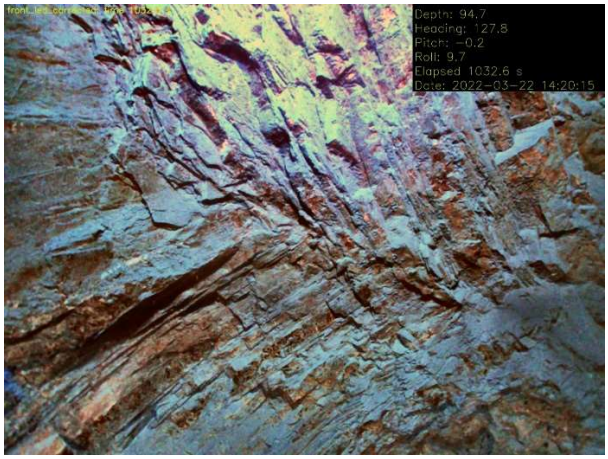

Plate 7: Another fracture in the axial plane of a small-scale syncline in the wall of the pumping shaft at -94.7m depth

Plate 8: Disharmonic folding in thinly bedded limestones in the wall of the pumping shaft at -94.7m depth

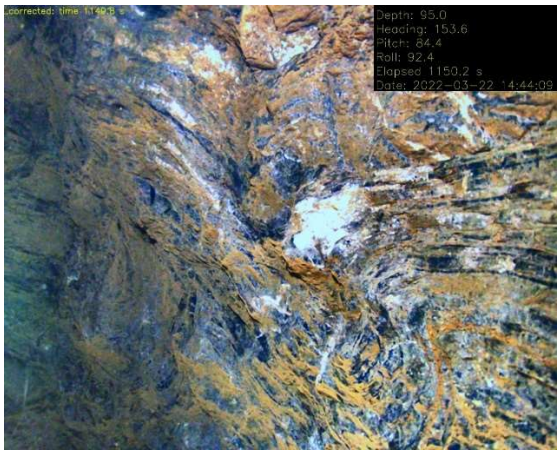

Plate 9: Further disharmonic folding in thinly bedded limestones in the wall of the pumping shaft at -95.0m depth

The ‘stope-like’ opening in the ‘main pipe working’ may well be an example of the saddle deposits at Ecton that were described by Watson (1860). He describes some of the ore deposits at Ecton as being ‘saddle’ (anticline) and ‘huckle’ (syncline) related, which had mineralised axial fracture and so called wing deposits following the bedding to either side of the fold axis.

Watson also notes a relationship of the ore deposits to what he describes as thick and thin beds. These may be taken to be those that we have described as the massive and the thinly bedded

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limestones. While Watson notes that both contain ore, his figures suggest that the former are more significant and this would be confirmed by the observation that the 'main pipe workings' seem to be hosted by the more massive limestones.

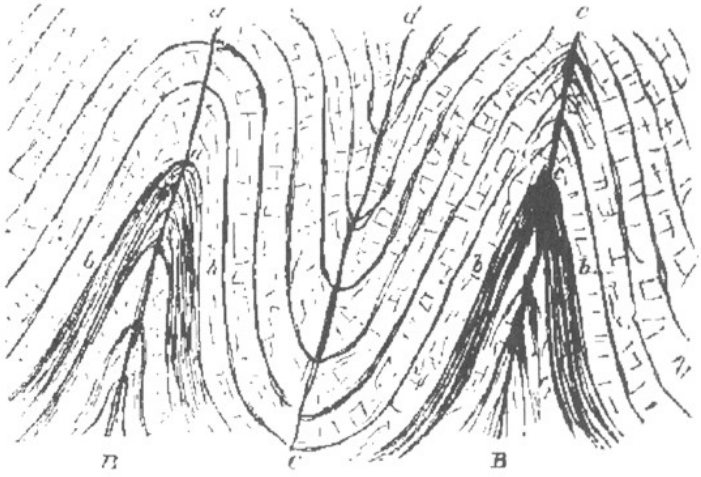

Figure 28 A figure from Watson's 1860 publication captioned 'Contorted beds of alternating limestone and shale strata, showing the formation of "saddles" and "saddle joints"'

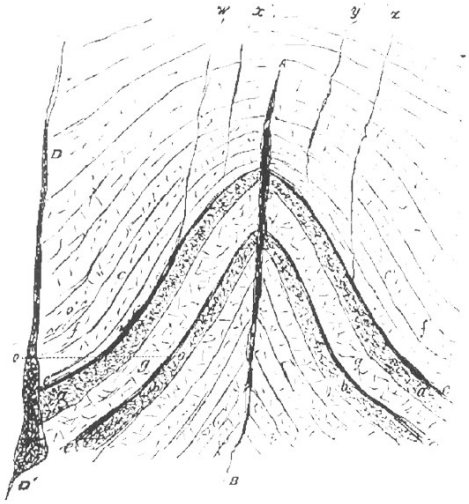

Figure 29 A figure from Watson's 1860 publication captioned 'Vertical section of the "bearing beds", showing the mode in which the ore is deposited'

The walls of the winding shaft show evidence of abrasion, caused by the passing of numerous kibbles during its operating life, which make the geology less clear. The top part of the shaft appears to be sunk through near-vertically bedded limestones from the river-level horizon to a depth of about -49m, with bedding surfaces forming two walls of the shaft. As with the pumping shaft individual beds can be followed for long distances. Consistent with observations in the pumping shaft these beds strike approximately north-south. Below about -65m the limestones are mainly thinly bedded with variable, but often near vertical, dips and contorted bedding in places. There is a prominent syncline at a depth of about -49m that is evident in opposite walls over a distance of several metres. Again, as seen in the pumping shaft, the axial trend is approximately north-south.

As noted from the 2019 dives (Shaw, 2020b) at least two, and possibly more than three, early phases of hydraulic fracturing and calcite vein-filling development can be identified. These are wide spread throughout the depth of both shafts, particularly in the more massively bedded limestones. While not unequivocal this veining appears to be more intense and better developed when in close proximity to the pipe vein deposit and as noted by Shaw (2020b) its presence was probably understood by the miners to be an indication that they were close to a pipe.

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The 2022 dives explored some of the open pipe vein workings more successfully than had been undertaken in 2019. Apart from the observations noted above on the saddle deposits these explorations do not provide further geological information but do confirm a number of factors. These are:

- The pipe is usually best developed in the more massively bedded limestones (which generally have steep to vertical dips).
- When well developed the 'main pipe deposit' was large (10's of metres high and wide).
- The hydraulic fracture fill calcite veining noted above is often evident in the wall rocks when not sediment covered.
- The pipe deposit has a complex structure with frequent branches and side pockets.
- The miners stripped the pipe of virtually all ore leaving little mineralisation behind, though occasional brown stains resulting from decomposition of sulphide mineralisation have been infrequently noted.

Geology – The North Winze (RS): The shaft is sunk through what seems to be fairly massive limestone with few bedding partings. Where apparent the bedding is near vertical (80 to 90 degrees) with an approximately north/south strike. The equivocal evidence is that there is a synclinal structure evident in the upper north-eastern part of the shaft but this is not clear and may be an artefact of shaft walls and camera position. There is a near vertical minor fault (or strong joint) with a *c.* south-east strike near the bottom of the shaft. Multiple phases of hydrofractured calcite veining are evident throughout the shaft demonstrating at least three phases of crosscutting vein development. This veining is widespread in the Ecton mine workings, particularly in more massive limestones in areas close to the pipe veins and may well have been considered to be an indication of proximity to mineralisation by the miners.

There are several pockets of mineralisation in the west wall of the shaft that seem to represent the continuation of the small 'pipe deposit' worked at and above the river-level horizon that can be observed intermittently from near the top to the bottom of the shaft. These comprise cavities with a banded mineral fill with vuggy centres. The fill seems to be mainly calcite but could contain other gangue minerals and the presence of brown iron oxides suggest that iron rich sulphides (such as chalcopyrite) have been present but are now corroded by exposure, either by air prior to flooding or later by water. These are very similar to the mineralisation that can be seen in the trial workings from the back of the capstan chamber and in the trial just to the east of the shaft. These pockets of mineralisation are likely to be why the shaft was sunk here and may well be why such a large shaft was sunk in the expectation of large ore deposits.

Archaeology – The Pumping Shaft (JB): The 2022 UNEXUP dive in March 2022 had two specific objectives in addition to testing the submersible robot. The primary one was to look at the leads identified in 2019 and in the 2020 report that may allow entry to unexplored passages. Secondly the plan was to look at features deep in the shaft that in 2019 were not clearly seen because of disturbed

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sediments in the shaft and also where there was significant uncertainly over their orientation. What was discovered is summarised here; for details of the archaeological features in the pumping shafts see Appendix 1.

Entering the shaft in nose-down mode had the great advantage that it was easier to avoid obstacles and thus not disturb sediments and hence reduce visibility. It also was very useful in making a check on orientations of features for, by carefully watching the videos from beginning to end, it was possible to check the two ends of the shaft had not been inadvertently visually reversed (as had been the case in 2019 (see below). However, there was also a disadvantage, for by not stopping in the shaft at regular intervals and spinning around it was easier to miss small features, particularly in the shaft corners as these were commonly beyond the edges of the camera images. This applies to timber notches and iron fittings, as for example at PS2 and PS6 that were not seen; the small side 'level' at PS7, while seen fleetingly, also did not appear clearly on the 2022 videos.

Open leads after the 2022 dives are now reduced from eight to three (PS7, PS15, PS19); these are returned to below.

Several features were looked at in more detail in 2022, including those at depth not seen properly in 2019 (PS16, PS18-19). Further detail was added elsewhere (PS5, PS8, PS9, PS15, PS17). One new feature, a miner's inscription was added (PS19A).

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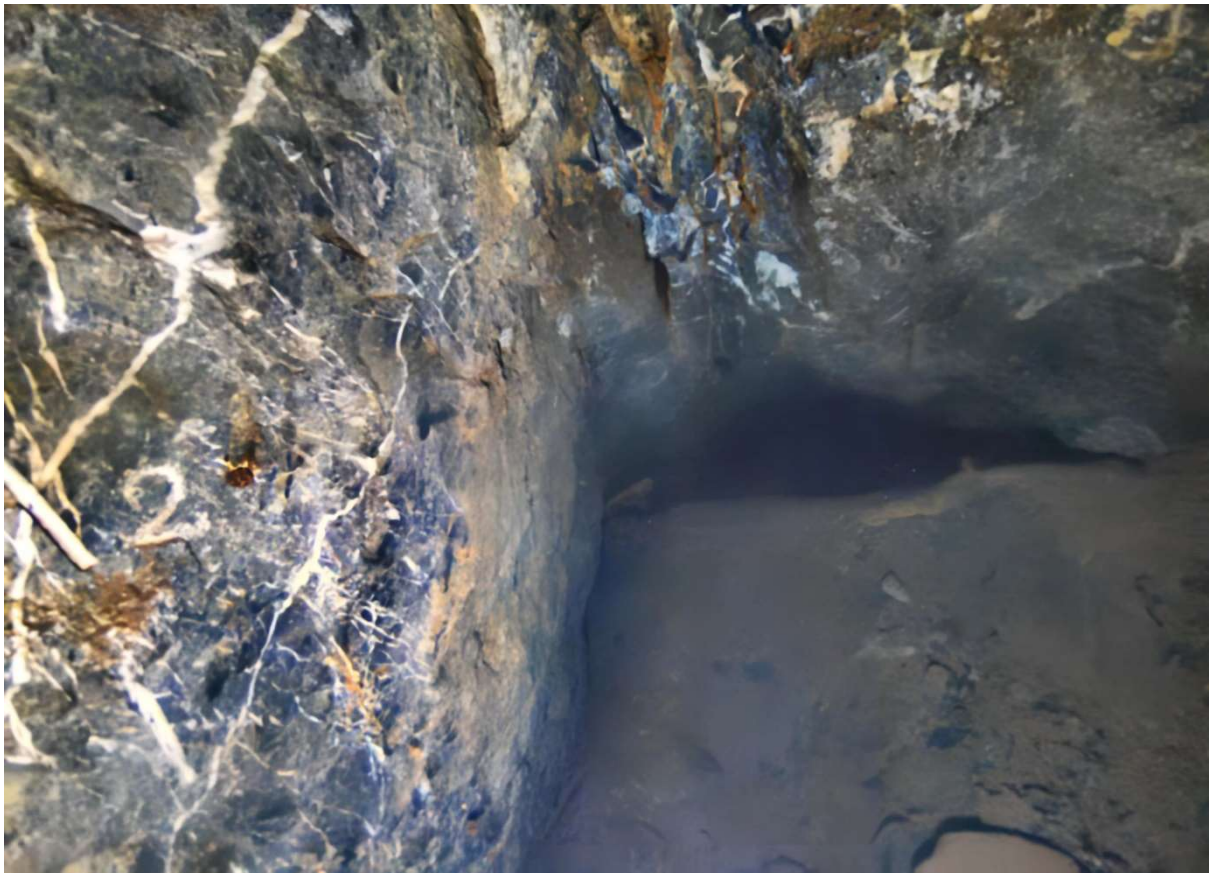

Plate 10: To the left is the PS19A number 2 inscribed with a pick by a miner for reasons unknown in the side wall of the pumping shaft. To the right is the largely backfilled probable PS19 'level' or possible 'side pipe working'. In the left wall of this passage there is an iron 'eye'

In four instances the orientation of features was wrongly identified in 2019 and had to be corrected (PS3, PS5, PS 14, PS16), while at others orientation was refined in 2022 (PS13, PS15, PS17-19). With PS16 it was established that this is probably linked with a 'side pipe working' in the winding shaft. While the depth assessment of features down the shaft for the most part was retained from 2019 (see Appendix 1 for explanation), in the case of PS20 and the lower part of PS21, both were adjusted downwards by 1m after seeing these features more clearly in the 2022 videos.

Specific details seen for the first time in 2022 included ironwork at openings (PS14, PS16, PS17, PS19) and timbers within them (PS8, PS9, PS16).

'Side Pipe Workings', 'Cross Cuts' and 'Levels' in the Pumping Shaft

While some of the changes and additions made in 2022, as just listed, are only details of no interpretative consequence, others have implications that demand revision of the previously

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published interpretations of features in the pumping shaft (Barnatt 2020, pp. 35-45, 60-62). In some cases the assessment of whether openings were 'levels' or 'side pipe workings' has changed or been modified, and more importantly when these were wrongly oriented in 2019 (PS3, PS5, PS16) this has implications for where their destination may have been; thus to save confusion the tables presented in 2020 are re-presented here at Tables 1 and 2 and some data shown on Figs 7 and 8 has been changed. The interpretative texts that went with assessment made in 2020 are also repeated below in somewhat modified form.

Table 1: 'Side Pipe Workings' leading off the Pumping Shaft

Feature	*Depth*	*Orientation*	*Character*
PS8	-53.0m to -59.3m	NNE	Moderate-sized but tall single cavity with three smaller holes leading off at the back and right side, at least one of which certainly links to the 'main pipe workings' via PW11B; it may well be that the other two also lead here.
PS9	-58.0m to -61.5m	NE to NNE	Possible 'side-pipe working' of small size with its entrance largely backfilled behind a blocking of timber and stone.
PS12	-62.5m to -65.0m	NNE	Probable partly-choked 'side-pipe working' of unknown size, going up behind a walled-up entrance.
PS15	-90.3m to -96.5m	NNE	Large 'side pipe working' with a moderate-sized entrance but becoming significantly larger inside in its upper part, with areas at the top that were not visible. A lower part is narrower; here a 'level' leads off to the NNE.
PS16	*c.* -95.5m to -99.0m	SE and possibly West	Small 'side pipe working' in the SSW side of the shaft has a passage heading south-east that becomes larger inside and a second possible one heading west. The former may well be the 'side pipe working' in the winding shaft at the same horizon (WS11).
PS17	-108.0 to -111.6m	South	Probable small 'side pipe working' that has been largely backfilled.
PS18	-115.0m to -117.5m	ESE	Small 'side pipe working' that only extends a short distance from the shaft and has no ways on.
PS19	-121.0m to -123.0m	SSW	Possible small 'side pipe working' that is more likely to be a 'level'; largely backfilled.

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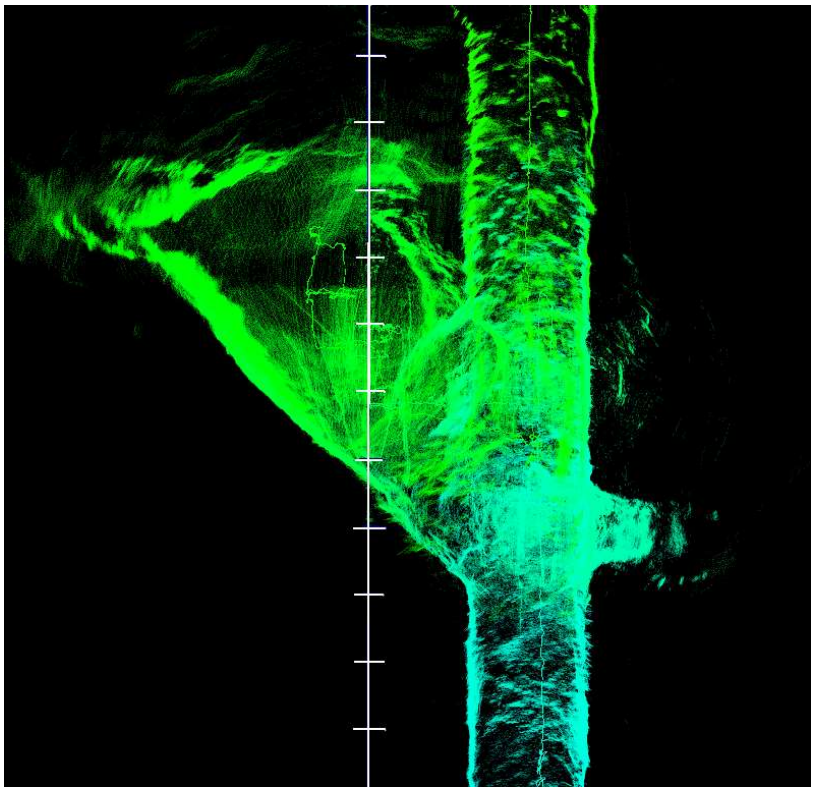

Figure 30 Sonar plot of large pipe-workings at PS15, here to the left of the pumping shaft, explored in 2022. The two intersect each other at -90.3 to -96.5m down (the vertical scale is at 2m intervals). PS16 lies to the right of the shaft, where the sonar plot shown here did not include one or possibly two continuations as they run away at angles from the orientation of the plot.

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Plate 11: The PS 16 'side pipe working' at c. -95.5m to -99.0m down the pumping shaft in its south-western side. To the left there is a passage with an in-situ timber rising diagonally from the wall and also an iron hook placed not far from the shaft. Both the floor and the rubble heap are partially covered by a fine sediment. This may be the same 'side pipe working' as that leaving the winding shaft at WS11. To the right side of the image there may be another passage running off but the dark area is perhaps just a shadow.

The 'side pipe workings' have been found at two horizons in the shaft, at *c.* -50m to -65m (PS8 and possibly PS9 and PS12) and at *c.* -90m to *c.* -120m (PS15, PS16, PS18, probably PS17 and possibly PS19). PS8 is interlinked with the large chamber in the 'main pipe workings' near its NNW end. At the lower horizon one working is significantly larger than the others. These two zones roughly match the depths of those in the winding shaft. The pumping shaft 'side pipe workings' are mostly aligned towards the eastern half of the shaft and thus have strong potential for being linked with the 'main pipe workings'.

Table 2: The disposition of 'cross cuts' and 'levels' in the pumping shaft.

NNE Side

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PS8	*c.* -57.0m to -59.0m	Possible 'level' (or small 'side pipe working') running from the back of a 'side pipe working' probably goes to the 'main pipe working' close by but this has yet to be verified.
PS12	-62.5m to -65.0m	Possible 'level' with a carefully-built dam wall sealed with clay, with what may be a 'side pipe working' behind that comes down from above. The 'level', if it exists, has an unknown destination but is possibly associated with the documented '*Deep Level*' at -62m. Or, more probably, the passage is a 'side pipe working' containing a cistern for the '*rising main*', or the dam was made to contain a nearby spring.
PS15	-95.5m to -96.5m	'Level' going roughly north-westwards from within the lower part of the large 'side pipe workings' here has an unknown destination.

ESE End

PS3	-8.0m to -8.9m	Choked 'level' with destination unknown.
PS5	-25.8m to -27.2m	This 'level' is at the same depth as WS2 in the winding shaft, so this was probably a 'cross cut' to here that did not follow a straight line.
PS9	-58.0m to -61.5m	Possible 'level' (or 'side pipe working') with unknown destination to the north-east or NNE, but possibly the 'main pipe working' or a 'cross cut' to the documented '*Deep Level*' at -62m. The entrance to this feature has a complex arrangement of *in-situ* timbers at its base (see Table 3 below).

SSW Side

PS7	-52.9m to -55.0m	This 'level' is at the same depth as WS5 in the east side of the winding shaft but is not going here; while it is heading southwards towards this shaft its destination is unknown.
PS13	-79.7m to -82.0m	'Cross cut' in the SSW side and WNW end of the shaft. Entered and shown to go to the winding shaft at WS8. The route between the two changes direction part-way along.
PS17	*c.* -108.0m to -111.0m	Possible' level' going roughly southwards from the SSW side of the shaft from close to its WNW end; destination unknown.
PS19	-121.0m to -123.0m	Probable 'level' (or possible 'side pipe working') that goes roughly south from the ESE half of the shaft and may well extend towards the now-inaccessible part of the winding shaft below the choke here.

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Plate 12: The open part of the PS9 'level' or 'side pipe working' at the south-east end of the pumping shaft. Much of the passage is filled with rubble and, out of shot, there is a complex arrangement of in-situ timbers supporting this backfill at the shaft wall; in total the passage was originally 2.5m high, with a roof at -58m and floor at -61.5m down the shaft. The passage has an unknown destination, but this is possibly the 'main pipe working' or it was a 'cross cut' to the documented 'Deep Level' at -62m. To the left is the large PS8 'side pipe working' lying at the north-east side of the shaft.

As can be seen from Table 2, there are 'cross cuts' to the winding shaft at PS13 and probably PS5 and PS19. The potential upper link to the pumping shaft at PS5 is small and irregular and may have been designed as an air-way used to bring ventilation to the pumping shaft from the pre-existing winding shaft while the former was being sunk. PS13 is larger and it may also have been initially used in the same way, but it is documented that in 1786-88 ore was transferred from half way up the pumping shaft, the lower part of which was also used for winding for this short period, with the ore then brought to the winding shaft for taking it up to the river horizon; PS13 is at the correct depth down the shaft and this may well be the route used. Given that both of the 'cross cuts' are not straight line links between the two shafts, it is tempting to suggest their first parts from the winding shaft were earlier and only later extended to the pumping shaft. However, it is hard to see why short blind 'levels' (known at WS8 and assumed at WS2) would have been driven if it was not the

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intention from the outset to reach the pumping shaft. It may also be that PS7, which although heading in the right direction for the winding shaft but not reaching this, is also a short blind 'level'.

Another 'level' (PS3), located near the top of the shaft, with a timber beam in the shaft at its entrance that is possibly a vestige of a platform, is fully choked with waste stone and runs to an unknown destination approximately to the ESE. At a greater depth a 'level' at the back of 'side-pipe workings' (PS15) runs to a destination unknown to the north-west.

A possible 'level' of particular interest (PS12) is that at -62.5m to -65.0m, which has a carefully built dam of limestone blocks and slabs across it with the interstices probably sealed with clay. This dam comes up to *c.* 1m from the roof and it was almost certainly designed to hold back water. Three potential interpretations need considering.

- Firstly, this possible 'level' may be associated with the documented Ape Tor '*34 Fathom Boat Level*' and its continuation going approximately southwards into the vicinity of PS12 documented as '*Deep Level*'. If so, PS12 would be a 'cross cut' to these that intersected an old 'side-pipe working' next to the shaft. If so, the wall was originally built as a dam to hold back any water that flowed from the direction of the canal. However, with its base at -65m, PS12 is below the stated depth of -62m for the '*Deep Level*' and '*Boat Level*' in historical records. This interpretation is thus perhaps problematic as it seems more likely that an access route from the shaft to the earlier passage would have been driven at -62m.
- A second interpretation is that the walled-off passage was used as a cistern for a 'lift' of 'pump pipes', with the passage behind being a utilised old 'pipe working'. However, there is significant uncertainly with this interpretation as there is insufficient historical documentation as to the depths that '*pitwork'* cisterns were placed in the shaft. In 1788 it was noted that there were three 'lifts' and it is thought the shaft was *c.* -154m deep at this time. Assuming for the sake of argument that the 'lifts' were of equal length, which may not be correct, this would place the top cistern at *c.* -51m. When the pumping shaft was first sunk, down to *c.* -128m, if there were three 'lifts' at that date this would place the top cistern at *c.* -43m. However, if there were initially only two lifts, the top cistern would have been at *c.* -64m, which matches the depth of Feature PS12. By the time the shaft was deepened for the last time in 1795 there may well have been four lifts with the top three retained as they were previously. However, the possibility cannot be discounted that each of the three pre-existing lifts were lengthened and the 'cisterns' moved; if the latter is the case then this would place the top cistern at *c.* -61m. Given the potential range of depths for the top '*pitwork*' cistern, the timber beam of PS10 at *c.* -60m as well as Feature PS12 at *c.* -65m could be considered, while nothing was identified above or below these within the range where a cistern would be anticipated. All this said, the data are too unclear to accept interpretation for PS12 as a cistern with any confidence.
- The third interpretation is that a 'pipe working' at PS12 was modified when the shaft was sunk, with the dam made to contain water from a spring that had been breached in the

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workings nearby, perhaps previous to when the shaft was sunk; from the dam the water could be removed in a controlled way via the shaft by dropping it to the nearest pumping cistern.

Two possible 'levels' (PS8, PS9), run back from 'side pipe workings' and are both a short distance further up the shaft than the last described. Thus they are roughly at the right horizon to provide links with '*Deep Level*', but it is unknown whether they do so; PS9 is perhaps more likely to just go to the 'main pipe workings' while PS8 almost certainly does. In addition, high on the east side of PS8, is an oval 'window' at about -56m that connects directly with the 'main pipe workings' (feature PW11B), confirming the close proximity of the two sets of workings. That PS9 had a strongly built timber structure at its base where it meets the pumping shaft could suggest it was designed for heavy sustained use, but what this comprised is unclear. However, as the 'level' here was largely backfilled the timbers are more likely to have been added simply to retain this backfill.

Some of the 'cross cuts' and other 'levels' are open and only have had sufficient fill added to create a flat floor (PS5, PS13 and possibly PS7, PS8). Others are partially or fully choked with waste rock that was added after they became redundant (PS3, PS9, PS17, PS19 and possibly PS12), while at a possible example leading back from 'side pipe workings' the extent to which they are open has not been seen (PS15).

Timberwork in the Pumping Shaft

In one case (PS3), the assessment of which end of the shaft that the horizontal timber/platform had been placed has changed and this has interpretative implications; thus to save confusion the table presented in 2020 is re-presented here as Table 3 and data shown on Fig. 8 has been changed accordingly. The interpretative text that went with assessment in 2019 is also repeated below in somewhat modified form.

The pumping shaft would originally have contained a '*rising main*' set of pipes, and perhaps an independent set of '*pump rods*', and the former are documented as removed in the 1850s. This '*pitwork*' was located at the shaft's north-west end, as indicated by a drainage channel here in the chamber at the shaft top; the timberwork first seen in 2019 at this end of the shaft, all of which are sawn and of rectangular cross section, may well have supported the '*pitwork*'. We know some of the 'pump pipes' were taken out and sold in the mid-1850s but it may be that from a short distance below the blockage at *c.* -124m to -127m they remain intact. There are other timbers at the other end of the shaft, the interpretation of which is returned to below.

Table 3: The disposition of horizontally-set timbers in the pumping shaft.

WNW End

Feature	*Depth*	*Character*

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PS1	-0.0m to -0.1m and -1.6m to -1.9m	A substantial beam, *c.* 0.3m high and *c.* 0.2m wide, with the site of another vertically above defined by notches in the shaft walls that are 0.20m wide and *c.* 0.12m high.
PS4	-11.5m to -11.8m	Two substantial timber beams at the same horizon as each other, each *c.* 0.30m high and *c.* 0.20m wide, with a gap of similar width between them; these were presumably surmounted by a platform made of timber planks but these have not survived.
PS10	-60.1m to -60.3m	Substantial timber beam, which is *c.* 0.2m high and *c.* 0.2m wide, placed at about *c.* 0.8m below the flat base of the main part of the 'side pipe working' at PS8.
PS14	-84.3m to -84.5m	Substantial timber beam that is *c.* 0.2m high and *c.* 0.2m wide.
PS17	-111.3 to - 111.6m	Two substantial timber beams, set at the same horizon as each other, which are each *c.* 03m high and *c*. 0.2m wide; these were presumably surmounted by a platform made of timber planks but these have not survived. Above there is what appears to be broad timber plank or two timbers laid horizontally, built to bring the floor up to a small probable 'side pipe working' or possible 'level' going off southwards to the side.
PS20	-124.0 to -124.3m	Substantial timber beam, of *c.* 0.3m height and *c*. 0.2m width, at about the same horizon as the base of 'side pipe working' PS19 at the other end of the shaft.

ESE End

PS2	-1.6m to -1.9m and -2.5m to2.8m	The sites of two pairs of timbers defined by notches in the shaft walls, each with a timber set above another, with these *c.* 0.3m horizontally apart. The two upper ones at the same horizon as the lower timber in PS1. Those notches furthest into the shaft would have held substantial timbers that were *c.* 0.3 high and *c.* 0.2m wide, while the other two were narrower at only *c.* 0.12m wide. Presumably these timbers were for two wooden platforms with timber planks, one above the other, with the larger timber defining the edge of this and the narrower ones placed beneath the platforms. Whether they were used together or sequentially is not known.
PS3	-8.6m to -8.9m	A substantial beam, *c.* 0.3m high and *c.* 0.2m wide, placed at the shaft end next to the floor of an entrance to a 'level'. There are also probable notches for another timber of smaller dimensions at a slightly higher horizon than the remaining timber, placed with its base aligned roughly with the top of that remaining at the shaft end; it is not clear if both timbers supported a timber-planked platform or not; the different depths in the shaft suggest not.
PS6	-50.3m to -50.6m	Four timber notches for substantial timbers for two timbers at the same horizon as each other. All the notches are rectangular with base and sides defined. The outer timber was set in the NNE and SSW walls of the shaft about 0.5m from the shaft end, while the other was placed against the shaft end. Each notch would have held timbers that were *c.* 0.3m high and *c.* 0.2m wide. They would presumably have supported a platform made of boards but these have not survived.

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PS9	-58.0m to -61.5m	The 'level' leading off here has a complex arrangement of timbers below its current floor, with backfill below and a two-timber platform at the base and other timbers placed on this, set above each other. There is a vertically-set iron bar in front of these near the centre line of the passage. These upper timbers stand out as having a different function to the other *in-situ* timberwork in the shaft, and appear to be designed to support the backfill in the 'level'.

All the timberwork lies to the ends of the shaft as would be expected, and where the horizontally-placed sawn beams are substantial they appear to comprise pitch pine (PS1, PS3, PS4, PS10, PS11, PS14, PS17). Although very little survives (but see PS11), it is documented that '*lacing*' partitioning was placed in the shaft after it was completed down to *c.* -128m in 1783. '*Bunding*' platforms are also documented as installed at the same time and thus several of the items of timberwork observed in the shaft may well date to their completion in this year.

What follows is a discussion on timbers used for '*rising main*' support, a second set of supports for a postulated '*ladderway*' at the other end of the shaft, and other timbers that were used to retain the entrances to side passages at both shaft ends; unfortunately the details are far from easy to interpret in a clear cut way.

Those timbers in the WNW end of the shaft may well have been at the edge of a side compartment in the shaft that held the cast-iron '*pump pipes*' of the '*rising main*', and possibly also independent timber '*pump rods*'. It is documented that in the part of the shaft explored in 2019 the '*pump pipes*' were removed in the 1850s when the shaft was being abandoned. Presumably the shaft compartment for the pipework was 'laced' with timber planks that have not survived as they may well have been made of wood that was not as durable as the main beams; alternatively the '*lacing*' partitioning needed to be removed to take the pipework out. This '*lacing*' would have protected the metal pipework when heavy objects were being taken up or down the central shaft compartment. The only places where there is more than one beam at the same horizon, which thus comprise platform supports are at PS4 and PS17, with the last at the entrance to a 'level'. There would presumably have been another platform at the shaft top, with PS1 being associated, placed to prevent falls down the shaft; the lower timber at PS1 may well have been designed to give additional support to the '*rising main*'. With PS4, and perhaps PS17, it seems likely that these timbers helped support the '*rising main*' and the implication of this. Given the width of the space between the beams, these pipes could not have been much more than *c.* 20cm in diameter. The mine was a relatively dry one and did not need massive 'pump pipes'. It is documented in the 1787-88 paperwork in the Boulton and Watt archive in Birmingham related to their installation of the steam engine at Ecton that the upper part of the '*rising main*' had a diameter of 9.0 inches (22cm) or 9.5 inches (24cm), while below the '*34 Fathom Level*' (-62m) the diameter was only 8 inches (20cm) (Barnatt 3013, pp. 177, 179); these measurements are reasonably consistent with the archaeological evidence recorded in 2019.

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The depth intervals down the shaft that the timbers were placed at its WNW end are far from regular (see Fig. 8). There is a particularly short space near the top of the shaft between PS1 and PS4 (measuring *c.* 9m). In contrast, there is wider spacing at depth between PS10 and PS14 (measuring *c.* 24m) and between PS14 and PS17 (measuring *c.* 27m). The exceptionally wide space between PS4 and PS10 (measuring about 58.5m), is sufficiently long to suggest there was at least one and possibly two timbers that have been lost without leaving identified traces. Thus, if for the sake of argument PS1 is treated as different, interpreted as associated with the platform top rather than an internal '*bunding*' platform, then we probably have evidence for four or five platforms within the shaft (PS4, PS10, PS14, PS20 and possibly PS17). When the shaft was first sunk to *c.* -128m, it is documented that seven such platforms were installed in 1783 thus we have found at least four or five of these; the very wide gap between PS4 and PS10 suggests that evidence for one or two are missing here, while there may have been another between PS14 and PS20 if PS17 was a later feature.

The timber beams at the ESE end of the shaft may well define a second side 'compartment' and this could have contained ladders. However, there are three timbers potentially defining this 'compartment', at PS2, 6 and 11; the beams of PS3 and PS9 had a different function as noted in Table 5. Interpretation of the partition's function is uncertain given the small amount of data. This said, if the timberwork at the three places down the shaft listed above were not associated with ladders it is hard to know what their function was.

'*Lacing*' partitions at the south-east end of the shaft are suggested by the placing of a once-vertical timber at PS11, with enough room for a ladder behind; this would have protected people in the shaft from large objects being moved in the central compartment. However, the surviving timberwork, taken alone, is significantly too far apart for '*lacing*' and perhaps ladders. Thus, it may be there were other beams down the shaft that have disappeared without trace, located between PS2 and PS6 and again below PS11 to the shaft blockage at this end of the shaft at *c.* -124m (see Fig. 8). This said, even if this is the case, ladders would almost certainly have had to be fixed vertically given how infrequent the timber platforms were, and these would be more suitable for initial '*pitwork*' installation and occasional later inspection of this, rather than an access '*ladderway*' used for miners to reach their places of work on a daily basis.

The arrangement of timbers at the shaft top as PS1 and PS2 is complex and hard to understand in detail but is likely to be associated with a platform across the shaft as a whole. Further down the shaft although there were platforms at both ends of the shaft there is no good evidence for platforms at both ends that matched. The only places where timberwork occurs at similar depths in both ends of the shaft are at PS3/PS4, and at PS10/PS11. However, the timbers here were out of synchronisation by *c.* 3m and *c.* 2m respectively and thus this may well be a fortuitous placing.

Archaeology – The Winding Shaft (JB): The 2022 UNEXUP dive in March 2022 had three specific objectives in addition to testing the submersible robot, first to look at the leads identified in

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2020 that may have allowed entry to unexplored passages, second to look at features deep in the shaft that in 2019 where there was significant uncertainly over their orientation and third to gain access to the 'main pipe workings' via a window in the winding shaft recognised during analysis of the 2019 dive data and published in 2020 (WS5). What was discovered in the shaft is summarised here while new findings in the 'main pipe workings are given below; for details of the archaeological features in the winding shaft see Appendix 2.

The dive in the shaft in nose-down mode had the great advantage that it was easier to avoid obstacles and thus not disturb sediments that would have led to reduced visibility. It also was very useful in checking orientations of features for, by carefully watching the videos from beginning to end, it was possible except at the very bottom of the shaft to check which of the two ends of the shaft were being observed, despite the occasional spinning of the robot. However, there was also a disadvantage, for by not stopping in the shaft at regular intervals and spinning around it was easier to miss small features, particularly in the shaft corners as these were commonly not recorded by the cameras. This applies to timber notches and iron fittings, as for example at WS3 and WS4 that were not seen.

No new features were found in 2022. The orientations of those features already known were for the most part confirmed, although that at WS13 is still uncertain due to lack of data. However, the orientation of the 'level' in WS11 was changed to north and that in WS12 to west. It was also realised, as result of this change, that the 'side-pipe workings' at WS11 and PS16 in the pumping shaft were probably interlinked. While the depth data of features down the shaft for the most part was retained from 2019 (see Appendix 2), in the case of WS10 and WS12 these were refined slightly. 'Side pipe working' WS13 was partially explored but the robot did not enter the two ongoing leads although a better view of these was obtained. Open leads after the 2022 dives are now reduced from four to three (WS1, WS12, WS13); these are returned to below.

Specific details seen for the first time in 2022 included ironwork at openings (WS12) and displaced tramway rails and pipes within them (WS2, WS4).

While some of the changes and additions made in 2022 as just listed are only details of no interpretative consequence, others at depth at WS11-13 have implications that demand revision of the previously published interpretations of features in the winding shaft (Barnatt 2020, pp. 45-50, 62-63).

<u>'Side Pipe Workings', 'Cross Cuts' and 'Levels' in the Winding Shaft</u>
In some cases the assessment of whether openings were 'levels' or 'side pipe workings' has changed or been modified, and more importantly one was wrongly oriented in 2019 (WS12). Thus, to save confusion the tables presented in 2020 are re-presented here as Tables 4 and 5 and some data shown on Figs 7 and 8 have been changed. The interpretative texts that went with assessment made in 2020 are also repeated below in somewhat modified form.

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Table 4: 'Side Pipe Workings' leading off the Winding Shaft

Feature	*Depth*	*Orientation*	*Character*
WS6	-56.5m to -57.5m	West and north	This 'side pipe working' has only a small entrance, but almost certainly gets larger inside where it extends upwards and out of sight to the north, with a complex set of collapsed support timbers below. It is linked on the other side of the winding shaft, via a short 'cross cut' (PW10) with the 'main pipe workings' to the east (PW6).
WS11	-95.3m to -99.5m	east and north	Large-sized 'side pipe working' with multiple cavities, with parts of two or possibly three timber working platforms remaining, and with a small 'side pipe working' leading off northwards at the back, that is probably the same 'side pipe working' as the one in the pumping shaft at PS16. WS11 may well also effectively be part of the same 'side pipe workings' as WS12, with a walled-off section between the two.
WS12	*c.* -99.0 to -103.5m	west and north	Large-sized 'side pipe working', with multiple cavities, extending down from the base of the entrance from the shaft at *c.* -100.5m, to an unknown depth and probably connected with WS13. One of the cavities leading off at the back is a probable 'level' leading off westwards. WS12 may well also effectively be part of the same 'side pipe workings' as WS11, with a walled-off section between the two.
WS13	-107.9m to -110.6m	west and north	A relatively large opening to a shallow 'side pipe working', which may extend upwards out of sight at the northern end and may well link upwards to the workings at WS11/12. At the 'side pipe working' floor there is a 'level' heading westwards.

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Plate 13: Looking diagonally upwards into the entrance of the ‘side pipe working’ at WS6 in the winding shaft, with a collection of timbers, some at least of which have collapsed downwards from within the working. The metal ring was placed here after the collapse

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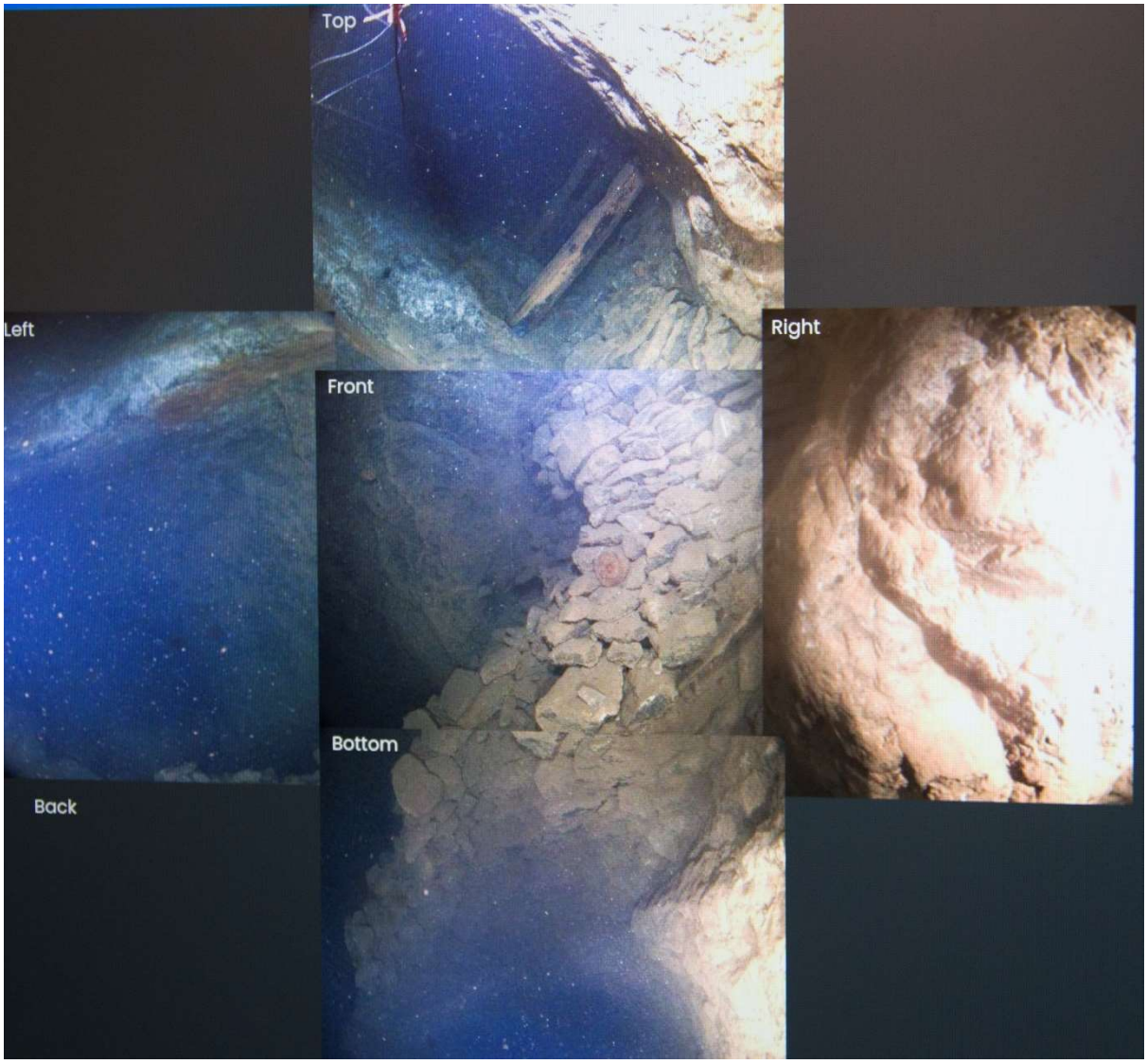

Plate 14: The five camera views photographed from a monitor in real time during the 2022 dive at the winding shaft, taken when the robot was facing roughly horizontally to investigate features at WS12. The main cavity of WS12 lies to the left, while the winding shaft is to the top and bottom. The drystone wall goes up to a timber platform at the left side of WS11; note the small circular 'wheel' near the centre of the 'Front' image.

The 'side pipe workings' were found at two horizons in the shaft, at *c.* -55m to -60m (WS6) and at *c.* -95m to -110m (WS11, WS 12, WS13); the workings in the latter are larger and more complex. These two zones match the depths of those in the pumping shaft. The orientation of the 'side pipe workings' from the shaft varies. However, the main interlinked ones (WS11-13) in their upper part run north and east, and thus have strong potential for being linked with the 'main pipe workings'. The 'side pipe workings' at WS12-13 lie to the west and north but may originally have been part of

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those at WS11 before the shaft was sunk. The uppermost 'side pipe working' (WS6) lies to the west of the shaft but is linked with the 'main pipe working' via a short 'cross cut' running eastwards.

Table 5: The disposition of 'cross cuts' and 'levels' in the winding shaft.

North End

Feature	*Depth*	*Destination*
WS1	-5.00m to -6.70m	'Level' with destination unknown.
WS2	-26.2m to -27.2m	'Level' at the same depth as PS5 in the south-east end of the pumping shaft, so probably this was a 'cross cut' to here that did not follow a straight line.

East Side

WS5	-51.9m to -53.9m	This 'level-like' feature almost immediately enters the 'main pipe working' (PW6) and it may well be an accidental breach made when the shaft was being sunk, with the opening later reshaped for reasons unknown.
WS7	-57.5m to -59.0m	'Cross cut' entered in 2019 and shown to go to the 'main pipe working'. This passage may have been designed to link the 'main pipe working' with the 'side pipe workings' at WS6 rather than having been used to load ore in the winding shaft, with this created later.

West Side

WS8	-79.0m to -81.4m	'Cross cut' entered in 2019 and shown to go to the pumping shaft at PS13. The route between the two changes direction part way along.
WS12	*c.* -100.5m	Probable 'level' (or 'side pipe workings') going from the 'side pipe working' here to an unknown destination.
WS13	-109m to -110.5m	'Level' going from the 'side pipe working' here to an unknown destination.

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Plate 15: The WS5 opening looked at from the PW6 'main pipe working', with the side walls of the winding shaft just visible behind the rubble-covered ledge between the two features.

As can be seen from the table, there are 'cross cuts' to the pumping shaft at WS8 and probably WS2, while another at WS7 goes to the 'main pipe workings'. The postulated upper link to the pumping shaft (WS2) is small and irregular and may have been designed as an air-way used to bring ventilation to the pumping shaft from the already finished winding shaft while the former was being sunk. That at WS8 is larger but it may also have been initially used in the same way. However, as detailed in the section above on the history of the workings, it is documented that in 1786-88 ore was transferred from half way up the pumping shaft (at its 1786 depth), which was also used for winding for this short period, with the ore then taken to the winding shaft for taking it to the river horizon; WS8 is at the correct depth down the shaft and this may well be the shaft-transfer route used.

Given that both 'cross cuts' are not straight line links between the two shafts, it is tempting to suggest their first parts from the winding shaft were earlier and then they were later extended to the winding shaft. However, it is hard to see why short blind 'levels' (known at WS8 and assumed at WS2)

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would have been driven if was not the intention from the outset to create a link with the pumping shaft.

Another 'level', at WS1, with a timber beam at the shaft that was possibly part of a platform, runs northwards to a destination unknown, and although this is the direction of the pumping shaft it does not enter this. At a much lower depth, two certain/probable 'levels' running west from within 'side pipe workings' also have unknown destinations (WS12, WS13).

Some of the 'cross cuts' and other 'levels' are open and only have sufficient fill to create a flat floor (WS1, WS2, WS5, WS7 and WS8, with the last having a pile of waste rock later placed here at the shaft edge. A probable 'level' has had waste rock added after it became redundant (WS12), while at another 'level' leading back from 'side pipe workings' it has been left open (WS13).

At WS1, above the 'level', there is a sloping 'garland' channel cut into the shaft sides that took water from here into the 'level'. Similar 'garlands' are to be found higher up in the winding shaft at '*Salts Level*' and in the shaft chamber at river-level horizon. All were created to take water running down the shaft walls into the adjacent passages in order to help keep the hemp winding ropes dry and thus reduce their weight.

Timberwork in the Winding Shaft

Details on timberwork have not changed since 2019 but they are repeated for completeness sake. At the 'cross cut' at WS2 at the north end of the shaft, the eastern side wall of the shaft nearby has a shallow picked slot running horizontally, with three sections of well-defined base, suggesting there may have been three timbers forming a platform here; this was perhaps installed temporarily as the 'cross cut' was being created. However, there does not appear to be a corresponding slot on the other side of the shaft so interpretation is tenuous. At a slightly lower depth in the shaft, at WS3, there are two possible circular notches in the western shaft side near the north corner. That to the left is set slightly further down the shaft compared to the other. However, both may well be fortuitous shaft-sinking scars. Further down, at WS4 there are one or possibly two picked rectangular notches, located in the western shaft side near the north corner, one placed above the other but with the lower one offset to the left. Both are of moderate size, rectangular with their long axis horizontal, but the upper one is uncertainly interpreted and may be a coincidental rock removal scar. On the opposite wall, in the eastern shaft side near its north corner, there is another picked notch, again of moderate size and rectangular in shape with the long axis horizontal; this matches the lower slot. The reason a horizontal timber was inserted in the shaft here is not known.

Given that the shaft needed to be kept clear for the 'kibbles', these timbers at the north end of the shaft, where correctly interpreted as such, may have been temporary installations made while the shaft was being sunk. However, at WS10, at *c.* -86m down the shaft, there is an *in-situ* timber beam at the south end of the shaft whose purpose is unclear; this must have been close enough to the shaft end to be out of the way of the 'kibbles'.

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Archaeology – The 'Main Pipe Workings' (JB): The 2022 UNEXUP dive in March 2022 had a specific primary objective in addition to testing the submersible robot, to look at the open lead at the end of the 'main pipe workings' identified in 2020; it was also to investigate any side cavities that were identified in the process. What was discovered is summarised here and given on Figs 6 and 7; for details of the archaeological features in the 'main pipe working' see Appendix 3.

The UNEXUP Dive in the Main Chamber at Depth

On this 2022 dive the robot entered the 'main pipe workings' at *c.* -53m by passing through opening WS5 from the winding shaft into the PW6 part of the 'main pipe working' chamber; minor new details were recorded here but it was also realised that the retaining wall at PW7 was much closer to PW8 than was originally thought. The robot then went into the NNW part of the main chamber that had not been explored in 2019 (PW11). The extent of the large passage here was identified from the new sonar plots; those of 2019 when the robot was further SSE could now be seen to be a little over-simplistic, stopping short in PW11A and not showing the low undercut at PW11B. Beyond the NNW end of the main chamber two sets of passages led off in the same direction, both partially explored but left as open leads (PW11A, PW11B); the former is a promising candidate for finding a significant amount of further passages beyond where we turned around, while the latter links with 'side pipe workings' (PS8) at the pumping shaft. Newly-seen artefacts comprised an iron wall pin in PW6 and a displaced timber beam in PW11B.

While some of the changes and additions made in 2022 are only details of no interpretative consequence, those at the NNW end of the 'main pipe workings' have implications that demand revision of the previously published interpretations of features in the 'main pipe workings' (Barnatt 2020, pp. 51-60).

The size of the main chamber was established accurately for the first time in 2022 by recording its NNW end. The overall dimensions of this cavity are now known to be *c.* 55m long by 20m wide; today the chamber is to *c.* 10-20m high, but originally was considerably more at its SSE end before this was partially backfilled by miners as they stripped back the 'pipe working' sides to bedrock while searching for ore in the 1790s. Beyond here, the passage at PW11A was explored for *c.* 10m. It was a tall 'stope-like' passage that was *c.* 15m high and *c.* 4m to 5m wide, which went horizontally north-westwards. In contrast, the nearby PW11B workings comprised four small but potentially conjoined entrances, with adjacent packs of deads and boulders. In one case certainly, and three probably, these holes lead to a 'side pipe workings' (PS8) at the pumping shaft. One of the entrances runs off from a deep undercut in the main chamber end and this was the only area entered by the robot. Second and third holes at floor level remain un-entered. However, the fourth hole, comprising a small oval opening in the main chamber wall above, has also been identified on the video of exploration of the 'side pipe working' confirming a link here.

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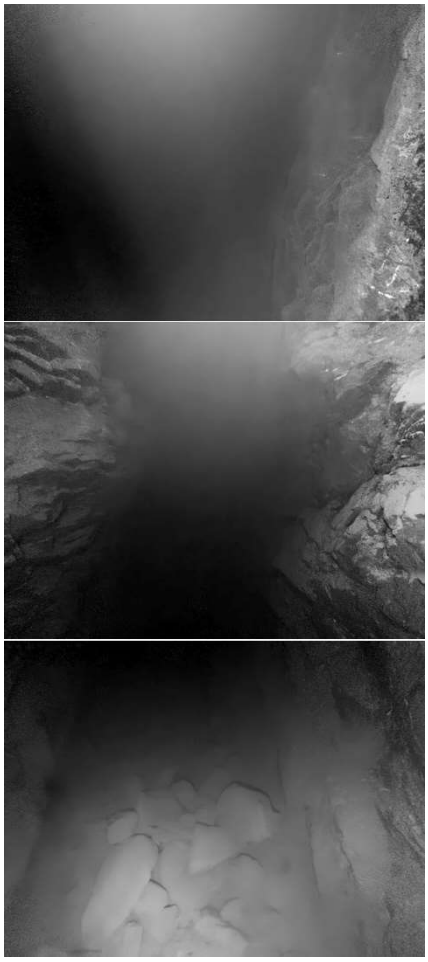

Plate 16: The tall PW11A ‘stope-like’ passage with sinuous sides running off the NNW end of the PW11 main chamber, which is so tall that it can only be captured by looking at three cameras simultaneously

Plate 17: One of the packs of deads at PW11B, with a bedrock pillar behind, and to the right one of the openings that has not yet been explored but probably goes to the PS8 ‘side pipe workings’ at the side of the pumping shaft

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Plate 18: The hole in the main chamber wall at PS11B that leads into the PS8 'side pipe working' entered from the pumping shaft

Plate 19: The hole in the main chamber wall at PS11B as seen from the other side where it is high in 'side pipe working' entered from the pumping shaft (PS8)

After the 2022 dives the two open leads at depth just noted still need further investigation to determine the extent and character of the ongoing workings. In the case of PW11A there is a need to establish whether passages can be found that link with the massive 'North Open' 'pipe working' known from documentation to exist at greater depth.

The BlueROV2 Dive in the Upper Flooded 'Pipe Workings'

Five short dives by the BlueROV2 submersible on 29th-30th September 2021 made significant advances in our understanding of passages here (RW1, PW3).

We now know there are at least two main passages descending vertically from the base of the PW1 into PW3, in the zone between the two chambers identified in 2019 (PW1; PW4/6/11). The way down used in 2019 was at the north-east corner of the PW1 chamber, while the other, which is large and 'stope-like', was entered in 2021; this goes WNW from close to the north-west corner of the same chamber. This second passage was descended to *c.* -15m at its ESE end to where there was a rubble floor, while a little further WNW it went significantly deeper and there was a timber across the passage. This passage has a roof that slopes downward going WNW to a point at *c.* -13m. Here, at its end, the passage was crossed near its roof by a 'cross cut' at roughly right angles, where there had been a 'bridge' over it with a base at *c.* -15m. Here there was presumably originally a wooden plank at floor level, while above there were two 'hand-rails'. One of these remains today and

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comprises what looks to be a corroded iron chain, which is fastened to iron hooks at either end; the hooks for the other 'hand-rail' are also extant. The 'pipe working' below here was followed down to *c.* -27m and may well go deeper. The 'cross cut' has not been explored in either direction, but it may well be coming from the south winze with a top striking chamber at the '*Deep Ecton Sough*' horizon just above the flooded workings. In the opposite direction, to the NNW, it may lead to another winze, this one leading down to greater depth. This observation is based on the postulation that what we have seen is an upper part of the stepped '*ladderway*' going down to the -62m '*Boat Level*', as shown but not named on the Meads' 1858 mine elevation. However, this is still to be confirmed.

Plate 20: The metal chain across the large 'pipe working' that runs WNW from the PW1 upper chamber in the 'main pipe working'. The camera is looking into the 'cross cut' running NNW. The chain provided a 'hand-rail' for a bridge near the 'pipe working' roof, with a hook on the opposite side for a second chain. Presumably there was once a timber that was used to walk on

Several small chambers, vertical holes and horizontal alcoves were explored at the eastern end of the PW1 chamber amongst the 'Swiss Cheese' of passages here. This included one that led up to the 'side pipe working' chamber with timberwork partially above the water-level horizon near the north-eastern corner of the PW1 chamber. The other uppermost passages at this end of the chamber were all entered and found to be small or just alcoves. However, the upper chamber with timberwork also had an unexplored hole going down, and there were holes in the PW1 chamber wall between -6m and -10m, all to the ENE, that were also not entered. A tall 'stope-like' passage immediately to the west of the chamber's north-east corner contained two horizontal timbers, one above the other.

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This feature proved to be only a shallow steeply dipping alcove where the hading limestone beds it followed had been removed, presumably in the 1790s when they were searching for more ore.

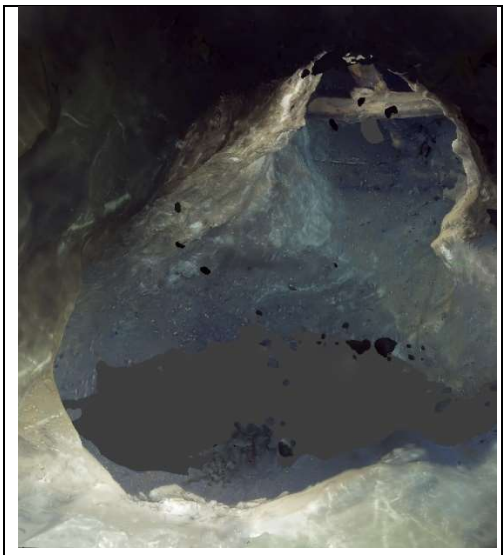

Plate 21: A composite image compiled using 'Agisoft Metashape' photogrammetry software using camera video footage taken by the BlueROV2 submersible. This shows the rising 'side pipe working' passage to the eastern end of the PW1 chamber. The timbers above, with two beams supported a timber working floor, one plank of which remains, can also be looked down upon from a small chamber' running from the north-east corner of the main void just above the water

Plate 22: A timber beam, presumably for a working platform, in the tall alcove near the north-eastern corner of the upper 'main pipe working' chamber at PW1

The BlueROV2 dives have also clarified the character and locations of artefacts on the upper chamber floor (PW2), and it is now known one of these is probably a pram of early to mid-20th century date; this may well have been thrown down the 'pipe working' entrance high on the ridgetop.

Archaeology – The North Winze (JB): The archaeological character of the North Winze and features therein were investigated during the two dives in March 2022; details of archaeological discoveries are given in Appendix 4. These dives were undertaken using the BlueROV2 submersible, which only has a single forward facing-camera, thus while all large features such as side passages are likely to have been seen others that were small, such as timber notches, may well

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have been missed because the camera never pointed in the right direction. Unfortunately the depth indicator was not working and thus the positions down the shaft of identified features could only be estimated, although the depth of the rubble fill at the current base had been plumbed previously.

The North Winze shaft at its top is somewhat trapezoidal in plan and it fills the full width of a horizontal trial passage heading westwards at the river-level horizon (Barnatt 2013, page 73, Fig 30). The shaft itself is spacious and measures about 3.0m by 3.0m in plan throughout its depth. It is recorded in the mine accounts in Chatsworth House as sunk in *c.* 1795 during a series of trials in this part of the mine. Its depth was plumbed in *c.* 2010 by John Barnatt and Richard Shaw and was found to be *c.*-19.5m deep (Barnatt 2013, p.77); we now know that this depth was to a rubble choke blocking the base of the shaft. The shaft is sunk through bedrock, with only occasional small calcite-dominated vughs and the usual masses of small calcite filled fractures in the bedrock as usually found close to the main areas of mineralisation at Deep Ecton Mine. Gunpowder shot hole scars were frequently observed in the shaft, usually facing downwards and sometimes it could be seen that these were found at regularly spaced intervals reflecting the initial shaft sinking.

It was already known, as features were visible without diving, that the shaft once had a complex wooden platform across its top, with the notches for the timber supports still visible in the shaft's rock sides to the east and west; some of these still contain the metal wedges used to tighten the timbers. There is also a 'side pipe workings' coming down from above (NW2) that probably predates the shaft and was intersected at the shaft top, with its base a short distance underwater (Barnatt 2012, pp. 306-10).

Close to the present shaft bottom there are short trial 'levels' running off horizontally to the east and west sides of the shaft (NW4, NW5), the latter abandoned shortly after it was started. A horizontal timber at the south side of the shaft is possibly a support beam for a now-gone platform across the shaft at the floor horizon of both trial 'levels'. However, the timber is not set into a notch cut into the floor of the NW4 'level', while the other end is not clearly visible on the videos and thus it may well be fortuitously arranged. It is not known how deep the rubble fill choking the shaft bottom is (NW6). If the rubble is shallow, with the rubble filling a sump below the two trials then there will be no further workings leading off. However, if the choke is deeper, then there may be further now-inaccessible 'levels' going in unknown directions. In either event, the shaft was probably abandoned before being put to use, presumably because no ore deposits worthy of sustained mining were found. While the rock from shaft sinking was presumably brought up using a '*stowce*' (hand-operated windlass) placed on the shaft-top platform (NW1), there is no large striking chamber that would have been desirable if ore was being brought up in any quantity.

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Plate 23: The rubble at the present NW6 base of the North Winze, presumed to have been thrown down in the 1790s after the trial using the shaft was abandoned. The danger sign only came down the shaft recently after it became detached from the modern safety chain at the shaft top

Amongst the stones of the rubble choke in the shaft there are several sturdy timbers, three rising vertically at the shaft sides; some at least are interpreted as likely to be from the timber floor that once covered the shaft top. However, while the walls of the shaft were not systematically searched, one notch for a sturdy horizontally-placed timber part way down the shaft was observed (NW3); this and further shaft timbers may have ended up at the shaft base. One possibility is that timbers going down the shaft supported a '*ladderway*' used to access the shaft bottom. There may also have been churn or rag and chain pumps, used to make sinking possible, with a small series of these going to the shaft top with platforms at each.

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Plate 24: Displaced timberwork on the floor of the entrance to the NW4 eastern trial near the present North Winze base. This is overlain by a modern scaffold pole in the shaft. To the bottom right in the gloom is the horizontal timber that is either also displaced or was a 1790s support for a platform across the shaft at the horizon of the floors of the short NW4-5 'trials levels' leading east and west.

The rubble in the shaft base is likely to have been thrown down the shaft in the 1790s shortly after the shaft trial had been abandoned, derived from several nearby short trials near and above the shaft top dating to this decade; it well may be that some or all of the shaft timberwork collapsed during this dumping. While we do not know what other trial 'levels', if any, may lie below the present shaft choke, it is worth noting that there is certainly a link between the North Winze and the 'main pipe

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workings' as indicated by hydrostatic adjustment in water-levels that match each other. This said, whether the workings themselves intersect or the water flows through natural fissures is not known.

All this work at and around the North Winze took place shortly after the main mineralised pipe failed at depth and trials were started in old workings in the search for previously missed ore deposits. The North Winze is of surprisingly impressive dimensions for a trial; it may well be that this ambitious project was undertaken with misplaced optimism at a time when the Duke of Devonshire's agent and his miners were still convinced that good ore was bound to be found in quantity somewhere at Deep Ecton Mine; this proved not to exist anywhere in the mine and after much searching over several decades the pumps were turned off. The North Winze presumably flooded for the first time at this time, kept dry until then by mine passages or natural fissures that took water away from its base.

Future Explorations

At the end of the 2022 dives there were still large areas of the mine we had not yet entered and hence there is much to be learnt in the future; the basic question is whether any of the leads we have identified are going to give viable access to the many passages, some going to over double the depth of the horizon of the chokes in the two main shafts, that have still to be explored.

If future explorations by submersibles are made at Deep Ecton Mine there are various open leads to investigate that have not yet been adequately explored. Three prime objectives were identified at the end of 2019 and these still apply. First the entry of further 'pipe workings' at depth: second entering the '*Boat Level*' at -62m: and third further exploration of the flooded complex upper 'pipe workings'. Those leads searched in 2021-22 and found not to be viable are identified in Table 6, while those passages still with potential for further discoveries are listed in Table 7 and shown on Fig. 13.

Table 6: Places explored in 2021-22 that now have no or only limited potential for exploration of further passages.

A: To access workings at depth

Feature	*Depth*	*Observations*
PS16	*c.* -95.5m to -99.0m	The main way on at this 'side pipe working' very probably goes to the 'side pipe working' at the winding shaft (WS11).
PS17	-108.0 to -111.6m	The probable 'side pipe working' or possible 'level' here has been backfilled and cannot be entered.
PS18	-115.0m to -117.5m	This 'side pipe working' has been shown to be small and only extending a short distance from the shaft with no ways on.
PS19	-121.0m to -123.0m	This probable 'level' or possible 'side pipe working' has been backfilled and cannot be entered

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WS11	*c.* -95.0m to -97.5m	The main way on at this 'side pipe working', located at the north end of the shaft, very probably goes to the 'side pipe working' at the pumping shaft (PS16).
PW11	*c.* -40m to -58m	While this spacious 'main pipe working' passage has been shown by the 2022 sonar survey to extend horizontally to the NNW as a broad feature its end has been identified. Continuations as smaller passages, at PW11A and PW11B, have now been identified. That at PW11A still needs its exploration completing to see if it goes down to depth (see Table 7).

B: To access the '*Boat Level*' and '*Deep Level*' at -62m

PS8	*c.* -57.0m to -59.0m	One hole within this 'side pipe working' certainly, and three others probably, go to 'main pipe workings' at the NNW end of the main chamber that was explored in 2022 at PW11B.
PS9	-58.0m to -61.5m	This part-backfilled broad passage is now known not to be tall enough for easy entry.
PS12	-62.5m to -65.0m	Close examination of this walled-off feature in 2022 showed that a possible horizontal passage above the dam is fully sealed with sediments and there is no open way on.

C: To complete explorations in the upper parts of the flooded workings

Feature	*Depth*	*Observations*
PW1	-0.0m to -11.5m	Some but not all of the side passages running off the main upper chamber were explored. Those with ongoing leads are given in Table 7 but others were discounted in 2021, including a steeply rising passage that went to timberwork in a 'side pipe working' visible from above water-level in a small chamber NNE of the main PW1 chamber.

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Plate 25: The dam across the PS12 possible 'level' and probable 'side pipe working' has sediments at its top to the left that could fully seal a postulated passage directly behind. The dark area here is a shadow cast by the submersible lighting. A probable 'side pipe working' to the right rises steeply upwards and presumably goes out of sight

From Table 7 it can be seen that there are still four leads in Section A with potential to give access to the extensive not yet entered lower workings and exploration here could greatly expand our knowledge of Deep Ecton Mine. There are no open leads in Section B that could give access to the historically and archaeologically important '*Boat Level*' at -62m. However, access to these may be possible by coming down from well above via a postulated '*ladderway*' as given in Table 7C, or coming up from somewhere in the 'main pipe workings' below via the leads given in Table 7A. There are still four leads in Table 7C where future exploration will add valuable detail on the complexity of the workings here.

For the most part these proposed explorations will only be possible once a submersible robot is used in autonomous free-ranging mode rather than being attached to an umbilicus.

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Table 7: Places still to explore in the future where there is potential to gain entry to places not yet explored in the flooded parts of Deep Ecton Mine.

A: To access workings at depth

Feature	*Depth*	*Observations*
PS15	-90.3m to -96.5m	While now entered twice, further explorations of this 'side pipe working' are needed at its top to see whether two potential ways on give access to the 'main pipe workings' or indeed whether they are part of this. Similarly, a small and part-choked 'level' leads off horizontally near the bottom of the working that, if it can be entered, may lead to further passages.
WS12	*c.* -100.5m	Entry of this probable 'level' or possible 'side pipe working' at the back of WS12 would establish the nature of this passage and may give access to the 'main pipe workings' at depth.
WS13	-109m to -110.5m	Entry of the 'level' at the back of 'side pipe working' WS13 would establish where it goes and may give access to the 'main pipe workings' at depth.
PW11A	*c.* -40.0m to -57.0m	This large 'stope-like' passage still needs its north-western end exploring to see if there are passages here that go down to depth.

B: To access the '*Boat Level*' and '*Deep Level*' at -62m

Feature	*Depth*	*Observations*
		There are now no open leads to these levels from the same horizon below water-level, but see PW1/PW3 below as the open leads here may well include the '*ladderway*' recorded by Meads in 1858 that led down to the '*Boat Level*'.

C: To complete explorations in the upper parts of the flooded workings

Feature	*Depth*	*Observations*
PS7	-52.9m to -55.0m	Entry of this 'level' will establish its destination.
WS1	-5.00m to -6.70m	Entry of this 'level' will establish its character and destination.
PW1/PW3	-0.0m to -22.0m	The extent and distribution of the uppermost passages leading off the flooded part of the upper chamber in the 'main pipe working' at its east end were explored in 2021. However, other holes leading off the main chamber below *c.* -6m to the ESE and -11.5m to the WNW have still to be fully assessed. These include the main way down to the ENE followed in 2019 and one that may lead to this coming vertically downwards from a hole above located a short distance beyond the eastern end of the PW1 chamber. The spacious 'stope-like' passage to the WNW also goes steeply downwards and this was followed to *c.* -27m and may well extend deeper.

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		A ‘cross cut’ at the end of the WNW passage has been seen where it intersected this ‘pipe working’ near its roof. Miners using this originally crossed the ‘pipe working’ on a bridge with a floor at *c.* -15m, and this ‘cross cut’ still needs exploration. It may well be coming from the South Winze in the southern striking chamber and there is a good chance this continues north-eastwards as an upper part of a postulated ‘*ladderway*’ down to the -62m ‘*Boat Level*’.
PW4/6	*c.* -22.0m to -58.0m	Explorations of the ‘alcoves’ and small passages going off the chamber side at various depths would give a better picture of the complexity of the ‘pipe workings’ in this part of the mine.

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Figure 31 The distribution of known potential leads for future exploration after the 2022 dives, as listed in Table 7, imposed on the Meads' 1858 mine section. A distinction is drawn between those that may lead to the 'main pipe workings' at depth, one that could lead to the documented canal at -62m, and others where there are further explorations to be made in the upper workings.

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Plate 26: This small, part-backfilled WS1 'level' heads north from the winding shaft at a point only just below c. -5.0m from the shaft top. It has not been entered and while it is heading towards the pumping shaft there is no matching opening at this depth and thus its destination is elsewhere

Appendix 1: The 1780s Pumping Shaft - Revised Archaeological Details (JB)

This Appendix describes the archaeological features and artefacts in, and viewed from, the pumping shaft, which were observed on the seven dives here in 2019 and another in 2022; all discoveries are described in detail in Table 8 below (also see Figs 6-8).

This appendix was first presented in the 2020 archaeological report and is re-presented here in updated and partially revised form. However, many of the features described in Table 8 were illustrated with photographs in the 2020 report and this should be referred to for these. The depth readings quoted in 2019 have been retained (see below), but the orientations of features from north

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have been checked and where necessary revised (features PS3, PS5, PS13-19). To save potential confusion the same catalogue numbers are also retained, while one new feature is followed by the letter A (PS19A).

The shaft itself (PS0) is rectangular in plan, measuring about 2.0m by 4.0m at its top, and originally dropped vertically to about 202m, but now it has a blockage at -124m to *c.* -127m (see PS21 below); this has prevented downward explorations below this point. As the shaft was descended its sides were seen to be relatively irregular but with a roughly sub-rectangular shape retained throughout, with ends that are narrower than the longer sides. Gunpowder shot hole scars were frequently observed, often facing downwards and sometimes these were seen to be at regularly spaced intervals that reflect its sinking, with the shaft bottom taken down by about 0.5m each time the depth was increased.

There are 'side pipe workings' that are intersected (PS8, 9, 12, 15-19) and also several 'cross cuts' and other 'levels' going off the shaft (PS 3, 5, 7, 9, 12-13, 15, 17, 19), some with their character interpreted with certainty, others less so. There were also large timbers and sites of timbers across the shaft near its ends that retained platforms and/or supported mine 'pitwork' and timber partitions (PS1-4, 6, 9-11, 14, 17, 20). Near the current accessible shaft bottom there is a simple miner's inscription (PS 19A). Artefacts such as displaced timberwork, tramway rails and small diameter pipes are found in various places (PS4-5, 13, 15, 17).

In the lower parts of the shaft the visibility of features on the 2019 videos was also often poor, particularly for features PS15-PS19. However, the clarity of the water was much improved in 2022 allowing better appraisal of features in the lower part of the accessible pumping shaft.

For reasons unknown there are minor discrepancies in recorded depths between the 2019 and 2022 dives, with the new dive instrumentation giving depths that were between *c.* 1m and 3m greater than in 2019, with this on average increasing with depth. There are several potential factors here. The 2019 dives had the 0 datum fixed at a target around -0.3m to -0.5m below standing water surface, while those of 2022 were set at the water surface. The robots have neutral buoyancy and this leads to a +/- 0.5m uncertainty factor every time the depth is set at the beginning of a dive. Secondly, the water density calibration used to determine depths can differ due to varying salinity of the water and although not a major factor we know from the 2019 conductivity measurements that this changes with depth at Ecton. Also, the latency in the response rate of the pressure sensor used to calculate depth may mean that during rapid descent or ascent the recorded depths are inaccurate; we only get more accurate measurements when the robot stops to look at a feature. There is a further +/-0.5m uncertainly due to the varying pitch of the robot that applies to all dives; the greater the distance the feature is from the robot the greater the error. The water-levels at the dive sites change from season to season but this may not alter the readings given below by a significant amount as both sets of Ecton dives were in the spring. There is no way of knowing from the dive data whether it is the 2019 or 2022 instrumentation that is the more reliable. The 2019 readings are retained in Table 8

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below because more features were examined carefully than in 2022 and there is thus more depth data.

In 2019 the compass directions for features given (as North, NNE, NE, ENE, East, etc.) in the original version of Table 8 were thought to be correct down to about -90m (PS1-PS14). However below *c.* -90m there was recognised significant uncertainly in orientation due the problems with the navigation logging (PS15-21). In 2022 the navigational problem that affected assessment of orientation had been resolved and all orientations of features have now been revised. In the upper part of the shaft it was found that PS3 and PS5 had been wrong, while lower down PS13-19 had to be corrected or refined.

Table 8: The Recorded Archaeological Data in the Pumping Shaft as revised in 2022.

Depth below 0m	*Feature Number*	*Description*
-0.0m to -1.9m	PS1	**Substantial Timber Beam and Notches for a Second Beam:** The extant beam is located to the WNW end of shaft and defines a narrow shaft-end compartment here. The timber is *c.* 0.3m high and *c.* 0.2m wide, and has a sawn rectangular cross-section. It is set horizontally between the two shaft sides, where it is placed in notches in the walls. Directly above this extant beam there are two notches for a second timber of smaller size, one located in each shaft side. To the SSW side of the shaft the notch is a carefully made rectangular slot, *c.* 0.20m wide and *c.* 0.12m high, cut into the lowermost course of the ashlar wall that defines the shaft 'collar' here. To the NNE side of the shaft there is a slot for the same timber, now filled with small stones, cut into the top of a sloping rock ledge. The two timber beams would have been *c.* 1.5m vertically apart, measured from the base of the upper one to the top of the still *in-situ* one below. It is likely that the upper timber helped support a platform at the shaft top, while the second was placed to give added stability to the '*rising main*' pipework, and possibly independent '*pump rods*', which went down the shaft from here. There are further timbers, at a comparable horizon as the *in-situ* beam, at the other end of the shaft at PS2. There are also timbers/platforms, and notches for these, further down at the north-west end of the shaft at PS3, PS4, PS10, PS17 and PS20, with other timbers at the south-east end of the shaft at PS2, PS6, PS11 and PS14.
-1.6m to -2.8m	PS2	**Notches and Rock-Cut Eyes for Four Timbers:** These recesses in the shaft walls are found in both shaft sides to the ESE end of the shaft. On each wall there are two pairs of wall-cut features, each with one above the other, with the pairs set *c.* 0.3m horizontally apart. Those nearest the shaft end were for two timbers that were somewhat smaller than the other pair. The upper timber beams had bases that were

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		c. 0.5m vertically above the bases of the bottom ones. On the NNE side of the shaft there are two roughly circular eyes for the upper timbers rather than notches, while each of the six notches has its base and two sides defined. The two sets of cut features closest to the shaft centre would have held timbers that were *c.* 0.3 high and *c.* 0.2m wide, while the other two were narrower and only *c.* 0.12m wide. The lower left one on the SSW shaft side has an iron fastening pin near its top. Taken together, perhaps these four timbers were installed to support two 'platforms', one above the other, both in the narrow shaft-end compartment here. Both had the larger timbers defining the edge of this compartment, with the narrower ones nearer the shaft end placed beneath the platform floors. The upper platform matches the PS1 horizon at the other end of the shaft where there is a single extant timber. Why there would be two platforms to the south-east end of the shaft, both a short distance below the shaft top and with so little vertical space between them is not known; perhaps one replaced the other. Alternatively, the upper set supported a platform, while the lower set was to give added strength at the shaft top to whatever fittings went down the shaft from this point. There are timbers/platforms, and notches for these, further down at the south-east end of the shaft at PS6, PS11 and PS14, with other timbers at the north-west end of the shaft at PS1, PS3, PS4, PS10, PS17 and PS20.
-8.0m to -8.9m	PS3	**Choked 'Level' and Substantial Timber Beam:** These features are at the ESE end of the shaft in the south-west half of this, with the timberwork roughly coincident with the floor of the 'level' (Fig. 8). The extant timber, with sawn rectangular cross-section, is *c.* 0.3m high and *c.* 0.2m wide, and is set close to the shaft end in notches in the NNE and SSW sides of the shaft. To the NNE end of the timber there is an iron pin in the shaft wall that helped keep the beam in place. Further into the shaft, on both walls there are probable notches for another timber of smaller dimensions at a slightly higher horizon than the *in-situ* one, placed so that its base is aligned roughly with the top of the other. At its entrance, the 'level' is *c.* 1.0m wide, *c.* 1.6m high from the timber upwards, and has a rounded top. The rubble fill within the 'level' extends to the roof at the back, with a slope that lessens markedly in steepness as it comes down towards the timber. The lowermost stones overlie the beam, while stones behind fill the gap between the beam and the shaft side. The destination of this 'level', which heads ESE, is not known. There are other 'levels' leading off the shaft, including one that 'cross cuts' to the winding shaft at PS13 and others probably doing this at PS5 and PS19. A possible 'level' at PS8 very probably goes to the 'main pipe working' and others, like that at PS3, go elsewhere at PS7, PS9, PS15 and possibly at PS12 and PS17.

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		There are comparable timbers/platforms, and notches for these, at the north-west end of the shaft at PS1, PS4, PS10, PS17 and PS20, with other timbers at the south-east end of the shaft at PS2, PS6, PS11 and PS14.
-11.2m to -11.8m	PS4	**Two Substantial Timber Beams:** These beams are each *c.* 0.30m high and *c.* 0.20m wide and form supports for a platform at the NNW end of the shaft. The timbers, with sawn rectangular cross-sections, are set in notches in the two side walls of the shaft and are placed with gaps between each of similar width to the timbers themselves. There is no sign of notches in the timbers' sides that would have helped hold the iron pumping pipes that almost certainly ran between them. There is a heap of stones, and three displaced small timbers or tramway rails, resting on the tops of the two beams that have presumably fallen from above. There are comparable timbers/platforms, and notches for these, at the north-west end of the shaft at PS1, PS3 and PS10, PS17 and PS20, with other timbers at the south-east end of the shaft at PS2, PS6, PS11 and PS14.
-25.8m to -27.2m	PS5	**Small Open 'Cross Cut':** This passage lies in the ESE end of the shaft at the SSW part of this (Fig. 7). At its entrance the 'cross cut' is *c.* 1.4m high and only *c.* 0.8m wide, with a flat roof at the shaft wall but arched inside. Further inside the 'cross cut' is nearly as broad as it is high. The floor is flat and sediment covered, with only a few stones and three small displaced timbers near the rock lip to the shaft. In 2022 the passage was entered for a short distance, but going in for less than 2m as disturbed sediments affected visibility and nothing new was learnt. On the shaft wall, a short distance to the right of the 'cross cut' at its floor horizon, there is a straight iron pin pointing diagonally upwards. This 'cross cut' may well be heading to WS2 in the winding shaft as this is at the same depth below water-level, but PS5 heads ESE from the pumping shaft so there can be no straight-line link. There is another 'level' leading off the shaft that is certainly a 'cross cut' to the winding shaft at PS13 and a probable example at PS19. A possible 'level' at PS8 very probably goes to the 'main pipe working' and others go elsewhere at PS3, PS7, PS9, PS15 and possibly at PS12 and PS17.
-50.1m to -50.6m	PS6	**Four Timber Notches:** These notches are at ESE end of shaft and are for two substantial horizontally-placed timbers at the same horizon. All are rectangular with the base and sides defined. The outer ones were set in the NNE and SSW walls of the shaft about 0.5m from the shaft end, while the other two are immediately against the shaft's end. Each would have held timbers that were *c.* 0.3m high and *c.* 0.2m wide. They would presumably have supported a platform made of boards. There are comparable timbers/platforms, and notches for these, at the south-east end of the shaft at PS2, PS11 and PS14, with other timbers at the north-west end of the shaft at PS1, PS3, PS4, PS10, PS14, PS17 and PS20.

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-52.9m to -55.0m	PS7	**Small 'Level':** This passage lies in the SSW side of the shaft at the ESE corner (Fig. 7). The open part at the top is *c.* 1.3m high and *c.* 1.0m wide, but inside it may have been partially backfilled, as from the shaft side the floor slopes up steeply from -55.0m to –53.6m depth and more gently above. It is unclear, because of sediments here, whether this sloping floor is bedrock or waste stone; the latter seems most likely from what can be seen. The 'level' is irregularly-shaped and has a steeply sloping side to the left, and an irregular curved side to the right. It runs off the shaft at a slightly diagonal angle from the SSW shaft side, heading roughly southwards. While PS7 heads in the right direction for the winding shaft and the hole in the shaft side at WS5 is at the same horizon, this goes into the 'main pipe workings' rather than linking with PS7. At the left side of the PS7 'level' by the entrance, half way up the steep slope, there is a horizontal iron pin. At a similar horizon on the right side, on the corner with the shaft wall, there is a horizontally-placed iron hook with a right-angled bend and outer half rising vertically to where there is a widened end. Perhaps this held a horizontal timber at the original floor horizon of the 'level'. There are 'levels' leading off the shaft that 'cross cut' to the winding shaft at PS13 and probably PS5 and PS19. A possible 'level' at PS8 very probably goes to the 'main pipe working' and others go elsewhere, as with PS7, at PS3, PS9, PS15 and probably/possibly at PS12 and PS17.
-53.0m to -59.3m	PS8	**Tall 'Side Pipe Working' with a Possible 'Level' and Other Openings:** This 'pipe working' lies in the NNE side wall of the shaft and spans much of its length except for a short stretch close to the ESE corner (Fig. 7). At the shaft wall it has an arched top, near-vertical irregular sides and is *c.* 4.0m wide and nearly 6.5m high; the left side has a prominent bulge part way down at *c.* -55.5m. The flat bottom of the main working, at *c.* -59.3m depth and has a lip of rock at the shaft side but inside the passage there are piles of rubble along the floor, going up to *c.* -58.5m on the right side. The main passage of the 'side pipe working' was explored in 2019 and 2022; as a tall feature it goes NNE for *c.* 4.0m. A short distance into the tall part of this main PS8 working, to the right when looking in and up, there is an oval hole at *c.* -56m that is also visible above the main three passages of PW11B (Plates 18-19); it can thus be demonstrated to be a window into the wall of the main chamber of the 'main pipe working'. Near floor level in the main PS8 'side pipe working' not far from the shaft to the SSW end of the 'pipe working', there is a low alcove that does not appear to link with PS9 nearby. Further in at floor-level a moderate-sized hole leads to the right and, given what we know of the upper hole noted above, it may well also lead to the 'main pipe working'; outside its entrance in the main passage there are displaced timbers on the floor. A short distance beyond this side passage, at the end

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		of the tall section of the main passage, there is a relatively small oval passage going horizontally forward at floor-level, again it may well lead to the 'main pipe workings' that are close by (see Fig. 7). At the shaft wall to the right side of the PS8 'side pipe working' opening, at *c.* -55.5m depth, there is an iron hook with horizontal base and upper arm at right-angles. At the left side of the PS8 opening, just within it at *c.* -58.0m depth and a short distance above the rubble on the floor, there is a second iron hook with horizontal base and upper arm at right-angles with an end beyond a second right-angle. This hook is set so that it rises diagonally from the passage wall. A short distance above this there is an iron pin with looped 'eye' at the end that is set approximately horizontally. Within the 'side pipe working' relatively near the roof there is a horizontally placed timber close to the main tall working's inner end. There are other 'levels' leading off the shaft, including those that may be associated with the 'canal level' at PS9 and the possible 'level' at PS12, others that 'cross cut' to the winding shaft at PS13 and probably PS5 and PS19, and others that go elsewhere at PS3, PS7, PS15 and possibly at PS17.
-58.0m to -61.5m	PS9	**'Level' or 'Side Pipe Working' with Substantial Stone Retaining and Timber Platform at its Base:** In the ESE end of the shaft, to the south side of PS8, there is a low but broad hole just above the backfill horizon of this (Fig. 8; Plate 12); despite the very close proximity of the two entrances this does not appear to link with the PS8 passage. The PS9 passage has been largely filled with rubble from *c.* -58.5m downwards, with only *c.* 0.4-0.5m of airspace above. The passage heads roughly north-east to NNE and its destination is unknown, but it may well lead to the 'main pipe workings' as these lie close by (see Fig. 6) and/or could even be associated with the Ape Tor '*34 Fathom Boat Level*' that was about at -62m depth. At *c.* 58.5m depth there is an iron hook in the shaft wall, with horizontal base and upper arm at right-angles, at the right side of the opening. This was placed, at about the same horizon as the top of the crude drystone wall retaining at the shaft. It is at a similar horizon to a horizontal iron pin within this opening, again to its right side, in the passage wall at *c.* -58.3m. At the shaft side the entrance to PS9 is crudely walled across, with timberwork in front of this, and below this a timber platform at the shaft edge with the base of its beams at *c* -61.5m depth. The platform has a substantial two-beam support that comprises a front timber set away from the shaft end with its base at *c.* -61.5m depth, which is rectangular in cross-section and *c.* 0.3m high and *c.* 0.2m wide/ There is another similar timber behind at the shaft wall. Both are horizontally placed between the two shaft sides and set into notches in the walls. To the right side, just below the timber at the wall-end, there is a vertical iron pin holding back a stone at the rock base of the opening here. Above the outer timber beam, there are two shorter timbers set end to end, laid on the beam top. The left one has a bolt with washer through it near its bottom close to the left end. Rising from the top of this left upper timber, near the centre of the passage and going up to close to the top of the retaining wall above, there is a long vertically-set iron pin. This has a square cross plate three-quarters of the way to the top and a circular washer near

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		the top. To the left side of the two upper timbers there is a gap between that placed centrally on the beam and the shaft wall, but with a third timber here set at a slightly higher horizon. Above the left end of the central timber there is also a smaller timber rising upwards, incorporated into the rubble of the wall, with the end of two timbers next to it protruding outwards from the blocking wall, one with a bolt and square washer at its end. To the right side of the passage, set against the rock wall and again above the outer beam with horizontal timber above, there is a vertically placed 'panel' of four short narrow planks laid horizontally, edge to edge and one above the other, which rise to close to the top of the drystone wall. The second and fourth planks up have bolts and washers protruding. The panel of planks has straight edges to left and right sides, the former somewhat damaged, with three rotted nails or bolts going through the planks near the right side. It may well be that most of the timberwork above the outer beam has been re-used from elsewhere and the metal fittings were already here when the structure at the end of the 'level' was constructed. There are other 'levels' leading off the shaft, including another possible 'level' that may be associated with the 'canal level' at PS12, others that 'cross cut' to the winding shaft at PS13 and probably PS5 and PR19, a possible 'level' at PS8 that very probably goes to the 'main pipe working' and others that go elsewhere at PS3, PS7, PS15 and possibly at PS17.
-60.1m to -60.3m	PS10	**Substantial Timber Beam:** This timber is of square cross-section and is *c.* 0.2m high and *c.* 0.2m wide; parts are rotted to give rounded corners. It is placed to WNW end of shaft, at about *c.* 0.8-1.0m below the flat rock base of PS8. The beam is placed horizontally between the two shaft sides, where it is set in notches in the walls, to define a narrow shaft-end compartment. This has the top end of a part-collapsed '*lacing*' partitioning timber described under PS11 resting upon it. There are comparable timbers/platforms, and notches for these, at the north-west end of the shaft at PS1, PS3, PS4, PS17 and PS20, with other timbers at the south-east end of the shaft at PS2, PS6, PS11 and PS14.
-62.1m to -62.3m	PS11	**Platform with Two Substantial Timber Beams and a Third Timber that may have been Part of '*Lacing*' Partitioning:** The platform is set horizontally to the ESE end of the shaft at about 1.8m below the base of the timber beam at PS10 at the other end of the shaft and with its top at about 0.6m below the bottom of the timber platform beams of PS9 at the same end as PS11. Part way along these beams there is a vertical timber, set between the two of them at its bottom end and rising upwards. This has fallen in a WNW direction and its top lies a little above the PS10 beam upon which the partitioning timber now rests at a diagonal angle. This timber is more rotted than the other two and may be a different type of wood. The two horizontal timbers at PS11 are each *c.* 0.2m high and *c.* 0.2m wide, and comprise supports for a platform located at the ESE end of the shaft. They are set in notches in the two side walls of the shaft and are placed with a gap between them of similar width to the timbers. There is a second much wider gap between them and the shaft wall, with no positive indication seen that there had been a third beam here. The timber nearest the shaft's end may well have been reused from elsewhere

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		as it has two cut rectangular notches on one side. There are several stones resting along the top of the two horizontal timbers that have presumably fallen from above. At the platform timbers SSW end there is a short length of rope looped around the bottom of one of these rocks. The displaced vertical timber is set between the two platform timbers, with a bent iron pin to one side, presumably originally fitted to hold it in place. This once 'vertical' timber may perhaps be a vestige of a wooden '*lacing*' partition between the side and main shaft compartments rising to above the horizon of the timber beams of PS9. There are comparable timbers/platforms, and notches for these, at the south-east end of the shaft at PS2, PS6 and PS14, with other timbers at the north-west end of the shaft at PS1, PS3, PS4, PS10, PS17 and PS20.
-62.5m to -65.0m	PS12	**Walled-off Possible 'Level' and Probable 'Side Pipe Working':** This passage lies to the NNE side of the shaft, has an uneven rounded top and sides, but a near-straight but sloping rock base. The overall height of the passage is 2.5m and its width is *c.* 2.0m. Other than the top *c.* 1.0m this passage is walled up (Fig. 7; Plate 25). The wall, the top of which is at *c.* -63.5m, is 1.5m high. This structure is carefully built of limestone slabs and blocks laid horizontally with *c.* 12 courses. The interstices are probably sealed with clay although the possibility that this is rotted mortar cannot be discounted (also see PS13). Close-up photographs taken in 2019 show this material in the interstices is red-brown in colour near the base but above it shades to a paler orange. Inside the passage opening, as viewed from the shaft, in the left third there is a relatively flat-topped layer with its top against the rock side of the passage. This comprises a limonite-type deposit that has also flowed over the top of the wall; its formation was probably associated with water dammed back here. Whether a 'level' ran back from here is far from clear. To the right two-thirds of the passage, beyond the wall there is a visible heap of rubble and sediments that extends up to the roof at the passage side; the passage may well go upwards here but this is out of sight. The interpretation of the passage and its dam is far from clear and three potential explanations are apparent. First, if a sealed 'level' exists, it possibly relates to the documented '*34 Fathom Boat Level*' at -62m and its continuation roughly southwards as '*Deep Level*', with the PS12 passage being a 'cross cut' though an old 'side-pipe working' to these. Second, the dam may be the side of a cistern utilising the passage behind that was for a lift of 'pump pipes' in the shaft, with the passage behind being the bottom of an old 'side pipe working'. Third, it could be a 'side pipe working' that was later modified to hold back water from a spring breached in this working. There are other 'levels' leading off the shaft, including another that may be associated with the 'canal level' at PS9, a possible 'level' at PS8 that very probably goes to the 'main pipe working' others that 'cross cut' to the winding shaft at PS13

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		and probably PS5 and PR19, and others that go elsewhere at PS3, PS7, PS15 and possibly at PS17.
-79.7m to -82.0m	PS13	**'Cross Cut' to Winding Shaft:** This passage lies in the SSW side and WNW end of the shaft, filling much of these except for the ESE part of the shaft side (Fig. 7). It is sub-rectangular in cross-section, with near-flat roof and floor, and originally this passage was a little over *c.* 2.0m high and *c.* 5.0m wide. It has sediments and rubble on the floor, together with a large displaced timber and a *c.* 0.6m high heap of stones to the pumping shaft side on the left; the stones have what may be red-orange clay in the interstices (see PS12). To the left side of the 'cross cut' near the pumping shaft and close to the roof at -80.5m depth, there is an iron 'eye' with an upturned looped end. The 'cross cut' was entered in 2019 from the pumping shaft end and at first it runs south-west for about 4m, going to a point where there is a blind end orientated south-west. Just before this end the 'cross cut' continues as a branch passage with an arched roof that runs to the south-east to enter the side of the winding shaft. There is archival documentation that indicates this 'cross cut' was used for transferring ore from the pumping shaft to the winding shaft in 1786-88, but it is not known whether the link between the two shafts was made in 1786 or at an earlier date. This is the same feature as 'Cross Cut' WS8 in the winding shaft. There are two other 'levels' leading off the shaft that probably 'cross cut' to the winding shaft at PS5 and PS19, a possible 'level' at PS8 that very probably goes to the 'main pipe working' and others at PS3, PS7, PS9, PS15 and possibly at PS12 and PS17 that go elsewhere.
-84.3m to -84.5m	PS14	**Substantial Timber Beam:** This beam lies to the ESE end of shaft, is *c.* 0.2m high and *c.* 0.2m wide, and is placed horizontally between the two shaft sides to define a narrow shaft-end compartment; it is set in notches in the shaft walls. Part way along the beam top there is a large dished hollow that reduces the beam depth by half. At a point roughly half way along the beam side, there is a bent iron pin with the looped 'eye' at its end. In the shaft end wall, nearer the corner to the north-east and at the same depth down the shaft as the beam, there is an iron 'eye' with circular end that protrudes horizontally. There are comparable timbers/platforms, and notches for these, at the south-east end of the shaft at PS2, PS6 and PS11, with other timbers at the north-west end of the shaft at PS1, PS3, PS4, and PS10, PS17 and PS20.
-90.3m to -96.5m (and rising to *c.* 84.5 inside)	PS15	**'Side Pipe Working' Chamber with a 'Level' at its back:** This large 'pipe working' chamber lies in the NNE side of the shaft at the corner with the WNW end (Figs 7, 12); it was partially explored in 2019 and 2022 but with open leads left at the top. At the shaft the opening is just over 6.0m high and *c.* 2-3m wide. The top is arched and the sides near-vertical but irregular. The main working, as entered in its top

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		half, runs north-west and becomes significantly wider to both sides once the opening has been entered, wrapping slightly around the shaft but with a narrow wall of rock between the chamber and the shaft walls, giving a total passage width of something like 10m. In this upper area, rubble rises steeply to the right side to *c.* -92m, with a displaced timber beam at *c.* -94.0m. The rubble also rises at the back of the chamber, going up to *c.* -87.5m; here, where there was a horizontal floor with a passage roof dimly visible above (confirmed by the sonar). At this top point the rubble slope is *c.* 9m away from the shaft side and the sonar readings suggest the flat floor extends at least a further 3m. The back of this working with a flat floor was not seen so it is not known whether it closes down or not; it may rise upwards and/or turn a corner. Similarly, a possible void in the roof nearer the shaft was again not clearly seen. The chamber extends upwards to about 6m above the horizon of the top of the opening to the shaft, to a point *c.* -84.5m with the roof lowering north-eastwards. A large amount of rubble has been tipped in this chamber and it was once significantly larger than it is now; the direction of tip strongly suggests that the passage at the top of the slope continued; it may well be that these led to the 'main pipe workings' in the '*North Open*'. To the left side of the entrance from the shaft, at greater depth than the parts just described, there is a walled pack going into the working to the left side of the entrance, with a flat top at *c.* -95.0m and base at *c.* -96.5m. To the right side of the wall, further inside the working, at about -95.5m to -96.5m, there is a small flat-roofed 'level' going NNE, with its entrance within a rubble slope here that partially chokes the passage. Going right again, the bottom part of the main working is narrow with a rock slope to the right side and part of the back, rising at about 45 degrees to meet the rubble noted above where the passage is wider. In this lower part of the 'side pipe working' the left-side was not clearly visible. There are other 'level' leading off the shaft, including PS13 and probably at PS5 and PS19 that 'cross cut' to the winding shaft, a possible 'level' at PS8 that very probably goes to the 'main pipe working' and others that go elsewhere, as here at PS15, to be found at PS3, PS7, PS9, PS15 and possibly at PS12 and PS17.
c. -95.5m to -99.0m	PS16	**'Side Pipe Working':** This passage lies at the SSW side of the shaft, taking up much of this (Fig. 7; Plate 11). It has a curved roof at *c.* -95.5m and sloping sides, with that to the left steep and that to the right rising gradually. Near the shaft edge there is rubble and a displaced timber on the sloping side of a *c.* 1.0m high heap of rubble and sediments within the passage. Where the rubble rests on a curving bedrock base at the shaft edge the lowest point is at *c.* -99.0m. The shape and overall height of this passage suggests that this is a 'side pipe working' rather than a 'level'. Inside this 'side pipe working' to the left side there is an oval passage that heads roughly south-east. This is somewhat larger inside that at the entrance and the end cannot be seen; this may well be part of the same 'side pipe working' as the one entered from the winding shaft at WS11. Near the entrance from the pumping shaft at a point a little up from the floor there is an iron hook with curved end on the left wall. Further inside a large timber can be seen rising diagonally from the left passage wall to what is assumed to be a roof.

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		To the right side of the passage entrance, beyond a section where the passage back comprises a rock wall, there is another possible lower passage, part filled with rubble and heading south-west; this has not been clearly seen and the dark passage-like area here may be nothing more than a shadow.
-108.0m to - 111.6m	PS17	**Platform with Two Substantial Timber Beams and a Choked Probable 'Side Pipe Working' or Possible 'Level':** The broad platform is set horizontally into the two walls of the shaft at its WNW end, while a side passage goes off from the WNW half of the shaft's SSW side (Fig. 7); this heads roughly southwards but beyond the shaft side it is immediately choked with rubble and smaller material. The two beams are each *c.* 0.3m high and *c*. 0.2m wide, with a gap of similar width between them, and they are located at about -111.2m to -111.6m down the shaft. Above these support beams there is what looks like a broad plank or two beams one on top of the other above forming a low support 'wall' in the central section of the platform with rubble behind, while the top of the platform has a rubble floor across its full width. The passage going off southwards has curved sides and a floor at *c.* -110m depth; it has the appearance of a 'side-pipe working' rather than a 'level', although the latter interpretation cannot be discounted. In the left wall, just inside the passage there is an iron 'eye' protruding horizontally. A displaced length of tramway rail on the floor protrudes from the choke. In the shaft wall to the right side of the opening, there is a possible shallow square timber notch at -108.5m for a timber measuring about 0.2m by 0.2m. There are comparable timbers/platforms, and notches for these, at the north-west end of the shaft at PS1, PS3, PS4, PS10, PS14 and PS20, with other timbers at the south-east end of the shaft at PS2, PS6, PS11 and PS14. There are other 'levels' leading off the shaft, including those that 'cross cut' to the winding shaft at PS13 and probably PS5 and PS19, a possible 'level' at PS8 that very probably goes to the 'main pipe working' and others that go elsewhere, as possibly at PS17, to be found at PS3, PS7, PS9, PS15 and possibly PS12.
-115.0m to -117.5m	PS18	**'Side Pipe Working':** This wide 'alcove-like' feature has a flat roof and a horizontal floor (Fig. 7). It lies in the ESE half of the shaft and spans parts of the two sides and its end. The relatively flat rock floor has some sediments and a few rocks. The back walls of the cavity can be seen in all directions with no passages going off, with these no more than about *c.* 2-3m from the shaft edge.
-121.0m to -123.0m	PS19	**Probable 'Level' or Possible 'Side Pipe Working':** This passage lies in the SSW side of the shaft and occupies its ESE half (Fig.7; Plate 10). It has a flat roof and the horizontal rock floor is located *c.* 1.0m above the highest part of the blockage at PS21. In the passage there are stones of various sizes in a pile of backfill rising towards the back, where the way on is nearly choked, with an air space going back that is less than 0.5m high.

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		At floor-level, in the shaft wall to the right there is a horizontal iron pin. Above this, at *c.* -122m, there is another iron pin with end upturned at right-angles. To the left side of the passage near the shaft wall there is a metal 'eye' a short distance below the roof at a similar horizon to PS19A. Set back into the passage there is a further horizontal pin, again located at its left side, near the top of the pile of backfill. This probable 'level' is correctly oriented to be a 'cross cut' to the winding shaft at a depth below where the latter is currently choked. There are other 'levels' leading off the shaft, including those that 'cross cut' to the winding shaft at PS13 and probably PS5. There is also a possible 'level' at PS8 that very probably goes to the 'main pipe working' and others that go elsewhere at PS3, PS7, PS9, and possibly at PS12 and PS17.
c. -121.5m	PS19A	**Miners Inscription.** This 'carving' comprised a large '2' with serifs, executed with the point of a miners' pick on a flat face of rock on the shaft's wall, located near the corner between its ESE end and NNE side (Plate 10). Why it was carved and what it signifies are obscure.
-124.0m to -124.3m	PS20	**Substantial Timber Beam:** This beam is of *c.* 0.3m height and *c.* 0.2m width, set in notches and lying horizontally across the shaft nears its WNW end. It is at about the same horizon as the top of the choke at the other end of the shaft. There are comparable timbers/platforms, and notches for these, at the north-west end of the shaft at PS1, PS3, PS4, PS10 and PS17, with other timbers at the south-east end of the shaft at PS2, PS6, PS11 and PS14.
-124.0m to - *c.* 127.0m	PS21	**Blockage in the Shaft:** The current shaft bottom comprises a pile of rocks that at one side is *c.* 1.0m below the base of PS19. The heap here fills the ESE half of the shaft, while to the WNW half the top of the fill is located at *c.* 3.0m lower; the side of this 'hole' is near-vertical. What lies at the base of this blockage, which has caused its formation here, is not known. The rubble perhaps lies over a wooden platform, and/or collapsed structures installed in the documented 1773 chamber at the original base of the shaft that had its floor at *c.* -128m. While the shaft was later deepened they may have placed a platform here so the chamber could still be used and the shaft may be open below.

Appendix 2: The 1760s-70s Winding Shaft - Revised Archaeological Details (JB)

This Appendix describes the archaeological features and artefacts in, and viewed from, the winding shaft, which were observed on the one dive here in 2019 and another two in 2022; all discoveries are described in detail in Table 9 below (also see Figs 6-8).

This appendix was first presented in the 2020 archaeological report and is re-presented here in updated and partially revised form. However, many of the features described in Table 9 were illustrated with photographs in the 2020 report and this should be referred to for these. The depth

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readings quoted in 2019 have been retained, and the orientation of features from north have been checked and found not to need adjusting. No new features have been identified.

The shaft itself (WS0) is rectangular in plan, measuring just over 1.0m by 2.0m at its top, and originally dropped vertically to about -282m. It now has a blockage at -112.5m to -113.5m (see WS14 below); this has prevented downward explorations below this point. As the shaft is descended its sides are somewhat uneven but the rectangular shape, with rounded corners, is usually retained; a more oval plan was only occasionally observed. Gunpowder shot hole scars often face downwards and sometimes these were seen to be at regularly spaced intervals that reflect its' sinking, with the shaft bottom taken down in stages by about 0.5m each time the depth was increased. The walls of the shaft have evidence of abrasion, caused by the passing of the two kibbles many times during the time the shaft was in use.

There are four 'side pipe workings' that are intersected (WS6, 11-13), one with working platforms and other timberwork (WS11) and two with associated 'levels' leading from them (WS12-13). There are also several 'cross cuts' and other 'levels' going off the shaft (WS1, 2, 5, 7-8) and a timber beam across a shaft end and possible sites of other timber beams that have now gone (WS2-4, 10). Artefacts such as displaced timberwork, tramway rails and small diameter pipes are found in various places (WS1, 2, 5-6, 8-10, 12-14), some of which may well have fallen from above.

In the lower parts of the shaft the visibility of features on the 2019 videos was often poor, particularly for features WS11-WS13, while the clarity of the water was not much improved in 2022.

In Table 9 below it should be noted that depth given as taken from the 2019 dive date should be treated as having a +/-0.5m uncertainty factor because of the varying pitch of the robot and minor differences in the point at which the -0.0m was set on different dives. Furthermore, there were the same depth reading uncertainties for the 2022 UNEXUP dive in the Winding Shaft as discussed in Appendix 1 for the Pumping Shaft; again the 2019 readings are retained here.

In 2019 the compass directions given in the original version of Table 9 (as North, NNE, NE, ENE, East, etc.) were thought to be correct down to about *c.* -85m (WS1-10). However, below *c.* -85m it was recognised that there was significant uncertainty in orientation due to problems with the navigation logging (WS11-13). In 2022 the navigational problem that affected assessment of orientation had been resolved and all orientations of features have now been checked and found to be correct; only WS13 is still uncertainly interpreted.

Table 9: The Recorded Archaeological Data in the Winding Shaft as revised in 2022.

Depth below 0m	*Feature Number*	*Description*

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-5.00m to -6.70m	WS1	**Small 'Level':** This passage lies at the north end of the shaft in the half towards its north-east corner (Fig. 7; Plate 26). The passage is round topped at the shaft wall and has a flat consolidated floor with a layer of rubble below; it was *c.* 1.7m high before the floor was added and it is *c.* 1.0m wide. The destination of this 'level', which heads northwards, is not known as there is no matching entrance in the pumping shaft. The 'level' bottom at the shaft wall is of rock and there is *c.* 1.0m of rubble fill above this. This fill contains a displaced sediment-covered timber at its top to the left. There is a small-diameter, displaced, metal pipe protruding from further down this fill to the right-of the timber; inside the passage its other end protrudes diagonally out of the passage floor. In the shaft wall, to the right side of the passage, set at a rock ledge, there is an iron pin with looped 'eye'. There is a 'garland' channel above the 'level', cut into both sides and the north end of the shaft, with an apex at the north-west shaft corner at *c.* -3.2m down the shaft; both arms descending diagonally to the top of the 'level'. Other 'levels' from the winding shaft are found at WS2, WS7, WS8, WS13 and probably WS12.
-26.2m to -27.2m	WS2	**Small 'Cross Cut' and Picked Slot:** This passage lies at the north end of the shaft (Fig. 7). It only occupies the left half of the shaft-end and at the shaft wall it is sub-rectangular in shape and is *c.* 1.0m high and *c.* 0.7m wide. About *c.* 1.0m into the passage, it suddenly gets significantly larger to the left-hand side. This passage may well be a 'cross cut' heading to PS5 at the same depth in the pumping shaft; however, PS5 heads south-eastwards from the end of this shaft so there can be no straight-line link and the passage presumably changes direction part way along. The floor of the passage is sediment covered with a few small rocks and there is what may be a short iron tramway rail to the right side. At the entrance a large square block of stone, *c.* 0.2 m high, has been introduced to bring the floor up to the same horizon as elsewhere; this protrudes slightly into the shaft. At an horizon just below the base of this stone, the adjacent eastern side wall of the shaft has a shallow picked slot running horizontally, with three sections of well-defined base, suggesting there may have been three timbers forming a platform here, perhaps installed temporarily as the 'cross cut' was being created. However, there does not appear to be a corresponding slot on the other side of the shaft so this interpretation is only tenuous. There are comparable 'cross cuts' to the pumping shaft and 'main pipe workings' at WS7 and WS8, with other 'levels' going to unknown destinations at WS1, WS13 and probably WS12.

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c. -29.0m	WS3	**Two Possible Timber Notches:** These recesses are both circular in shape and are located in the western shaft side near the north corner; also see WS4 for similar features *c.* 4m further down the shaft. That to the left is set diagonally slightly further down the shaft compared to the other. Both may be fortuitous shaft-sinking scars.
c. -33.0m	WS4	**One or Possibly Two Timber Notches:** These recesses, like WS3 *c.* 4m above, lie in the western shaft side near the north corner, one above the other but with the lower one more to the left. Both are of moderate size, rectangular with their long axis horizontal, but the upper one is uncertainly interpreted and may be a coincidental rock-removal scar, while the lower one is obviously carefully picked. On the opposite wall, in the eastern shaft side near its north corner, there is another picked notch, again of moderate size and rectangular in shape with the long axis horizontal; this matches the lower slot. The reason a horizontal timber was (or timbers were) inserted here is not known, nor is it known whether it was (they were) a temporary or 'permanent' fixture.
-51.9m to -53.9m	WS5	**Opening:** This large hole lies on the east side of the shaft and is *c.* 2.0m high and *c.* 3.0m wide (Fig.8; Plate 15). The passage has a rounded top, curved sides and flat rock floor; there is rubble on this that is up to *c.* 0.5m thick. Within the floor rubble there are a displaced short section of iron tramway rail of flat-bottomed type, a small cross-sectioned timber and a short length of small-diameter metal pipe. After a distance of only *c.* 0.5m-1m at floor-level the 'main pipe working is entered with its side dropping away steeply below the hole and rising vertically above. While 'level-like' in appearance, the opening at WS5 may have started life as an accidental breach in the shaft wall made when it was being sunk, located at a point where the shaft broke into an 'alcove' in the 'main pipe workings'. It appears that the hole has been enlarged and tidied for reasons unknown.
-56.5m to -57.5m	WS6	**'Side Pipe Working' and Displaced Timberwork:** This passage lies to the west side of the shaft, opposite 'Cross Cut' WS7 but with its rock floor starting at *c.* 1.0m higher up the shaft (Fig. 8; Plate 13). At its entrance the WS6 side passage is only *c.* 1.0m high and *c.* 2.0m wide, with an irregular diamond-shaped cross-section matching the sloping bedding. The passage has a floor that slopes upwards and it appears to get broader inside. It is certainly higher and here the floor comprises a rubble heap sloping down from the right. There is also an adjacent small alcove located to the right in the corner of the shaft, with its floor a little lower than the main opening, at *c.* -58.5m. This feature is irregular in shape, with a narrow cleft behind and a little rubble on the floor.

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		In the entrance to the main passage at *c.* -57.0m down there is a sturdy horizontal timber with sawn rectangular cross-section extending to both passage sides. In its central area there is a small beam resting diagonally on it with the upper end pointing diagonally upwards and into the shaft. Right of here there are short parts of two small timbers at different angles behind and to the underside of the main timber. To the left side of the passage there are two long sturdy timbers of moderate cross-section. There is a gap between then and both are fastened to the main beam at right-angles to it. They slope steeply upwards into the passage and here rest on timberwork behind (see below). That nearer to the passage side has a large angular boulder resting on it at the shaft edge. Visible a little further into the passage there are two long sturdy timbers with sawn rectangular cross-sections fastened to each other to form an L-shaped structure; these have clearly collapsed from elsewhere. It may well be that, as suggested by the jumbled nature of the timberwork, all these timbers have fallen from above and wedged here, coming from within the working going upwards; originally they may well have formed a complex framework of uncertain interpretation. Hooked over the diagonal plank at the centre of the passage at its entrance there is an open-ended drum-shaped object, with tapering side, of about 50cm maximum diameter and 10cm width. This appears to be made of iron and is of unknown function; it seems likely its placing on the timber is not fortuitous but was done purposefully for reasons unknown at a later date than the timberwork collapsed.
-57.5m to -59.0m	WS7	**'Cross Cut' to the 'Main Pipe Working':** This passage is located to the east side of the rectangular shaft (Fig. 8). At the shaft wall it is *c.* 1.5m high and *c.* 1.5m wide, with a sub-rectangular profile with a slightly arched roof. Just within the entrance near the roof there are straight iron pins, one to either side passage wall, each pointing diagonally upwards. In the shaft wall to the north of the opening there is a straight iron pin set nearly horizontally but with its end a little higher that where set in the wall. This is the same feature as PW10 and what lies further within the 'cross cut' on its floor is described under this. There are comparable 'cross cuts' to the pumping shaft at WS8 and possibly WS2, with other 'levels' to unknown destinations at WS1, WS13 and probably WS12.
-79.0m to -81.4m	WS8	**'Cross Cut' to the Pumping Shaft:** This passage lies at the shaft side to the west. At its entrance it is now *c.* 1.5m high and 3.0m wide and has an arched roof (Fig. 7). The lower *c.* 1.0m of the 'cross cut' has been backfilled and at the shaft wall this has been retained by a crude drystone wall, using limestone slabs, blocks and

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		rounded pieces. The original flat rock base of the 'cross cut' at the shaft side is at –81.4m depth, *c.* 2.5m below the roof. This is the same feature as 'Cross Cut' PS13 in the pumping shaft and was entered from here in 2019. The interior of the 'cross cut' is described under this. To either side of the 'cross cut', part way up the sides on the corners between the winding shaft wall and the passage, at -80.0m depth there are iron eyes, one per side and each with an upturned looped end. On the floor of the 'cross cut' to its SW side, next to the shaft, there is a long iron bar with attached short, curved end-bars at right-angles; this may be a displaced tie rod. There is documentation that indicates this 'cross cut' was used for transferring ore from the pumping shaft to the winding shaft in 1786-88, but it is not known whether the link between the two shafts was made in 1786 or earlier. There are comparable 'cross cuts' to the pumping shaft and 'main pipe workings' at WS7 and possibly WS2, with other 'levels' to unknown destinations at WS1, WS13 and probably WS12.
-80.5m to -85.0m	WS9	**Artefacts:** These objects extend down from the west side of the shaft at WS8 to WS10, wedged at a variety of angles. They comprise a long displaced length of small-diameter metal pipe with its top resting against WS8, and further down two displaced bent iron tramway rails of flat-bottomed type. One rail sticks out of the rubble at WS10 while the other rests on the top of the same rubble heap. The lower end of the pipe is set on a small ledge in the shaft on the horizon as but away from WS10, just above the horizon of the rubble heap at this feature. There was a *c.* 2mm diameter transparent nylon fisherman's line, presumably used in the past to plumb the depth of the shaft, which in 2019 was tangled around the two rails and this extended to the bottom of the open shaft at WS14. In one place in the shaft the line was tangled with a short piece of sawn rectangular cross-sectioned wood and immediately below this with a short length of flat-bottomed type tramway rail. A little lower down it was tangled with another short bent piece of flat-bottomed type tramway rail. In 2022 the line became caught in the impellors of the submersible robot and the arrangement of line and artefacts was disturbed by snapping the line when preparing to haul the robot to surface.
c. -84.5m to -86.0m	WS10	**Substantial Timber Beam and Possible Alcove:** This beam has one end set horizontally into eastern side of the shaft near the southern end wall; at the other end it is set into the south-western corner of the shaft. Above this beam there is a heap of fallen material extending from the timber to the end wall of the shaft. Here there are three large displaced timber beams at near-horizontal angles to the first,

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		together with at least seven smaller timbers in the pile of rubble that rests on the fixed beam and the lowermost of the displaced beams. There is a small, shallow, alcove above and behind the beam and rubble heap but whether this had any purpose or is fortuitous in not known.
-95.3m to -99.5m	WS11	**'Side Pipe Working':** The moderate-sized working lies on the eastern side and the north end of the shaft (Fig. 8). It has an entrance that has a rounded top, near-vertical walls, and a rounded base to the right and centre but with a narrow downward continuation to WS12 to the left-hand side; the last is at the north end of the shaft. The broad open passage above here at the shaft end and side is *c.* 3.0-4.0m high and approximately 4m wide. Within the WS11 'pipe working', to the right-hand side, at the south-east corner of the passage, there is a sturdy horizontal timber set into the 'pipe working' wall at -97.5m with a second behind, both once supporting a working platform, with two remaining planks resting on the beams. The steep slope of waste stone below here extends downwards to -98.5m, where there is bedrock that slopes forward to the shaft edge. To the right and centre, the back of the WS11 'pipe working' was barely visible in the gloom but appeared to be backfilled with waste stone. To the centre there is a timber beam secured by two iron pins supporting part of the roof running into the backfilled workings here, with its near end attached to what appears to be a second beam set vertically and running down to the floor of a rock buttress within the working between its two halves. In the roof of the 'pipe working' close to the shaft edge, near the right side, there is a probable iron pin with looped end. Inside the WS11 'pipe working', to the left-hand side, beyond the protruding rock buttress and at the north end of the shaft, at a similar horizon to the right-hand platform, there are two sturdy horizontal timbers at -97.5m. These are set in the walls of a narrow but deep passage at the end of the shaft. These timbers again supported a planked platform, now part-collapsed, with rubble resting above planks to the left half and only one surviving plank against the wall to the right. High in the left wall of the 'pipe working' passage, well above the platform, there is an iron 'eye' with looped end. Below the left-hand platform, a vertical wall of waste stone extends down at the back of the platform and there is another timber set at a gentle angle at *c.* -98.0m set in front of this wall with a space between the two. In front of this on the right wall, at a point diagonally downwards from the upper end of the timber but close by, there is the site of another horizontal timber set in a slight notch in the rock, with a square-section U-shaped iron bar fastened to the wall and designed to hold the second timber's base and two sides. To the top left there is a second iron pin

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		protruding diagonally upwards from the passage wall that was placed to help secure the same timber in place. Below this horizon the wall continues downwards to the top right hand side of WS12 at *c.* -99.5m. Above the top timber platform to the left at the north end on the shaft, behind this at the back of the working, there is a round-topped 'side pipe working' with rubble on the floor, which goes back in a northerly direction; the end could not be seen; this may well be the same 'side pipe working' as that in the pumping shaft at PS16.
c. -99.0m to -103.5m	WS12	**'Side Pipe Working' and 'Probable Level':** This moderate-sized working lies on the western side and northern end of the shaft, located at a lower horizon than WS11 and effectively a continuation of this (Figs. 7-8; Plate 14). Including the wall coming down from W11 and a cavity to its left, the 'pipe working' passage has a large oval shaped entry at the shaft wall, with arched top, which is *c.* 3.0m high and *c.* 4.0.-5.0m wide; inside, the workings here are complex. Inside, to the right-hand side of the 'side pipe working' of WS12 at the northern shaft end, there is a steeply sloping drystone wall of waste stone coming down from WS11, with a slope of rubble below it dropping to *c.* -100.5m. On the rubble there is a small circular object that may possibly be a wheel from a tramway tub. Immediately left of the drystone wall there is a shallow alcove running away from the shaft that is choked with rubble. On the left wall outside this opening, which here forms a back wall to the cavity, above the right side of the descending centre/left 'pipe working' described below, there is an iron 'eye' with looped end. At the centre and left-hand side of the shaft-side 'pipe working' opening, at its base there is a linear heap of rubble with curved top, starting from the opening next to the wall noted above and dropping towards the left edge of the 'pipe working' at -100.5m down. This rubble heap is set on top of a narrow ridge of rock between the shaft and a large 'side pipe working' passage going downwards on the other side of the knife-edged ridge. On the crest are two displaced small timbers. Against the shaft side the waste stone is only a few stones high to the left, but to the right as the heap rises in height there is a crude pack wall at the shaft side that is *c.* 1.0m high. On the other side of the rock ridge from the shaft, the stone heap here descends into the 'pipe working' going down as a steeply sloping crudely built 'wall' above a point where it rests on rock. Below here the 'side pipe working' goes down vertically. The present base of this working in the left part of the hole has rubble and displaced timbers, some large, at approximately -103m to 104m depth. In the central part there appear to be boulders with voids between in a descending narrow 'stope-like' working. To the right there are two to three horizontally-set substantial timbers across this passage; presumably vestiges of a working platform. The base of the working below here could not be seen.

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		At the back of the WS12 'side pipe working' just described that goes down, at roughly the horizon of the base of the opening to the shaft, there are four passages running away from the shaft, the bases of which in two cases were not seen. To the right, below the base of the 'knife edged' wall horizon, the first passage is an irregular opening that is *c.* 1.5m wide, only the top of which was seen at *c.* -102m; this may be part of the main passage going downwards described in the paragraph above. To the centre of the 'side pipe working', at around wall-top horizon, the second passage has a flat top and rubble on the floor. This opening is about 1.5m high and *c.* 1.0m wide and it may well be a 'level'**;** there is a comparable 'level' within 'side pipe workings' at a lower horizon at WS13. To the left-hand side of the 'side pipe working' as WS12 a third passage is an irregular, tall, narrow working. In its upper part, which rises above wall-top horizon, it hades steeply down to the right, while below it is more vertical with the base not visible; this again may well be part of the main passage going downwards described in the paragraph above. At the back of this passage, near the top and to the right side, an oval hole goes on roughly horizontally; here there is a vertically-set iron pin at its entrance at floor-level.
-107.9m to -110.6m	WS13	**'Side Pipe Working' and 'Level':** This relatively small working lies on the northern end and western side of the shaft below WS12 (Fig. 7). Here there is a large but shallow opening with irregular top, which at the shaft is *c.* 2.8m high and about 3m wide. Inside the working, the rock floor slopes up at about 45 degrees to the right and the 'pipe working' goes upwards and out of sight here; this has not yet been entered. There is rubble on the floor of the passage, including on the right-hand slope where the material appears to have come down from above. In the base of the working to the left-hand side, amongst and above the rubble, there are at least four broken and rotted displaced timbers, one of which is relatively large. From the back of this shallow 'side pipe working' to the left-hand side at floor horizon there is a regularly-shaped 'level', with rounded top at -109.0m; it is *c.* 1.5m high and *c.* 1.0m wide. This goes back away from the shaft in a westerly direction and it has not yet been entered. There is a comparable probable 'level' within 'side pipe workings' at WS12 at a higher horizon. In the shaft adjacent to WS13, at about the horizon of the roof of the 'level', there is the end of a displaced small-diameter metal pipe just outside the entrance, going downwards nearly vertically to WS14.
-112.5m to -113.5m	WS14	**Blockage in the shaft:** This current shaft bottom comprises a pile of large rocks and smaller material, with at least three part-buried pieces of small-diameter metal pipe within the fill. There are also five longer lengths of small-diameter metal pipes rising from here at a variety of angles and resting on the shaft sides; one is longer than the rest and extends up to the top of WS13, another has a flanged end.

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		What has caused the blockage here is not known; the shaft may be open below.

Appendix 3: The 'Main Pipe Workings' - Revised Archaeological Details (JB)

This Appendix describes the archaeological features and artefacts in the 'main pipe workings' that were observed during the two dives here in 2019, five short dives using the BlueROV2 submersible in shallow workings in 2021 and one dive at greater depth using the UNEXUP robot in 2022; all discoveries are described in detail in Table 10 below (also see Figs 6-8).

This appendix was first presented in the 2020 archaeological report and is re-presented here in updated and partially revised form. However, many of the features described in Table 10 were illustrated with photographs in the 2020 report and this should be referred to for these. The depth readings quoted in 2019 have been retained (see below). To save potential confusion the same catalogue numbers are also retained, while two new features are designated PW11A and PW11B.

In 2019 the 'main pipe workings' were explored down to *c.* -58.5m. The NNW end of the main chamber was first clearly seen in 2022 (PW11) and a 'stope-like' passage beyond here and nearby side passages, all with floors at *c.* -56m to -59m were partially explored, with one left as an open lead (PW11A), while the other (PW11B) has one hole certainly, and three others probably but as yet untested, which lead to 'side pipe workings' (PS8) at the pumping shaft.

The workings accessed in 2019-22 comprise a large upper chamber at -0.0m to -11.5m with side passages going off (PW1), with another chamber below starting at about –22m (PW 4, PW6, PW11). The second chamber becomes massive in size from -35m and extends NNW. Between the two chambers (at PW3) and to the sides of the upper chamber (at PW1) there is a complex series of smaller but sometimes still spacious passages. Most of these were left unexplored in 2019; however, side passages going off the upper chamber and parts in the area below (PW1, PW3) were explored in 2021. One lead going downwards from PW1 from a side working to the ENE was left unexplored in 2021, a second was descended to *c.* -15m at the ESE end of a broad 'stope-like' passage located near the north-west corner of the PW1 chamber but visibility was poor and nothing was clarified. A third dive in what is thought to be part of the same 'stope-like' passage was at its other end to the WNW. This located a 'cross cut' at -15m to the WNW of the main chamber at PW1; the 'pipe working' here was followed down to *c.* -27m but may have continued deeper.

Below, in the second large chamber (PW4, 6), explorations in 2019 showed that this cavity while large was once significantly larger but has been partially backfilled from the south-eastern end and there is now a heap of waste stone likely to be well be over *c.* 25m deep. Going NNW from the floor below the hole coming down from above, the rubble slopes steeply downwards and there are retaining walls that hold this material back (see PW7-8); the location of PS7 has been revaluated as it has now been realised it was further down the slope and much closer to PS8 than was originally thought. The lower chamber also has openings to its sides and NNW end that were not explored

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during the first dives. However, a floor at -58.5m at the bottom of a large hole in the chamber floor led immediately into a short 'cross cut' to the winding shaft (PW10); this was explored in 2019, while in contrast the 'main pipe working' going NNW from here was not explored until 2022 (PW11). In the 2022 dive it was found that the main chamber as a broad feature (PW11) ended after *c.* 15m but a narrower 'stope-like' passage led off north-westwards from its NNW end (PW11A); there were also further small side passages (PW11B), which lead off the main chamber westwards and south-westwards heading towards the nearby pumping shaft and associated 'side pipe workings'.

There are artefacts scattered on floors and ledges of the 'pipe workings' (see PW 2, 5-6, 9-10, 11B). These include displaced timberwork, but also with other items, many of which may be relatively modern in date and probably reached their present positions after having been dropped from above the water-level horizon, some from surface at the 'pipe working' entrance high on the hill.

In many parts of the 'main pipe workings' the visibility of the features on the videos was poor in both 2019 and 2022, due to the distance from the robot in larger workings, and because of disturbed sediments in the water; sonar data often had to be used for the assessment. Similarly, explorations in workings in PW1 and PW3 in 2021 were hampered by the disturbance of sediments.

In Table 10 below it should be noted that depths given are mostly taken from the 2019 dive date and these should be treated as having a +/-0.5m uncertainty factor because of the varying pitch of the robot and minor differences in the point at which the -0.0m was set on different dives. In addition, there may be further uncertainty for the same reason as in the Pumping and Winding shafts. The depths recorded for the first time in the 2021-22 dives have been taken at face value as not enough points were assessed in both 2019 and 2021-22 to allow cross-comparison.

In 2019 the compass directions given in the original version of Table 10 (as North, NNE, NE, ENE, East, etc.) were of uncertain precision due the problems with the navigation logging, except at PW10/WS7 at the bottom of the explored workings where the shafts were intersected. This said there was no reason to think they were significantly in error and they have been retained for the data recorded in 2022. Many of the orientations recorded in 2021 during the Blue ROV2 dives in the upper part of the 'main pipe working' are hard to interpret for the usual reason – that the position of the ROV relative to the feature being observed makes a significant difference to the orientations given. As the ROV did not record x/y coordinates to allow its position to be established all stated orientations took second place when assessing archaeological features, as following the videos as they passed from feature to feature often proved more useful in assessing orientations.

Table 10: The Recorded Archaeological Data in the 'Main Pipe Workings' as revised in 2022.

Depth below 0m	*Feature Number*	*Description*

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-0.0m to –11.5m	PW1	**Top 'Main Pipe Working' Chamber, Side Passages, Timber Platform and 'Cross Cut':** This mined chamber which contained the dive platform comprises a large irregular cavity, the lower part of which is below water; at the water-level horizon it measures *c.* 5m north/south and *c*. 9m east/west (Fig. 7). Underwater, to the west the rubble-covered floor in a relatively narrow area is a rock ledge at shallow depth. This floor, which slopes down eastwards, goes for about *c.* 3m horizontally to where the chamber's western end wall from a short distance below the water-level horizon goes vertically downwards; below here the chamber measures *c.* 6m east/west. To the east end and both of the sides of the chamber, the walls also go down roughly vertically from the water-level horizon. At both ends, the floor it is up to *c.* -11.5m down but in between there are heaps of rubble rising higher. Within an 'alcove' in the chamber wall at *c.* -11.5m to the ENE there is the lip of the main way down into PW3 that was used in 2019. Another way down, first explored in 2021 lies at beyond a slab near the north-western corner of the PW1 chamber that lies across a 'stope-like' passage. Above the main 2019 way down there are several 'windows' cut into the walls of the chamber at its eastern end. These include three that are a short distance below water-level at depths of *c.* -1.0m, *c.* -1.5m and *c*. -2.5 to -4.5m. The upper two are very small and lie below the opening above water in the chamber wall close to its north-east corner that leads into a small side-chamber (see Fig. 6). The lowermost of these three openings lies a little further towards the north-east under the corner of the chamber at water-level and is above the main way down to PW3. It is larger and is located within the left side of a large, prominent but relatively shallow alcove at the chamber end. In the *c*. -2.5 to -4.5m opening noted above, which in effect is another small side chamber, there is a horizontal iron pin with upturned end to the left located in the side-chamber wall at a short distance above the centre of the alcove. There is also a second pin on a steep rock slope just inside the side chamber to its right side. Inside the entrance to this side-chamber, located in the roof to the right, there is a hole going steeply upwards that leads to an upper side-chamber visible above water-level to the ENE of the main chamber of PW1 (Plate 21). This can also be entered at its top via a small 'cross cut' above the water-level horizon coming north-westwards from another side chamber at the river horizon (see Fig. 6). In the upper side-chamber there are three horizontal timbers spanning the passage below the water surface that were observed from below by the submersible but can also be seen from the unflooded area above. These timbers, which were part of a working platform, comprise two beams set horizontally across the passage with a plank resting on them at right angles. Returning below, the lower side-chamber also has a hole going downwards, with the two pins noted above at its top; this was not descended hence its depth and size are not known, but it may go down into PW3. Going horizontally east in the same lower side chamber, in its left half there is a rock bridge between two relatively small holes, one above the other, at its east end. The lower one was entered in 2021 but disturbed sediments made it difficult to determine what lay here although it appeared to be small. Again at the north-east corner of the PW1 chamber, below the side chamber with two pins in the alcove described in the paragraph above, at the back and within the

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		alcove there is another tall opening that has an angular top at *c.* -5.5m. Its lowermost part provided the main entry point to the way on down to PW3 used in 2019. At a short distance down into this opening, looking north-eastwards away from the chamber, there is a rock bridge with its top at *c.* -7.5m, and another one at *c.* –9.5m. Below the lower 'bridge' the passage becomes wider as there is an alcove to the right; here there is a second hole beyond a 'pillar' between the two that goes off to the south-east. All these holes going eastwards have yet to be entered. There is another oval hole in the main PW1 chamber-end upper alcove, this one located in its right hand side to the south-east, with its top at *c.* -2.5m depth and base at *c.* -5.0m. This has three small oval cavities at the back, where close inspection in 2021 showed they were only shallow. Two to the left, one above the other, had rubble on their floors; the possibility that the upper one has a small passage running back diagonally left and out of sight cannot be dismissed. To the left of the openings already described, on the north side of the PW1 chamber at its east end, there is a large but relatively narrow and high alcove where vertical beds of rock have been taken out, all parts of which only extends back a short way (Plate 22). There are two sturdy horizontal timbers set across the alcove at *c.* -6.5m and *c.* -10.5m. The former is set at a distance in front of the back wall, while the other is on the floor of the alcove next to the wall of the main PW1 chamber. This alcove, oriented NNW and hading steeply down to the right, has a top at just below the water-level horizon and a bottom at *c.* –10.5m. Below the upper parts of the PW1 chamber wall near the north-west corner there is a broad and deep 'stope-like' passage heading approximately WNW, the roof of which has been followed; this passage goes down steeply but has not yet been adequately explored; what we know is given under PW3. Here in the PW1 entry only the upper part of the passage is described. At the beginning, to the ESE end there is a large stone slab wedged across the passage at *c.* -11.5m. There is an iron pin at the passage's left top, also at *c.* -11.5m. Three dives in 2021 went WNW along the passage near its top, which has a gently descending roof from *c.* -8m to *c.* -13m. Next to the far end of this passage it is intersected roughly at right angles near its roof by a 'cross cut' with a floor at *c.* -15m. The orientation of this passage is roughly NNW/SSE and it is about 1.5m high and 1.0m wide, with a rounded top and a rock floor. Where it crossed the 'pipe working' passage coming from the ESE, the latter comprises a deep hole descending into PW13 and this is again described under this. The 'cross cut' route originally had a bridge over the 'pipe working' that presumably once had a timber plank at floor-level that has now gone, but with 'ridges' in floor sediments to the NNW end hinting at its former presence. There were 'hand rails' to both sides of the plank at a little over half way up the 'cross cut' sides. That to the WSW side still remains and comprises what is probably an iron chain rather than a bar, now with encrustations hindering interpretation, which is fastened to the wall at both ends with now corroded and sediment-covered iron hooks (Plate 20). On the other side of the plank the chain has gone but the support pins with hooked ends remain at the 'cross cut' wall to either side of the bridge. This 'cross cut' may well come from the small South Winze in a 'striking chamber' that is located just above the water-level horizon, at a point a short distance from the 'main pipe working' to the south-west (Fig. 6).

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		The destination of the 'cross-cut' to the NNW of the 'pipe working' is currently unknown. Near the south-west corner of the chamber, at *c*. -3.0m to -4.5m down, there is an oval hole in the chamber side that is slanted at a diagonal to vertical with rubble on the floor with another cavity of similar size directly below it. The lower one was confirmed in 2021 to be only a shallow 'pipe working' alcove. The possibility that the upper 'alcove' may have a slanted passage running off diagonally to the left cannot be discounted. Artefacts in the PW1 chamber are described under PW2.
-6.5m to -11.5m	PW2	**Artefacts in the First Chamber:** These objects included a pile of items near to the northern side of the PW1 chamber at about -10.0m to -11.5m depth on the top and west side of a steep-sided rubble pile going down to voids of PW3 to either side. To its west side there is a metal frame with cross bars and two spoked wheels, with another badly bent frame above this with at least eight more cross bars. These two objects may well be modern and the lower one is almost certainly the wrecked remains of a pram of early to mid-20th century date. On the same side of the chamber, but *c.* 2-3m further east and at about -11.5m down by the lip of the main hole down into PW3 used in 2019, there is a displaced timber beam and several other smaller timbers, a small-diameter metal pipe (possibly a scaffold pole), and a small metal frame with rounded corners (possibly modern). At the southern side of the chamber there is a metal pipe, probably a scaffold pole, resting on the passage wall in the eastern half of the chamber. Nearby to the east there are two displaced timbers on the floor of a broad ledge at approximately -7.0m to -7.5m down, located below the south-eastern hole within the large alcove at the chamber end. There is another pipe or bar on the south side of the chamber to the west of the pole resting horizontally on a ledge further down. Further towards the western end of the chamber, on a rubble-covered ledge part way down a steep slope at approximately -6.5m, there is a small metal two-compartment frame; this again may be modern.
-11.5m to -22.0m	PW3	**Vertical Irregular and 'Stope-Like' Passages:** The way down to depth used in 2019 lies to the east end of the First Chamber near its north-east corner; this passage continues down to a point at about -22m at the top of PW4 where the hole gets significantly larger. As well as this void there are other passages going down to the east of this and also a large 'stope-like' passage to the WNW. What is described under PW3 is in effect a lower part of the area of complex passages that also extend upwards into PW1. The main way down near the PW1 chamber's north-east corner comprises an irregular spacious passage, which drops near-vertically downwards from -11.5m depth to -22m depth, where it enters the roof of the large chamber at PW4. The descending PW3 passage between the two is rectangular in plan and measures about 7m north/south by 10m east/west.

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		To the east of the main entry point to PW3, other passages come down from above that were glimpsed in the videos as the robot descended but these have not been explored or even clearly seen. The broad 'stope-like' passage heading WNW from near the north-west corner of the main PW1 chamber, which clearly descends for some distance has not been adequately explored; A descent in 2021 near its ESE end went down to *c.* -15m following the north wall but visibility was poor and little was clarified other than that it was a large passage; another dive showed the passage at this end had a rubble floor at about this depth; this soon falls away to the WNW. Here there is an iron pin at the passage's left side at *c.* -11.5m, while well below this there is a timber across the passage that was just visible in the gloom in 2019 at a significantly lower depth than the pin. At the ESE end the 'stope-like' passage is open to the PW1 chamber going up to river-level horizon, but further WNW it has a roof, at first at *c*. -8.0m that lowers to *c.* -13m further on. At the far WNW end of the passage it was descended below the 'bridge' at the 'cross cut' here (see PW1). A little further down the passage extends a short way further to the WNW but its end can be seen and this is only a large alcove. There is a large slab on a ledge with two displaced timbers, rubble below, an iron bar placed vertically and attached to an iron pin fastened to the passage side at about -19.5m. There was a second pin coming horizontally from the wall at *c.* -23.5m and an iron hook at about 1m further down. The main 'stope-like' passage here descends roughly vertically, and comprises an irregular 'pipe working' that was followed steeply downwards to *c.* -27m, reaching a point where the cavity was large and appeared to continue to greater depth; whether or not it connects with PW4 is not known.
c. -22.0m to -39.5m	PW4	**Large 'Main Pipe Working' Chamber:** This mined chamber descends vertically from the main way down at PW3, which comes into its roof, and gets significantly larger towards the bottom where the PW6 extension runs off to the NNW (Fig. 7). Its upper part, which measures roughly 15m by 20m in plan, is roughly oval but very irregular in shape, with an extension lying roughly to the north-east that is not as wide as the rest. Below, the chamber becomes significantly larger in size from about -35m. Here it is again roughly 20m across on the north-east/south-west axis but below -35m there is a long extension at PW6 and PW11 and in total it is *c.* 55m long. The floor at the south-east end, directly below the way down from above, is at *c.* -39.5m. Alcoves or passage entrances of various sizes in the side walls of the PW4 chamber were seen on the 2019 sonar point-cloud images but were not explored. The PW4 chamber is interpreted as the upper part of a massive chamber, which includes PW6 and PW11 below, but with the lower half at PW4 and PW6 partially backfilled with deads. The floor of the PW4 chamber comprises a large amount of mine waste, mostly rubble, with large heaps across the central section of the chamber. To the south-west near the end of the chamber there is a large 'hollow' that appears to be blind. In contrast, a second large 'hollow' at the north end of the chamber continues down

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		as Passage PW6. Comparing what was found with the Meads' 1858 mine section, this suggests that the backfill in the chamber is considerable and may well be over *c.* 25m deep at the PW4 end. Artefacts on its floor are given under PW5.
-36.0m to -39.5m	PW5	**Artefacts on the floor of the PW4 Chamber:** These objects include: a bent iron grill; a displaced tramway rail of flat bottomed type; various displaced timbers; a small-diameter iron pipe or scaffold pole; sediment-covered iron pipes, bars or rails; a small iron ring; and a small square iron frame. Some of these may be modern.
c. -35.0m to -58.5m	PW6	**Spacious 'Main Pipe Working' Chamber with Sloping Floor:** The PW6 passage is interpreted as a lower part of a massive chamber which is partially backfilled, The chamber also includes PW4 to the SSE and PW11 to the NNW. In total it is *c.* 55m long and *c.* 20m wide, with a height of up to nearly 20m above the backfill. The floor of the PW6 part of the chamber runs relatively steeply downwards from that part to the SSE at PW4, going roughly NNW at the top of the backfill of waste stone, down to -58.5m at the bottom of feature PW8 (Fig. 7). As with the PW4 chamber the PW6 walls and roof are irregular. The roof to the south-east end of the extension is at about -35m, continuing nearly horizontally from here to the NNW, dropping by something like only 5m by the time the far end of PW6 is reached. The passage has an approximate width of 20m, with a height at the south-eastern end of about 12m, but with this height increasing to nearly 25m to the NNW by PW8 and PW10. Near the base of the explored working, at about 25m horizontally along the passage from PW4, there is a large hole in the floor that is described under PW8. 'Cross Cut' PW10 leads off from the bottom of this at -58.5m. Two small irregularly-shaped side-passages were seen to the south-west side of the main passage at between *c.* -51.0m and *c.* -54.0m depth, located a short distance above the top of PW8, at the top of a steep slope where the chamber side goes vertical. The hole to the right is superficially 'level-like', but very soon enters the winding shaft (see WS5; Plate 15). It may be that when the shaft was sunk it accidentally breached a pre-existing 'alcove' in the 'main pipe working' at this point. There is rubble on the floor at its entrance with a short length of displaced tramway rails of flat-bottomed type and a long timber of small cross-section. The other opening, to the left side from within the chamber, is a little smaller. It was not entered but appears to be an irregular 'side pipe working' or small 'alcove' with its floor rising steeply inside. Both of these openings are in a large 'alcove' in the west side of the 'main pipe working'. On the right wall of this large western alcove, at a point which roughly corresponds with the roof horizon of the openings described in the last paragraph, there is an iron pin protruding horizontally from the vertical rock wall. Two retaining walls within PW6 are described under PW7-8, while the 'cross cut' at the bottom and artefact on the floor in front of this are described under PW9-10.

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		Much of the floor of Passage PW6, except perhaps for parts of the lower slope (see PW7), comprises mine waste including much rubble and this may well be of significant depth, especially at the south-eastern end of the chamber (see PW4). Whether the current base of the chamber, which coincides with the floor of 'Cross Cut' PW10 and 'side pipe workings' at PW11B at -58.5 to -59.0m, is the original depth of this working is not known; however, this is unlikely as the Meads' 1858 drawing suggests it probably extends down to between -62m and -65m. On the sloping rubble floor of PW6 there are several timber planks and beams, small-diameter metal pipes (possibly scaffold poles), a metal frame with a box-like shape at *c.* 41.0m (possibly modern), and a metal grill at *c.* -40.5m (possibly a 20th century 'walkway-type' grating).
-51.5m to *c.* -53.0m	PW7	**Retaining Wall:** This built structure is constructed of roughly-coursed limestone slabs and blocks, and is located near the end of Passage PW6 close to PW8 (Fig. 7). Its *c.*1.0m wide flat top crosses the full width of the passage at -51.5m. On the up-slope side the rubble does not quite reach the top of the wall. On the down-slope side this wall is up to *c.* 1.0m high and sits on what is possibly a protrusion of bedrock with a steeply sloping face that runs down to PW8; however, if the Meads' 1858 drawing is correct, then the resemblance to bedrock may be fortuitous. The wall was presumably built to prevent rubble running further down and blocking 'Cross Cut' PW10.
c. -53.5m to -58.5m	PW8	**Retaining Walls:** These built structures lie at the bottom of Passage PW6, near PW7, and keep clear a relatively small flat sub-rectangular area below (Fig. 7). This is the current base of a large hole in the floor between the PW6 and PW11 parts of the main chamber, located immediately outside 'Cross Cut' PW10, and the walls partially retain the debris floor of the 'main pipe working' at PW6. The bottom wall stands to approximately the same height as the 'cross cut' entrance at PW10 to both of its sides, and here it is well-built with limestone slabs and blocks, but on the opposite side of the central area in front of the 'cross cut' it is less regularly built and of variable height, with a low section towards PW11. The flat floor area defined by the wall measures about 7m in the direction of PW10 and 4m at right angles to this. Behind and above the lower wall just described there is a near-vertical but crudely built wall of blocks that is about 2-3m high, which holds back the rubble slope of PW6; above this and set back again is the wall of PW7. Both walls taken together have a total height of about 5m and, with PW7, were almost certainly built to prevent rubble blocking the 'cross cut'.
-58.5m	PW9	**Displaced Timberwork:** This object is located on the flat floor of the deep hole in Passage PW6 defined by PW8, located immediately in front of the entrance to 'Cross Cut' PW10. It comprises a sturdy timber with remaining short fragments of two smaller timbers fastened to this at right-angles. Originally they were probably part of a vertical timber wall or horizontal working platform, which was sited somewhere higher up the workings.

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-57.3m to -58.5m	PW10	**'Cross Cut' to the Winding Shaft:** This passage runs roughly westwards and is cut into a steeply sloping rock wall in PW6. The entrance has a slightly arched top, near-vertical right-hand side and a somewhat more curved left-hand side. It is *c.* 1.2m high and *c.* 1.0m wide and has a flat floor with a displaced timber. Inside, as the winding shaft is approached, there is a low pile of rubble on the floor with at least two displaced tramway rails of probable flat-bottomed type and several timbers. There is also an iron 'eye' with a looped end on the left wall of the 'cross cut' near the roof. After about 3m from the entrance, just beyond the rubble heap, the passage enters the main winding shaft at WS7. The 'cross cut' was perhaps designed to transport ore from the 'main pipe workings' to the winding shaft for haulage towards surface, but as there is no loading chamber at the shaft, it may never have been used in earnest. Alternatively, its purpose may have been to gain access to 'side pipe workings' beyond the winding shaft at WS7, with the passage created at a time before the winding shaft was sunk. The shaft here and workings beyond this to the west are described under the Winding Shaft in Appendix 2
c. -40.0m to -58.0m	PW11	**Spacious 'Main Pipe Working' Chamber:** The 'main pipe working' continues horizontally from PW6 but this area was not explored until 2022 (Figs. 6-7). This passage lies to the north-east of PW8 and PW10 and runs roughly NNW for about 15m; it is up to *c.* 15-20m high and *c.* 15m wide. Its floor is roughly horizontal and comprises fine sediments and rubble. In total the chamber, comprising PW4, PW6 and PW11, is *c.* 55m long and *c.* 20m wide. Smaller passages at PW11A run from the chamber's NNW end and others at PW11B lie on the chamber's west side at PW11.
c. -40.0m to -57.0m	PW11A	**Tall 'Stope Like' Passage:** This 'stope-like' passage leads off the 'main pipe working' chamber of PW4/6/11 at its NNW end in the right-hand half of its end (Plates 5, 16). This heads north-west and has a floor at its entrance at *c.* -57m with this gradually rising to *c.* -56m where exploration was halted at about 10m into this working; the floor comprises fine sediments with rocks but in parts at least it looks as if there may well be a solid rock floor not far below. In the lower parts of the passage the walls are *c.* 2m to 3m apart. However, during exploration the passage rose to a roof out of sight but recorded by the sonar as *c.* 15m above the floor with the passage here *c.* 4m to *c.* 5m wide.
c. -56.0m to -59.0m	PW11B	**'Side Pipe Workings':** A series of probably interlinked small 'side pipe workings' lead off the 'main pipe working' chamber of PW4/6/11 on the western side near its NNW end. These passages, which lie relatively close together, start within a large alcove in the chamber side and head south-west through to west. There are three openings at the base of the chamber, two at least of which at least may well connect with the 'side pipe workings' in the pumping shaft at PS8, while one may go to PS9.

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		Looked at from the chamber, the passage to the left is an irregularly-shaped opening with a sloping flat roof at *c*. 2m above the floor. To the right side of the entrance to this first opening there is a pack of deads rising to the roof. The second opening, just beyond these deads, also has a flat roof, but at *c.* 1.5m above the floor. A large displaced timber can be seen within this passage lying on the floor. There is a second pack of deads to roof height to the second opening's right side, with this starting in front of the chamber wall and going back to a bedrock 'pillar' behind (Plate 17). Beyond this to the right there is a broad undercut rising about *c.* 1.5m from the floor and running for some distance northwards with two features a short distance inside. Here, to the left, there is an irregular oval passage going back. Further to the right there is another pack within the undercut, comprising a stack of large boulders that again rises to the roof. The floor of all three passages at the chamber floor horizon comprises mostly rubble but also finer sediments. At an estimated 4m above the undercut on the vertical wall of the chamber, above the middle pack at *c.* -56m, there is an oval hole in the chamber's vertical rock side, with a single rock on its bottom lip. There is visual confirmation on the 2022 dive video that this hole lies high within the 'side pipe working' at PW8 (Plates 18-19).

Appendix 4: The *c.* 1795 North Winze- Archaeological Details (JB)

This Appendix describes the archaeological features and artefacts in the North Winze that were observed on two dives in 2022; all are described in detail in Table 11 below (also see Fig. 6).

The dives were undertaken using the BlueROV2 submersible, which only has a single forward facing-camera; while orientations were recorded during the dive, unfortunately the depth indicator was not working on the day. Thus, while depth could be estimated near the top and bottom (as the overall shaft depth was known) to something like $^{+}$/-1m; this accuracy could not be achieved elsewhere in the shaft. Similarly, while orientations of what was being seen from the camera were recorded, readings for the same feature changed according to where the submersible was in the shaft and this could not be measured as there is no facility to do this on the BlueROV2. Thus, as with the other shaft dives, the positions of features in the shaft in Table 11 have orientations given in terms of which side of the shaft the features were found.

The shaft itself (NW0) is spacious, roughly rectangular in plan, measuring about 3.0m by 3.0m in plan throughout its depth; the latter was plumbed in *c.* 2010 by John Barnatt and Richard Shaw and was found to be *c.*19.5m deep (Barnatt 2013, p.77); we now know that the depth was to a rubble choke blocking the base of the shaft (NW6 below). The shaft at its top is somewhat trapezoidal in plan (Barnatt 2013, page 73, Fig 30) and it fills the whole width of a horizontal trial passage heading roughly westwards at the river-level horizon; while the shaft is oriented NNW/SSE, for the sake of simplicity its ends, which match the walls of the trial passage, are called the north and south ends here; similarly the sides are described as the east and west sides. As the shaft was descended its sides were seen to be relatively irregular but with a roughly sub-rectangular shape retained in parts

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at least. Gunpowder shot hole scars were frequently observed, usually facing downwards and sometimes these were found at regularly spaced intervals that reflect the initial shaft sinking.

There is a 'side pipe workings' that is intersected at the shaft top (NW2), and close to the present shaft bottom there are short trial workings in the east and west shaft sides (NW4, NW5), the latter abandoned shortly after it was started. Amongst the stones of the rubble choke (NW6) there are several sturdy timbers of the shaft, three rising vertically; these are interpreted as possibly from the timber platform that covered the shaft top (NW1). Alternatively, one horizontal timber (NW6) may have been part of a platform across the shaft at the floor-level horizon of the two trial 'levels' but this interpretation is not particularly convincing. Also, while the walls of the shaft were not systematically searched, one notch for a sturdy horizontal timber part-way down the shaft was observed (see NW3) and further timbers originally part-way down the shaft may have ended up at the shaft base. The only artefacts observed were at the current shaft base and were modern (NW6).

Table 11: The Recorded Archaeological Data in the North Winze in 2022.

Depth	*Feature Number*	*Description*
-0.0m to -0.8m	NW1	**Shaft-Top Floor:** The archaeological features here comprise slots and eyes for timbers supporting a floor over the shaft top; they were not seen by the cameras on the dives but are obvious from shaft top (see Barnatt 2013 page 212, Plate 71; Barnatt 2012, p. 308, Feature 3.173). The east and west sides of the North Winze, close to the top, have two complex horizontal lines of slots and eyes. In all cases the eyes lie to the east, while the west side has slots. The upper line of features comprised four joists, with a timber close to both the north and south shaft walls, and with the central space slightly wider than the two adjacent gaps. This arrangement may well suggest there was a trap door or doors at the centre space, used for shaft access and a '*stowce*' (hand-operated windlass) with a winding kibble (ore bucket) that went down the shaft. Two of the slots have *in-situ* rectangular metal plates, placed at the slot backs, added here to tighten the timbers in place. The lower line of slots and eyes, which form a discrete line just under 0.5m below the first, had timbers almost touching the north and south sides, and three more that were rather irregularly spaced, including two close together where perhaps one re-placed the other. On the east wall two eyes are missing, while the notch against the south corner to the west is matched by two closely spaced eyes to the east. Why two lines of timbers existed is not clear. It may be that they represent two different phases of floor, although this does not explain why one was placed lower than the other and it seems more likely they go together, especially as only one phase of use for the North Winze is documented. If so, then the lower line may be

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		designed to give added strength to a frame for something heavy over a particularly large diameter shaft, perhaps a large 'stowce', but the details are obscure. However, further uncertainty is created by one timber in the lower line appearing to run across the central hole for the '*stowce*' suggested by the top line of timbers, but perhaps timbers here only ran from the shaft sides to a rectangular frame around the central hole.
+6.5m to -2.3m	NW2	**Bottom of a 'Raise' to Upper Trial Workings:** Intersecting the south end of the North Winze shaft near the south-east corner there is the base of a 'raise' going to a set of trial workings above that are also interlinked by a second 'raise' with the capstan chamber next to the pumping shaft. The lower part of the 'raise' at the North Winze was not clearly seen by the cameras on the dives but is obvious from shaft top (see Barnatt 2012, p. 309, passage 3X). The NW2 passage continues down a short way below the floor of the 'trial level' at the North Winze top and it may be NW2 was an earlier feature where mineral was followed downwards that was later intersected by the 'level'. This said, both features are likely to date from the 1790s and they probably followed each other in relatively quick succession over a *c.* 1-5 year period. The 'raise' is rather irregular, ascending nearly vertically but twisting somewhat sinuously, measuring not much more than 1m across. It is 6.5m high from the North Winze top and 'level' floor here to the floor of the workings above. It also descends for just over a further 2m below the 'level' floor before its sinuous passage has been fully cut away by the large winze as it goes down.
c. -10m	NW3	**Timber Notch:** At very roughly half way down the shaft a single rectangular notch for a sturdy timber was seen on the dive video for the first dive. This was located on the east side of the shaft and comprises a shallow slot created with the point of a pick that is *c.* 20cm wide and 30cm deep.
c. -16.5m to -19.0m	NW4	**'Trial Level':** Running from the east wall of the shaft in its southern half there is a short horizontal 'level' running off eastwards. This has solid walls, roof and near-vertical 'forefield' at the end. The floor has a rubble spread with old timbers that in effect is probably a part of the shaft choke material and this is included in the NW6 description. The 'level' is *c.* 2.0m wide with vertical walls and is *c.* 2.5m high. The roof has rounded corners and it is at approximately the same horizon as the roof of Feature NW5; its length to a forefield is estimated to be *c.* 2.5m. The rock floor of NW4 at the shaft edge is horizontal and the vertical wall of the shaft goes down from here for *c.* 0.5m-1.0m to the rubble choke.
c. -16.5m to -19.0m	NW5	**Unfinished 'Trial Level':** Running from the west wall of the shaft in its northern half there is a short unfinished horizontal 'level' running off westwards. This has only just been started over much of its compass, dropping back under 0.5m, while to the top left it has been driven in by *c.* 1.5m-2.0m. The sides are just off vertical,

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		while the roof is horizontal and the unfinished floor at the shaft side is angled diagonally down to the north but if work had continued would presumably have been made horizontal. Inside the unfinished 'level' there is a rock ledge at the 'floor' and a steeply sloping 'wall' to the north side where removal was abandoned before the intended passage wall, as seen at the shaft side, was reached. The 'level' is *c.* 1.5-2.0m wide and *c.* 2.5m high, with a roof that is at approximately the same horizon as the roof of Feature NW4. The vertical wall of the shaft goes down by *c*. 0.5m to the rubble choke from the lowest point of the NW5 'level' entrance.
c. -19.5m	NW6	**Rubble Choke, Displaced Timbers and Possible Platform:** The current 'floor' of the shaft and that of the 'trial level' at NW4 are both covered with rubble comprising angular stones of moderate to small size (Plates 23-24). The depth of this rubble in the shaft unknown while, in contrast, in the 'level' this is only a shallow deposit. At this depth the shaft has clearly defined corners that allow the positions of the two 'levels' and artefacts to be accurately determined. The most important objects here are a series of at least eight sturdy but partly rotted timbers. Two of these are nearly vertically placed and rise from the rubble. Near the north-east corner of the shaft the first is a sturdy one that appears to be rectangular in cross-section. This rises to well above the top of the nearby 'level' at NW4 and its rotted end rests on the shaft wall; the visible part is *c.* 4.5m long. The second is located near the south-west corner of the shaft and is a sturdy timber that rises at a near-vertical angle but only to a horizon less than halfway up the side of the unfished 'level' as NW5. Near the base of the first timber there is another much shorter one that rises from the rubble diagonally. A fourth large timber lies horizontally against the full length of the southern end of the shaft at an horizon just below the floor horizon of the NW4 'Level'; rubble rests on part of its top (Plate 243). This beam is possibly a surviving support for a platform across the shaft at the floor-level of both 'trial levels' (NW4, NW5). However, the timber is not set in a notch in the shaft wall, while the other end is not clearly visible, and thus the timber may well be fortuitously arranged. Other timbers include parts of five lying in the rubble on the floor of the NW4 'Level', including one sturdy beam, and at least four other short timbers in the rubble at the shaft, three or four of which appear to be parts of sturdy timbers. Modern artefacts on the rubble comprise at least two scaffold poles and a modern 'Danger Deep Shafts' sign; the latter was attached to the safety chain at the east side of the shaft top until relatively recently.

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