UNEXMIN DELIVERABLE D7.6

GEOSCIENTIFIC EVALUATION OF PILOTS

Summary:

This deliverable includes geological and archaeological interpretations from the pilot missions, concentrating principally on the Ecton pilot where by far the greatest amount of geological and archaeological data were obtained.

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List of Abbreviations

Abbreviation	Description
ASL	Above Sea Level
CUDHg Idrija	Idrija Mercury Heritage Management Centre
DVL	Doppler Velocity Log
EC	Electric Conductivity
EMET	Ecton Mine Educational Trust
ESC	Electronic Speed Controller
GeoZS	Geological Survey of Slovenia
Hg	Mercury
IMU	Inertial Measurement Unit
INESCTEC	Institute for Systems Engineering and Computers, Porto
INS	Inertial Navigation System
LED	Light Emitting Diode
MSU	Multi Spectral Unit
N/A	Non Applicable
octomaps	Virtual representation of space, calculated from the point cloud, used for navigation
pH	Negative logarithm of the hydrogen ion concentration
RPM	Rounds Per Minute
RCI	Resources Computing International Ltd
SBP	Sub Bottom Profiler
SLS	Structured Light System
TU	Tampere University
UNIM	University of Miskolc
UPM	University of Madrid
USB	Universal Serial Bus
UX-1	Autonomous Explorer for Flooded Mines
VESC	Vedder Electronic Speed Controller

Old British Measurements

A number of old documentary sources of information on Ecton Mine have been quoted in this report which use old British units of length. These are explained below and their metric equivalent given.

Foot (plural feet) abbreviation ft = approximately 0.3048m
Yard (plural yards) abbreviations yd and yds = approximately 0.9144m
Fathom (plural fathoms) abbreviations ftm and ftms = approximately 1.8288m

1 foot is made up of 12 inches
1 yard = 3 feet
1 fathom = 6 feet or 2 yards

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1 Introduction to the UNEXMIN project

UNEXMIN is an EU-funded project that has developed a novel robotic system, for the exploration and mapping of Europe's flooded mines. The Robotic Explorer UX-1 design uses non-invasive methods for 3D mine mapping to gather valuable geological, mineralogical and spatial information. This potentially opens new exploration scenarios so that strategic decisions on the re-opening of abandoned mines can be supported by data that cannot be obtained in any other way, without major costs. The robot, so far proven in tethered remote control mode, is designed also to operate autonomously, using new technology that is only made possible by recent developments in autonomy research. UX-1 is the first of its kind. Major research challenges are related to miniaturisation and adaptation of deep sea robotics technology to this new application environment and to the interpretation of geoscientific data.

In Europe, it is estimated that there are 30,000 closed mine sites and that many of these may still have considerable amounts of essential raw materials remaining. Many of these closed mines are now flooded and the most recent information on their status and layout can be decades or hundreds of years old. The complex underground layout, topology and geometry of most underground mines, make it impossible to do surveying by conventional or remotely controlled equipment. Exploration and surveying by human divers can prove dangerous and even lethal in harsh deep mine conditions with many flooded mine workings deeper than maximum safe diving depths, and their potential instability.

The objectives of UNEXMIN are supported by a combination of science and technology from deep sea robotics solutions with user requirements from the mining industry. They led to a fine-tuning of UX-1 and its' equipment so that the novel technology could best serve end-users.

The objective of this deliverable is to present the geoscientific results from pilots carried out in four abandoned and flooded underground mines in Europe. The first pilot was in the Kaatiala Mine, Finland, and the second one was in Idrija Mercury Mine in Slovenia. The Urgeiriça uranium mine in Portugal was the third test site and the fourth was in the Deep Ecton Mine, UK in May, 2019. There is little or no geoscientific data from the first three pilots, because the focus during the tests was put on UX-1 robots control, manoeuvrability, autonomy, sensor systems and other technologically-related issues, while the dives in the Ecton trials focused more on mine exploration, and generated a very large volume of data, both geological and archaeological, of which a preliminary assessment is presented in this deliverable.

2 Summary of Geoscientific Objectives

The geoscientific objectives of UNEXMIN's pilots, as part of work package 7, are to demonstrate the use of UX-1 instrumentation in the UNEXMIN submersible robots to obtain valuable geoscientific data which contribute to the knowledge of the mine and its regional setting.

These data include the geology and the industrial archaeology, both of which are highly relevant to the prospects of reopening abandoned mines. The main body of data collected was at Deep Ecton Mine which was worked for copper, lead, and zinc. Although there is no prospect that this mine will ever be reopened, because the ore body was completely worked out, and because the mine is now a protected entity both as a Scheduled Monument and as a Site of Special Scientific Interest, it provides a clear demonstration of how the UNEXMIN technology can be used in other complex abandoned mines.

2.1 Instrumentation Summary

Instrumentation on the UX-1 robots is summarised here. These are the scientific instruments from which geoscientific information has been obtained.

Figure 2.1 gives a summary of the instrumentation which was built into the robot potentially providing data for geoscientific interpretation.

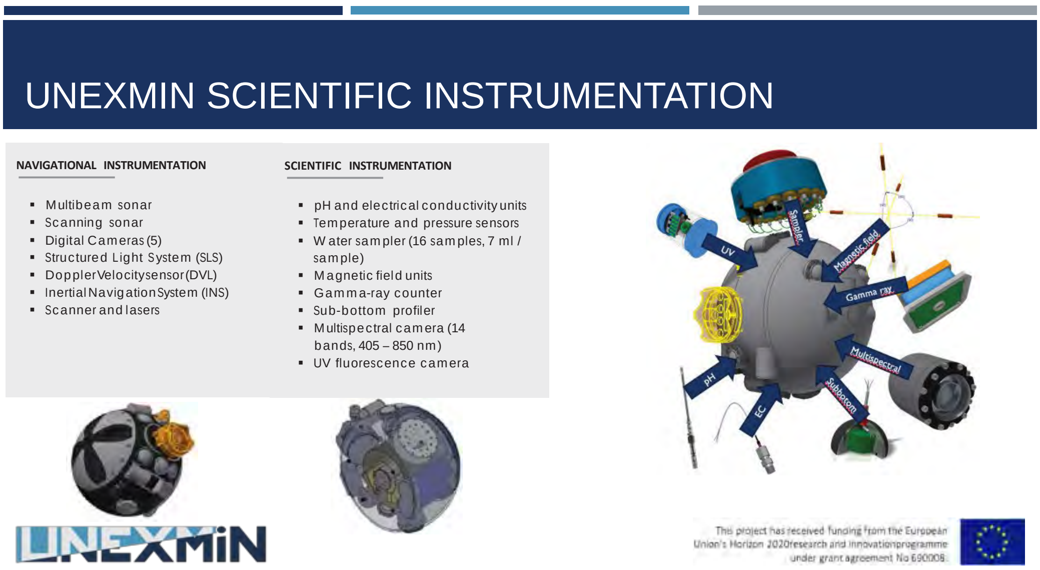

Figure 2.1 A summary of the instrumentation on the UX-1 family of submersible robots

2.1.1 Scanning Sonar and Structured light system

These systems obtain point clouds of open spaces, which can be used for example, for help in future drilling plans, calculating dewatering costs etc. These also allow detection and measurement of orientations of geological structures (dip, strike, folds etc.), and are the source information to create virtual reality models of a mine.

They generate huge amounts of data, and require a great deal of pre-processing to filter the data from rogue points such as spurious echoes, etc., as well as correction of any navigational error.

2.1.2 Visible light cameras

These are probably the most important 'instruments' on the robot as they provide images which are directly usable for interpretation of geological and mining features. Most of the illustrations in this report have been produced by the visible light cameras. There are five of these mounted on each robot, directed forward, left, right, up, and down.

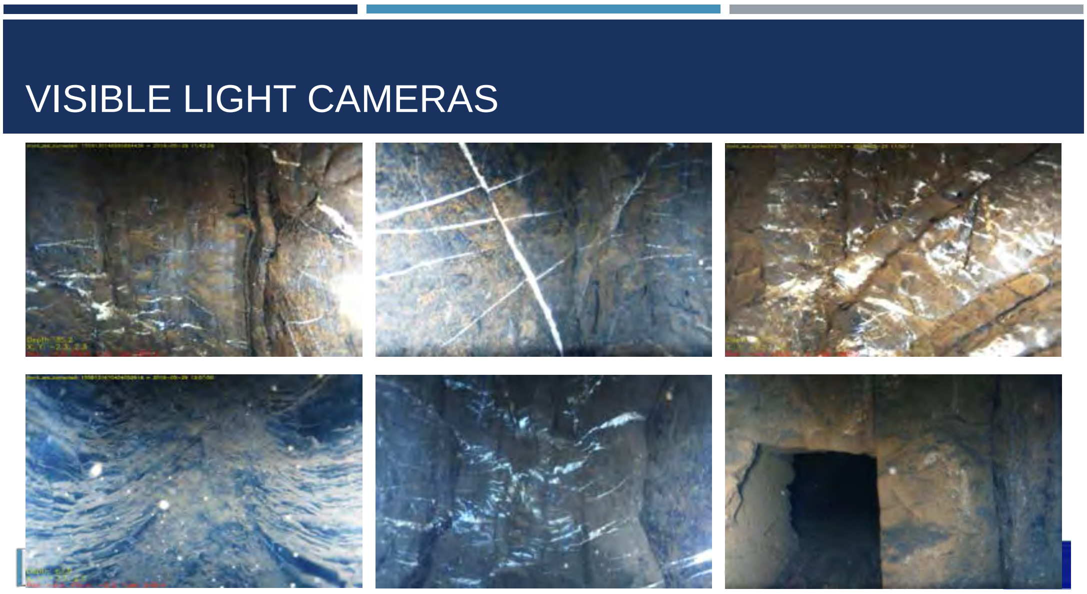

Figure 2.2 Images from visible light cameras on UX-1a and UX-1b robots.

From these images, geologists can identify rock types. Together with UX-1 robot's orientation data geologists can deduce approximate orientations of planes (dip and strike, folds, fault planes etc.). They also allow detection of obstacles, debris, rock falls, blocked passages, and an assessment of the condition of support. They allow identification of exposed bedrock for other target analysis (e.g. multispectral).

However, this involves manual processing (time-consuming); assessments might not be very precise, and the images may not be very useful in muddy water or in large openings where the light intensity is too low to give good images.

2.1.3 pH, EC, Thermometer, Water sampler

The purpose of all of these instruments is to detect the physical and chemical properties of mine water, such as would be needed in the event of future dewatering. They can help to detect possible thermal or electrical conductivity anomalies (in the case of hydrothermal activities, CO2 degassing through active faults etc).

It should be noted that the pH electrode must be calibrated regularly to obtain accurate measurements, and only small amount of water can be sampled, so representativity can be problematic.

EC (electrical conductivity) measurement in Deep Ecton

The pH and EC measuring units wereas tested under real conditions in the Deep Ecton Mine, and we present an example of a typical result of EC measurement unit here during the dive. This geoscientific instrument can collect quasi continuous data during a whole dive.

The recorded and evaluated data originated from the dive in the Pipe on 27 April. Figure 2.3 shows the result of the measurement together with the depth.

From the launch site, to 21.2 m depth the EC has a value between 258–264 mS/cm. At 21.2 m a sudden change was detected, and the EC increased to 402–430 mS/cm. Between 29.8 m and 32.2 m a peak was detected which has a maximum EC (515 mS/cm) at 30.2 m. From that depth the EC has a constant value between 398 mS/cm and 430 mS/cm till the robot reached the 22.3 m depth again. The former peak was not detected during the rise, but several disturbances were measured in the 22.3 m – 18.7 m section. From 18.7 m the EC reached the 258–264 mS/cm value.

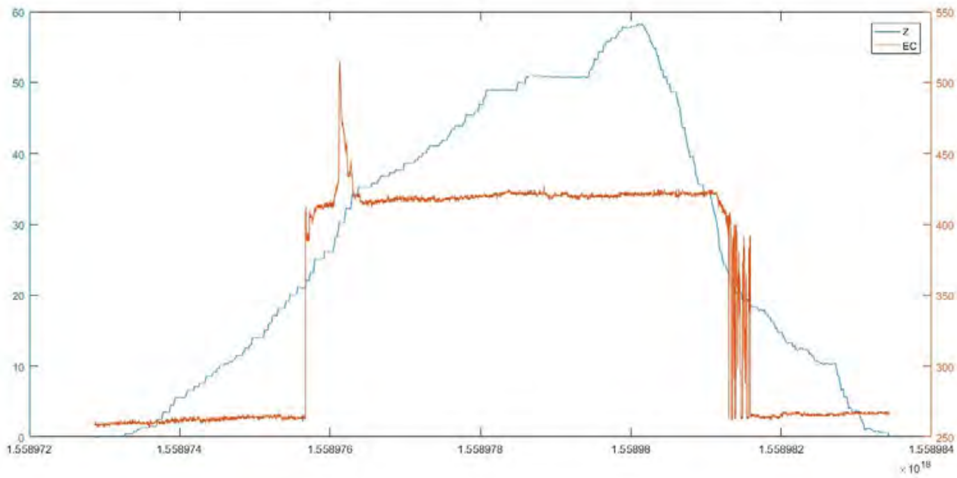

Figure 2.3 EC measurement in the Pipe. The blue line represent the depth in m and the red line represents the EC value in mS/cm

The measurement shows that in the Pipe 2 different EC value can be detected. Between 0 and ~22 m 258–264 mS/cm and between 22 m and 58.4 m 398–430 mS/cm values are the common. From the other sensor and camera data the peak can not be explained, most probably a small water current was in the pipe near the 30 m depth which was not touched during the rise. The reason for the disturbances between 22.3 m and 18.7 m is the robot mixed the water during the dive.

2.1.4 Ultraviolet camera

This uses the same cameras as for visible light, but with ultraviolet illumination. It allows rapid detection and identification of fluorescent minerals, as demonstrated in Figure 2.4.

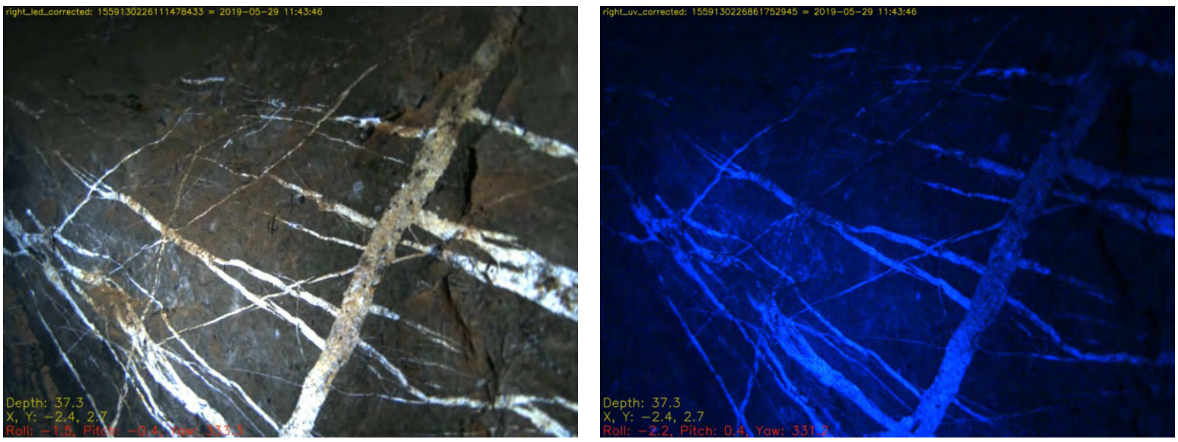

Figure 2.4 Use of the ultra-violet source, in this case highlighting veins of fluorescent calcite

2.1.5 Multispectral camera (14 bands)

This is potentially a very powerful method for mineral identification, because it can readily detect some minerals with specific absorption patterns in IR light,. It is an imaging technique which generates a huge amount of data. Superimposing of MSU images is hard, because the robot moves and rotates, so pixel matching is a difficult manual process. There are a number of statistical methods for processing the data (documented in Deliverable D6.3), of which the most promising is based on neural network algorithms, which have been used to develop an automated calcite detection method (Figure 2.5). However, the automatic mineral detecting algorithm was not available at the time the work reported here was undertaken because it requires additional testing and ideally should be used in conjunction with advanced image-pixel-matching methods.

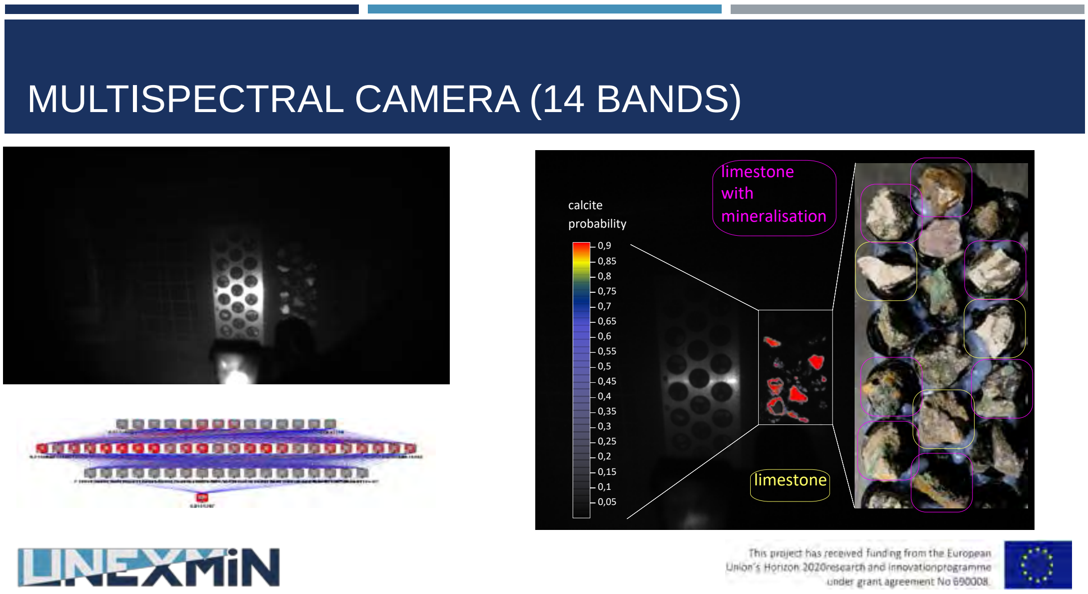

Figure 2.5 Multispectral camera and neural network algorithm to identify calcite.

2.1.6 Gamma Ray Counter

This can detect increased rates of gamma radiation, which is useful for detecting radioactive minerals such as those containing uranium or thorium, or potassium-rich rocks, like granites, pegmatites etc.) especially if the radioactive element is dissolved or suspended in the water. Detection of radiation in wall rocks is more problematic because of rapid attenuation of gamma rays by absorption in water. Figure 2.6 shows the results of a test in the shaft at Urgeirica uranium mine.

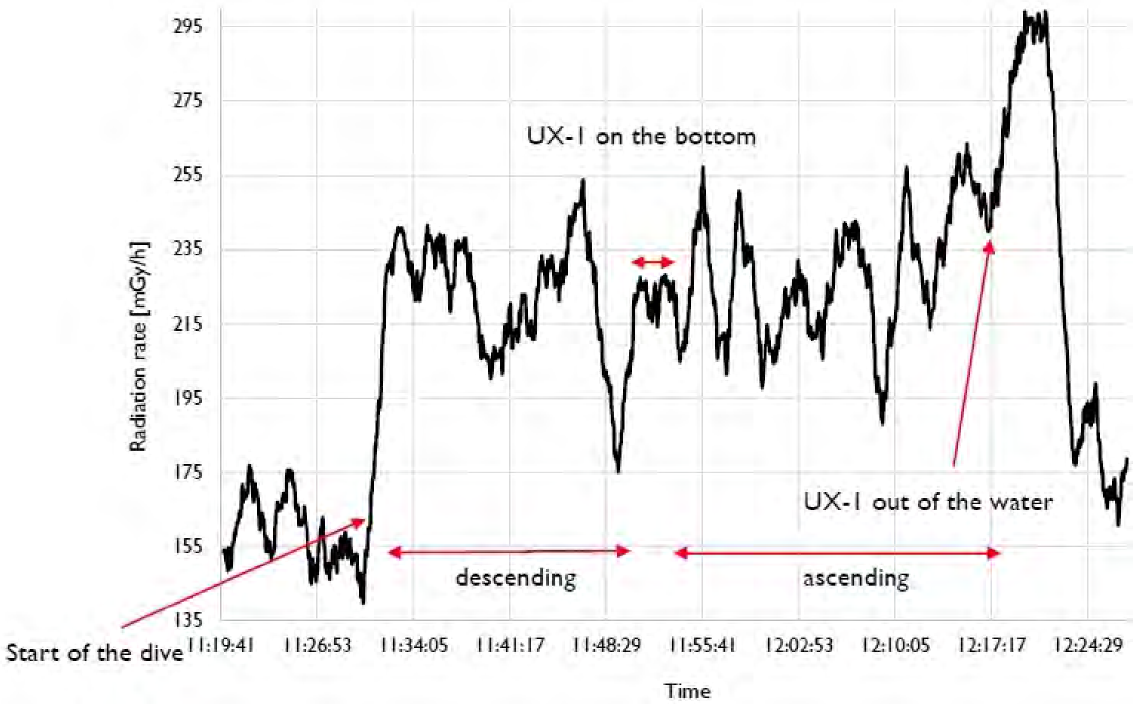

Figure 2.6 Gamma ray detection in the Urgeirica uranium mine shaft. As the robot entered the water, the detected gamma ray level increased markedly; at the end of the dive, on leaving the water, the level increased again. The interpretation of this is that the main source was dissolved radon gas, which bubbled to the surface during the dive and accumulated just above water level.

2.1.7 Magnetic field meter and sub bottom profiler

The magnetometer in principle can detect magnetic anomalies which are commonly associated with some ores or paleoremanent magnetism present in igneous bodies, but was not mounted in the UX-1a robot used for most of the tests, and has not yet been tested in real conditions.

The sub-bottom profiler can detect sediment depths and tunnel floor rock structures precisely, but did not work well during the tests; this unit requires further calibration and testing in follow-up work.

3 Geoscientific interpretation from Kaatiala, Idrija, and Urgeiriça

3.1 Kaatiala

This mine consists of a flooded open pit (quarry) with some underground workings accessed by horizontal tunnels from near the bottom. The location and regional geology are described in D7.1 and D7.2. The principal purpose of this pilot was to test the robot's propulsion, navigation, and instrumentation systems, and little or no data was collected that could be used for any geological interpretation.

3.2 Idrija Mine

Because the shaft and the one cross-cut accessed by UNEXMIN are entirely lined by concrete and stone, it was not possible to obtain any geological data. The purpose of the Idrija mission was to test the robot capabilities. The location and regional geology are described in D7.1 and D7.3.

3.3 Urgeiriça mine

The third field test of the UX-1a robot was carried out in a closed underground uranium mine Urgeiriça in Portugal. The location and regional geology are described in D7.1 and D7.4

There are 6 vertical shafts in the mine. Underground development occurred in drives 15 to 30m wide that extend horizontally up to a total of 1600m. Overall with 19 different working levels, the mine reached a depth of 500m. The galleries are accessible by the main 'Santa Bárbara' shaft through a hatch at the surface (1m by 1m in size). The 'Santa Bárbara' shaft is 400m deep and the water level is about at 8 to 10m below surface. The first 20m of the shaft wall are secured with concrete, while at deeper levels the shaft is entirely lined with heavy timbers.

The mine site is geologically situated in the geotectonic unit of Central Iberian Zone in the Iberian massif The predominant host rock in that region is porphyritic medium to coarse grained two mica granite with numerous quartz and jasper veins trending N50—70°E and dipping 75° to the southeast. The granites are relatively altered.

Three bigger faults are associated with the deposit (one horizontal and two vertical ones), as well as numerous smaller faults and fractures. Most of the mineralisation is connected to the fractured zones.

The origin of the deposit is believed to be connected to Alpine movements that reactivated Hercynian faults. The main minerals in the hydrothermal veins are reported to include microbotryoidal sooty pitchblende and uraninite (UO_2), pyrite (FeS_2), marcasite (FeS_2) and jasperoidal quartz (SiO_2), with sporadically galena (PbS) and chalcopyrite ($CuFeS_2$) (Pinto et al 2016). Wall rock alteration is common, mainly sericitization, cloritization, hematization, jasperization and kaolinisation (Portugal et al. 1971).

The UX-1 robot explored the main shaft down to 104 m below water level (4th level, 110 m deep). The entrances of the first four levels were mapped (1^{st} level at 30 m, 2^{nd} at 60 m, 3^{rd} at 85 m and the 4^{th} at 110 m below surface).

1^{st} level at 22.5 m: The entrance chamber of the first level was partially collapsed, choked with rock debris, timber and pipes, so only a few metres of the tunnel were investigated so as not to risk the robot.

2^{nd} level at 49.3 m: Collapsed after a few metres so it could not be entered.

3^{rd} level at 75 m: In good condition, so this level was used in multiple test dives to test and to develop the instrumentation.

The whole shaft was imaged. Accessible parts of side tunnels were also explored until further exploration was prevented by collapsed wooden supports. No in-situ rock was visible in the shaft. The walls were obscured in most places by the heavy timber cage-guides and supports, with planking in most places.

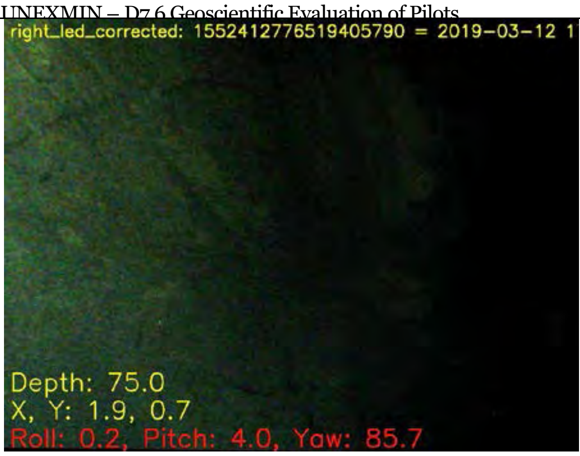

Figure 3.1 Narrow veinlet containing black mineral, possibly pitchblende

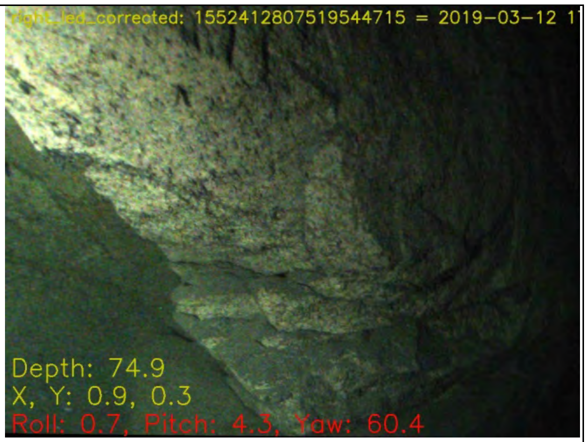

Figure 3.2 Granite with veinlets of black mineral, possibly pitchblende

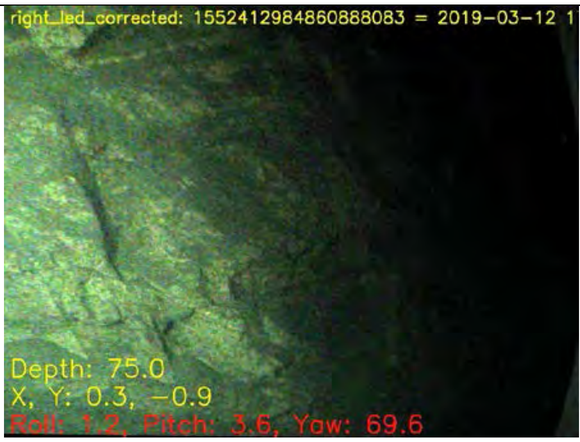

Figure 3.3 Yellow/green staining on broken surface of granite. Unfortunately there are no ultraviolet-source images or multispectral data for this part of the mine to assist identification.

Figure 3.4 Yellow staining on broken surface of granite. Unfortunately there are no ultraviolet-source images or multispectral data for this part of the mine to assist identification.

Figure 3.5 Apparent colour differentiation in granite on closer inspection is more likely to be due to varying quantities of grey sediment on differently oriented surfaces

Figure 3.6 Evidence that fine sediment is lying on the less vertical surfaces and giving a false impression of colour contrasts in the granite

Where the planking was broken or missing, it could be seen that the rock behind was mostly in the form of loose boulders.

The only rock that was certainly in-situ was seen in the 75m level, but this was insufficient to give information on the regional petrological or structural context. Figures 3.1 to 3.4 show examples, with comments on the mineralisation.

Because there were no radioactive minerals in the training set used for training the multispectral identification system (as a result of safety regulations), it was not possible to check the identity of the yellow minerals observed. No ultraviolet imaging was obtained which could have helped to identify these secondary minerals.

Visual inspection of the available rock images showed that there was a risk of misinterpretation due to sediment lying on some of the exposed rock surfaces (Figures 3.5, 3.6). This is something that needed to be kept in mind when exploring Ecton: although mostly 'clean', in places it was clear that there has been substantial buildup of silt following mine closure. A particular problem at Ecton, not encountered in the other pilot sites, is the steady accumulation of crystalline calcite, as calcite rafts form on the water surface, and periodically break up and sink.

4 The Ecton Mine pilot mission

4.1 The geology and history of Ecton Mine

Ecton Mine is located to the south-west of a Lower Carboniferous limestone inlier in central England, sometimes called the 'Derbyshire Dome' which represents a shallow-water lagoon surrounded by a ring of reefs. Ecton lies outside the lagoon and is hosted by limestones and shales of a deeper water facies.

The history and geology have been summarised in Deliverable D7.1 and D7.5 and are documented in detail by Barnatt (2013), Ford (2000), and Porter (2004). The primary mineral deposit consisted of copper and other metal sulphides in a near vertical 'pipe' and associated fracture-filling veins, within a Lower Carboniferous deep-water (predominantly) limestone sequence. The mine was a major producer of copper, as well as lead and zinc, in the second half of the 18th century, with production at lower volumes continuing until the 1850s. The deeper parts of the mine were abandoned and the pumps were stopped in 1855, and the mine had flooded to river level by 1858.

4.2 The UNEXMIN pilot mission

Three launch sites were used, in the pumping shaft (which descends vertically from the Deep Ecton adit level), the winding shaft (which descends vertically from the engine house on the hilltop), and the upper part of the flooded pipe workings. All three were accessed from the Deep Ecton adit level. Their spatial relationship is shown in plan (Figure 4.2.1) and section (Figure 4.2.2 and in more detail Figure 4.3.1).

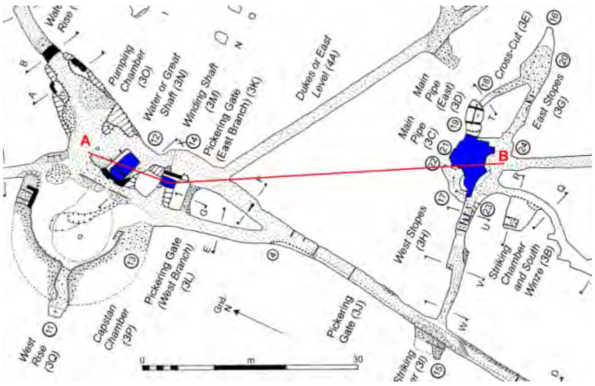

Figure 4.2.1 (above) plan of UNEXMIN launch sites. Base plan used was the mine survey by John Barnatt.

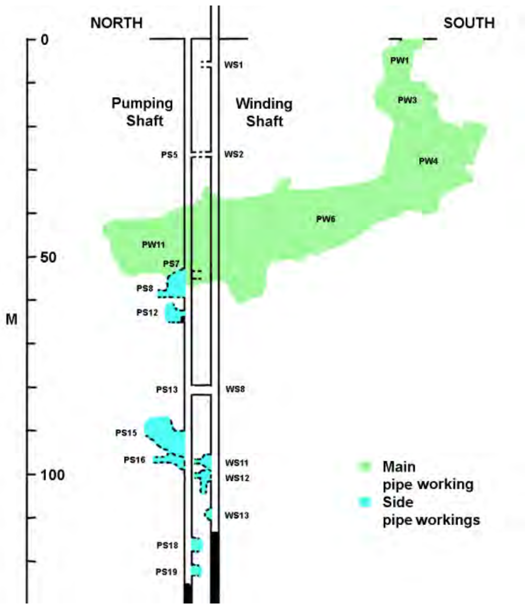

Figure 4.2.2 (right) approximate scale section showing the parts of the mine explored by UNEXMIN. (drawing by John Barnatt).

4.3 Summary of Archaeological Results from the Ecton Mission

At Deep Ecton Mine, which in the 18th century was one of the most important copper mines in Britain, there are large flooded workings that extend down to 300m below river level (Figure 4.3.1). These have not been seen since the later 1850s after the mine pumps were turned off in 1855 and the workings gradually flooded. The UNEXMIN dives, done in partnership with the Ecton Mine Educational Trust, allowed an exciting opportunity to enter workings not seen for over 160 years.

While the primary aim of the dives was to test two of the submersibles, we were also able explore workings for which our prior knowledge was minimal. The most useful source of historical information on where now-flooded features lie is a schematic and over-simplified elevation through the workings dating to 1858. One thing that was obvious once the dives started, as long suspected, is that the 1858 elevation shows everything on the same plane but in fact there is a conflation of features that in reality are in front 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.

During the ten dives undertaken less than 10% of the recorded workings to be entered, with explorations concentrating of the two main shafts and the upper parts of the massive 'pipe workings' in the mineral deposit. Open leads were left and hopefully these will allow future access to unexplored parts of the flooded workings, which include further vast mined caverns, an underground canal level 62m below water level and various tramway levels.

The pumping shaft was explored to a blockage at about -125m, while the winding shaft was choked at a little under -115m. These are sunk through bedrock, where the bedding was often near-vertical, with the base of saddles in the folding also seen. Both shafts had levels leading off their sides at various depths, some connecting the two shafts, others going elsewhere. In the pumping shaft there were various substantial timbers, thought to be for helping retain the now-removed pump rising main pipes and rods, the entrances to some of the levels and perhaps also ladders. Other features here included three complex groups of mineral workings in 'side pipe workings' and a 'level' at or just below the underground canal horizon with a walled 'dam' at its entrance.

In the main 'pipe working', entered from a launch site in a chamber within the mine, a route through convoluted passages led down to a huge 'pipe working' with highly irregular sides that descended from about -20m to a little under 40m. This was massive towards the bottom measuring roughly 20m by 45m across. Below here much of the working had been backfilled with mine waste, but a route on starting above this led diagonally down, via two low retaining walls holding back stone dumps, to the present base of this working at about –58.5m. Here a short level led to the main winding shaft, with a part-choked working leading off beyond. No intact timber working-platforms remained in the 'pipe workings', but on the rubble floors there were scattered displaced timbers and also such items as iron tramway rails and metal pipes. 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, working 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.

A detailed account of the archaeological discoveries from the UNEXMIN pilot mission at Ecton is included in Annex 1.

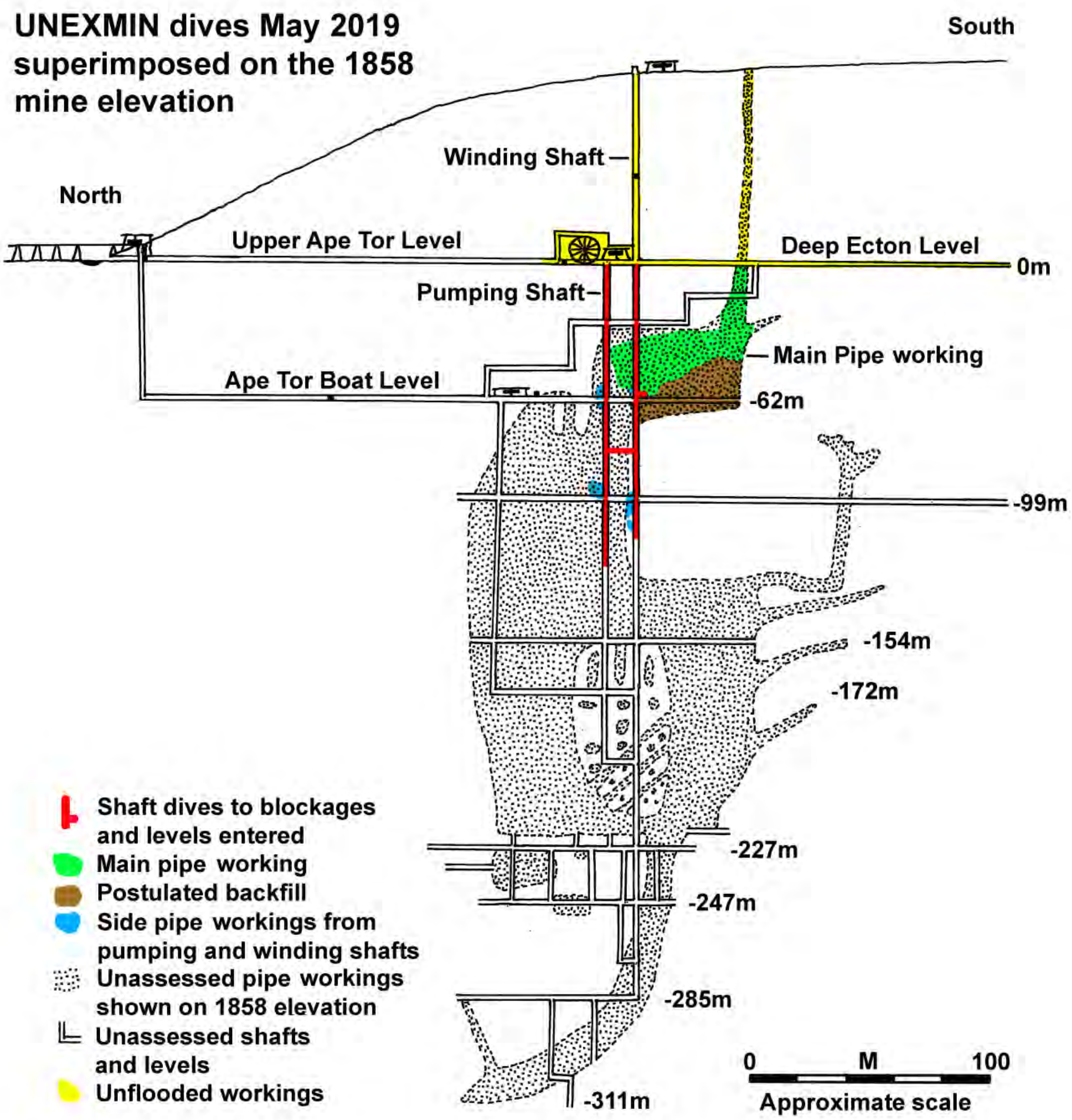

Figure 4.3.1: The approximate extent of passages explored during the UNEXMIN dives undertaken in May 2019 at Deep Ecton Mine, superimposed on the schematic 1858 mine section, with recorded depths of levels are also given (the scale of the 1858 drawing is only approximate because it shows the lower parts of the workings at a slightly larger scale than those parts above).

4.4 Summary of Geological Results from the Ecton Mission

The ten UNEXMIN dives at Deep Ecton have provided a wealth of new information on the geology of the mine by the remote exploration of the mine workings not seen since about 1855 and never studied by a 'modern' geologist. Our geological knowledge of the mine has been greatly enhanced allowing the mines' geology to be better understood in relation to the regional geological picture. The dives have confirmed that the structural geology of the mine is complex and provided some information about the geological controls on the formation of the pipe vein (examples are on Figures 4.4.1 and 4.4.2). The exploration also confirms that the mine was thoroughly stripped of all ore prior to closure in the 19th century and that very little ore remains in the workings explored during the project.

The pipe appears to be mainly or entirely within more thickly bedded limestones that are probably a reef knoll facies part of the Milldale Limestones. This may well have formed a favourable host rock for the pipe mineralisation which may have been partially controlled by the structural geology.

Detailed interpretations and notes on the geological data from Ecton Mine are included in Annexes 2 and 3.

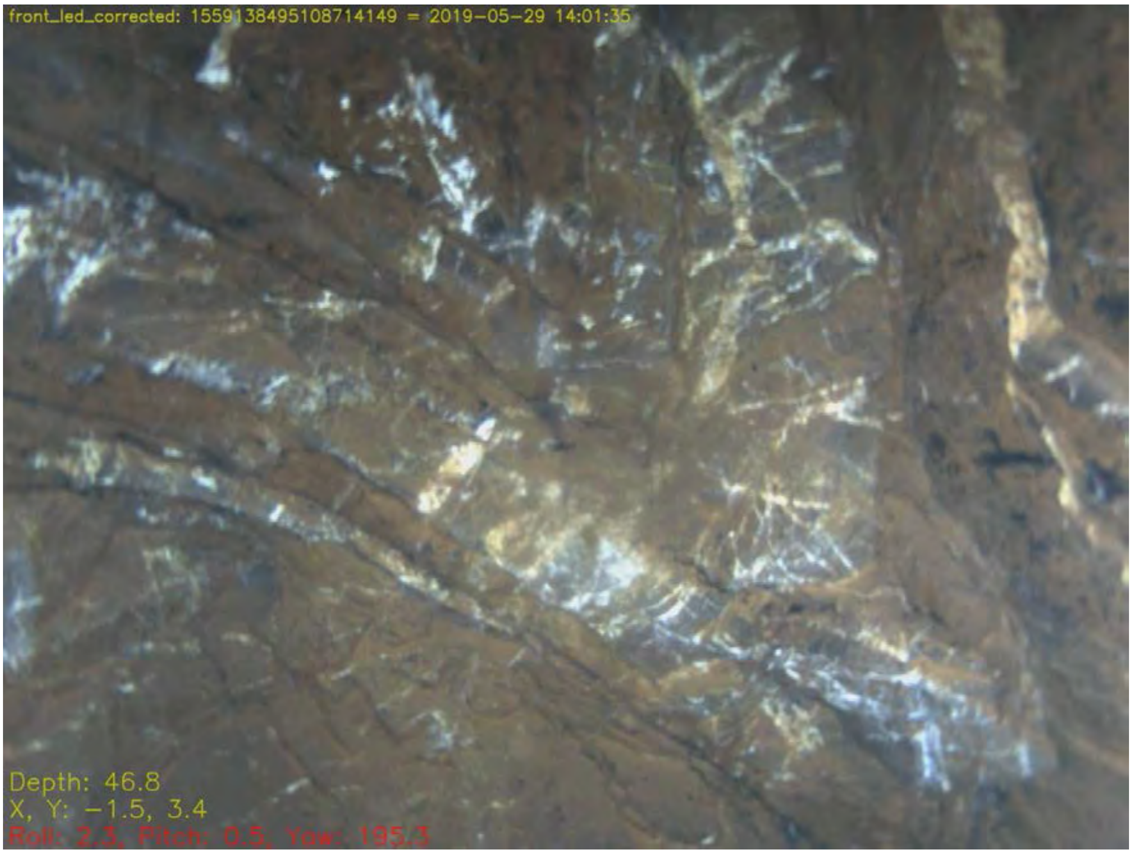

Figure 4.4.1 Acute synclinal fold in more thickly bedded limestone with post-folding calcite veining that is an early phase of the mineralization at Ecton (46.8m Winding Shaft).

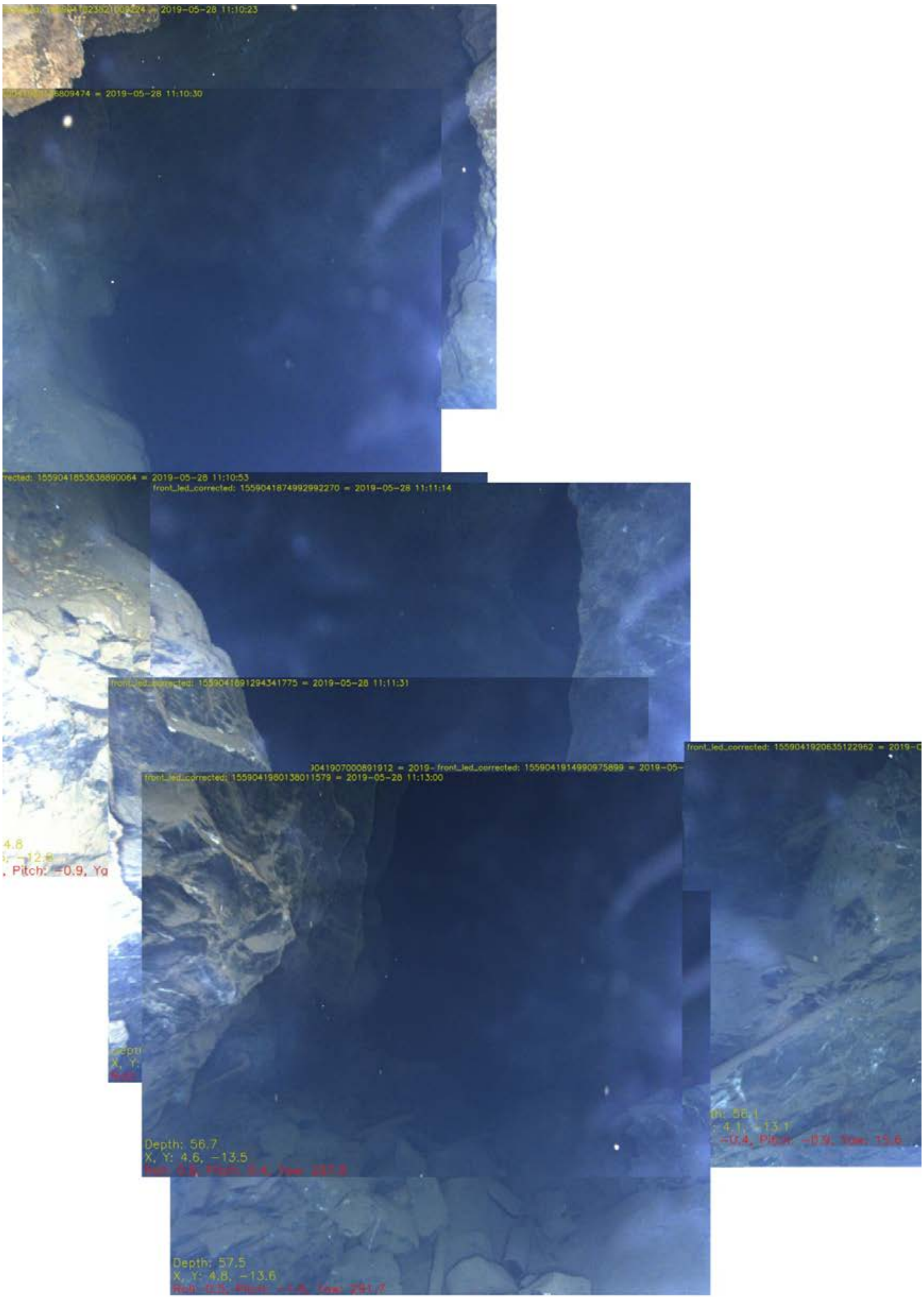

Figure 4.4.2 Composite image of one of the large pipe workings, over 5m high, encountered in the Great Shaft. Note steeply dipping thickly bedded limestones in right hand wall and more massively bedded reef knoll limestones in the left hand wall. (51 to 56m Great Shaft).

5 Conclusions

The wealth of geological information eventually provided by the 10 successful dives at Ecton Mine not only demonstrates and validates the effectiveness of the UNEXMIN design and construction, but also will provide material for much further study of this mine, by the Ecton Mine Educational Trust and its academic partners, as well as yielding data which will be integrated into its educational activities for students in schools and universities. All of the pilots have provided valuable tests of the technical capabilities of the UX-1 robots, leading up to this.

The archaeological data alone have tested the published 18th and 19th century accounts confirming some - but refuting others - and the huge quantity of data that still needs detailed inspection and analysis will undoubtedly add greatly to our knowledge of the history of this important mine.

The geology of the Ecton area has previously been studied only at surface and in relatively shallow (above river level) mine workings. The data obtained from the UNEXMIN trials will lead to a thorough reassessment of the geological interpretation of this area, which has a tectonic and mineralisation history contrasting greatly with the surrounding areas both to east and west. Such a contribution to regional geological knowledge was one of the stated aims of the project and demonstrably has been achieved.

6 References

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7 ANNEX 1: Detailed Archaeological Report from Ecton Pilot Mission

Dr John Barnatt, September 2019

7.1 Summary

During the ten dives carried out by UNEXMIN in May 2019 at Deep Ecton Mine in Staffordshire, England, much 18th and 19th century archaeological evidence was found, seen for the first time since the workings below river level were allowed to flood in the 1850s. The site is a Scheduled Monument of National Importance protected by law and care had to be taken not to cause any damage. The dives in the main pumping shaft, to about -125m where it is blocked; in the main winding shaft to a little under -115m and also blocked; and in the main workings in mineralised pipe deposits to -58.5m, allowed a variety of features to be recorded. These included a massive 'pipe working' chamber, and in the shafts there are cross-cuts between them and levels going elsewhere; timbers that supported platforms and pumping pipes; and smaller 'pipe workings', that they intersected.

Although, for largely technical reasons and time constraints, we only accessed less than 10% of the documented workings, much has been learnt about the character of these features and how they were used and interlinked. The information we have from historical sources only gives broad outlines of the development of the mine workings below river level, which extend down to about -310m; with much detail not recorded. We confirmed that the main source of information on their distribution, an elevation drawn in 1858, was grossly over-simplified and that the shafts are sunk through bedrock to one side of the mineral workings rather than passing through them. To our surprise we discovered that the larger of two 'pipe working' chambers entered by our submersible had waste rock in a heap at the bottom that may well have been over 25m deep. The presence of this waste allows us to postulate that, as miners in the 1790s stripped back the walls of the 'pipe workings' looking for further deposits after the rich mineral deposit failed at depth, they simply dropped this material into voids below that had already been assessed.

A variety of open leads remain for future exploration and there is a strong possibility that the lower workings not yet seen can be accessed once the submersible can be operated in autonomous mode.

7.2 Introduction

Deep Ecton Mine: this mine, near Warslow in Staffordshire, in central England (entrance at National Ordnance Survey Grid SK 0963 5813), was one of the most important copper mines in Britain in the 18th century. Here there are large flooded workings that extend down to over -300m below river level. These have not been seen since the later 1850s after the mine pumps were turned off. The UNEXMIN dives here, done in partnership with the Ecton Mine Educational Trust, allowed an exciting opportunity to enter workings not seen for over 160 years.

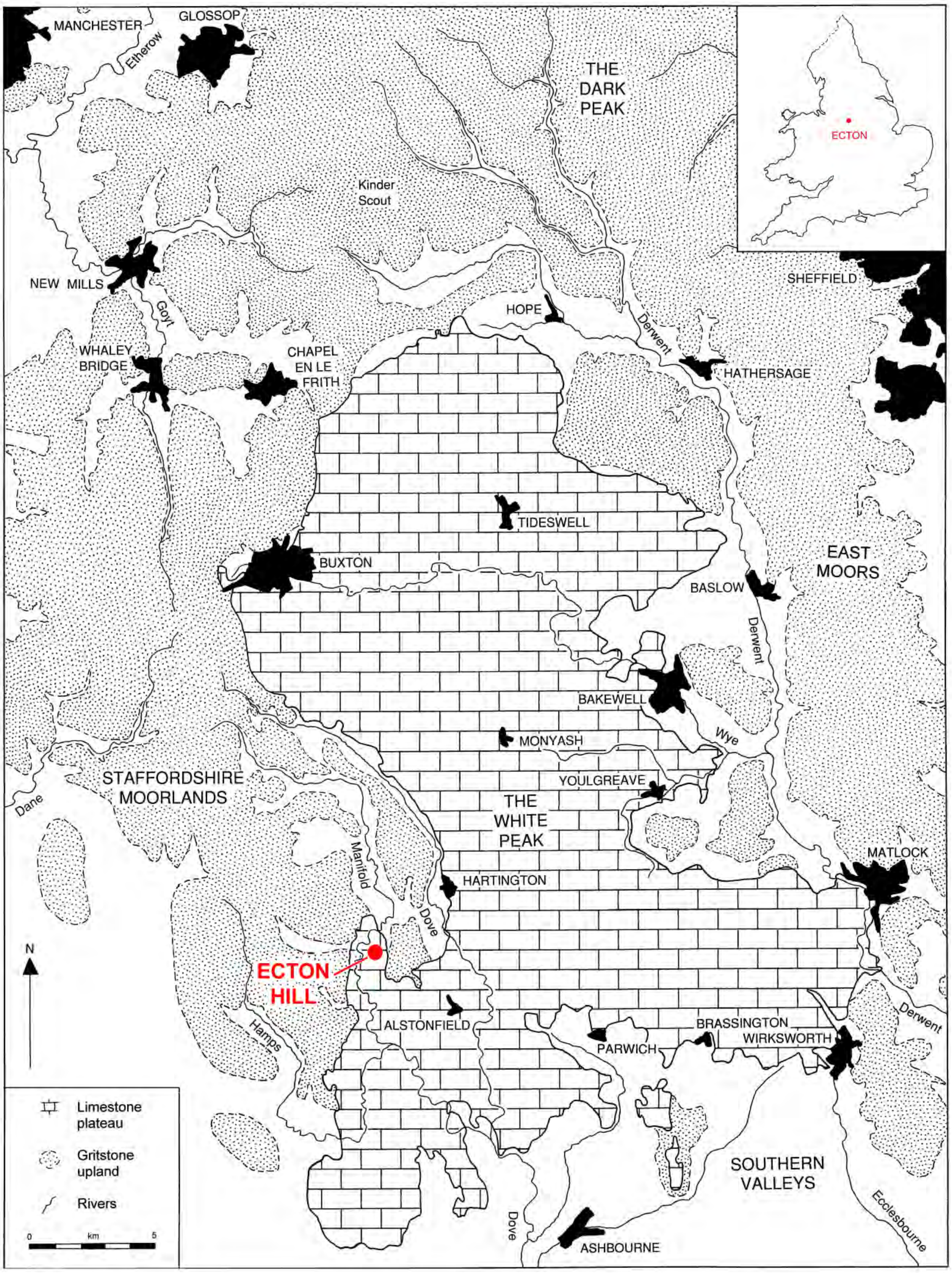


Fig. 7.1: The location of the Ecton Hill.

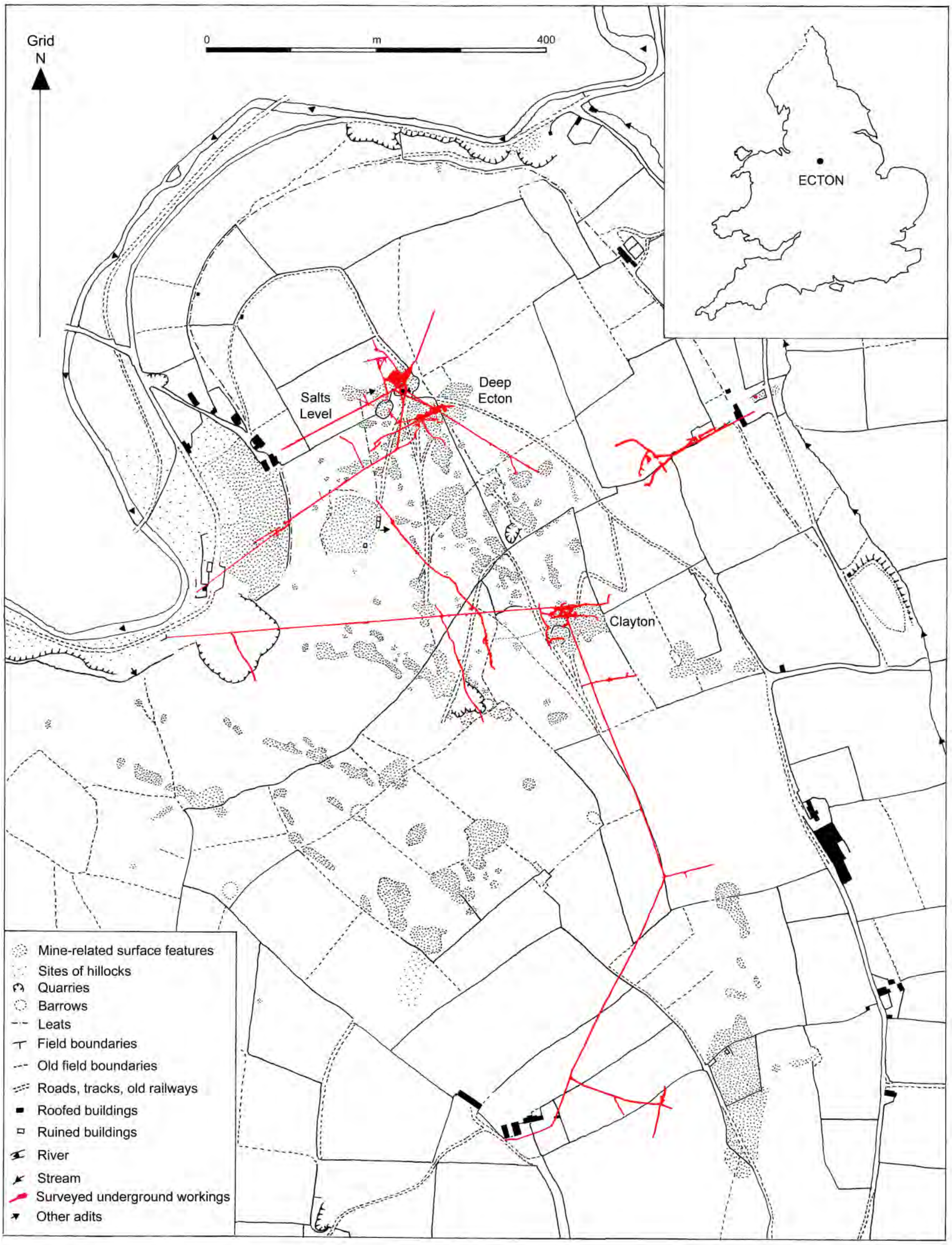


Fig. 7.2: Ecton Hill and the location of the main underground workings at river level, and also of Salts Level *c.* 35m above Deep Ecton Mine.

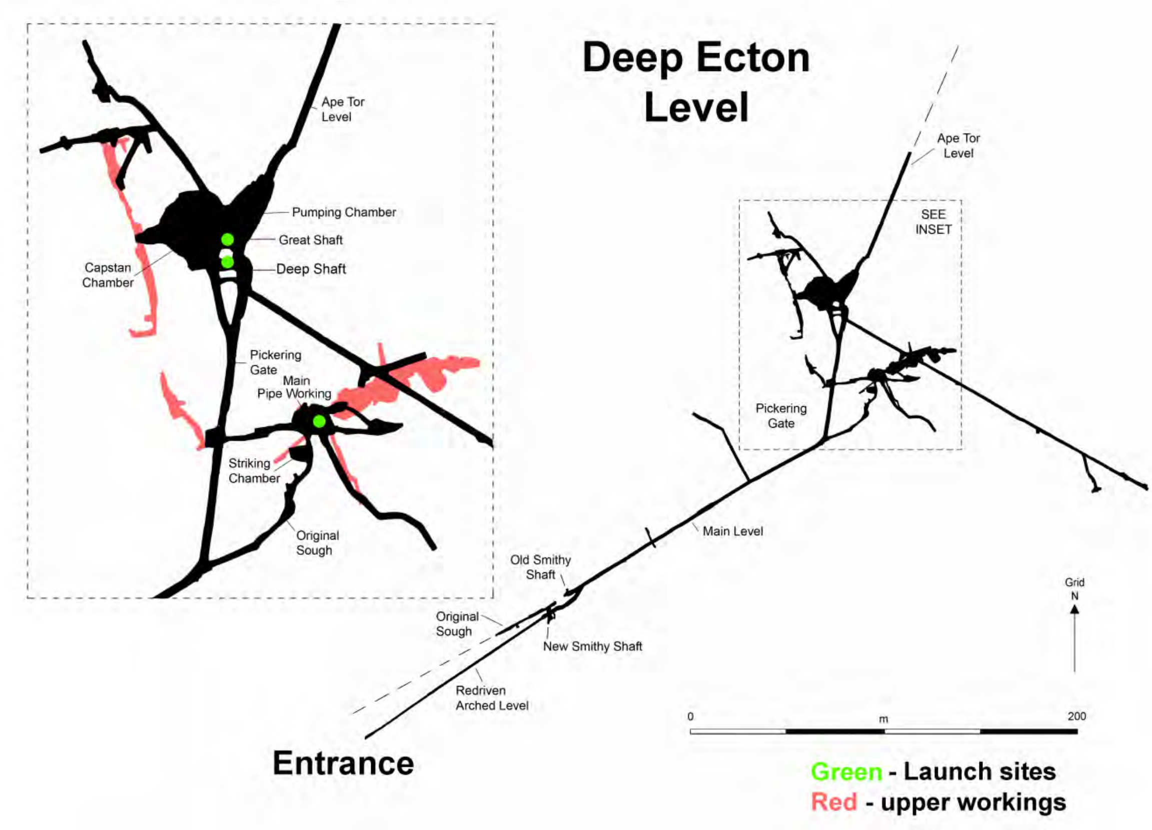


Fig. 7.3: The Deep Ecton Mine workings at river level and immediately above.

Preliminary Work: The above-water workings were surveyed in detail by the author and assistants in the later-1990s and 2008, with plans, elevations, catalogues of features and interpretation produced, as part of an assessment of all the Ecton Mines for Historic England, then English Heritage (Barnatt 2012; 2013). More recently these same areas were surveyed by Mark Hudson of Geoterra Ltd. using a hand held laser to produce three-dimensional point-cloud data. These latter surveys do not supersede the earlier ones, but rather they complement each other, the conventional survey good for recording archaeological detail in an intelligible way, the laser survey good at providing 'fly-through' images good for visualisation of the workings in three-dimensions and for presentational purposes.

As a vital preliminary task the entrance area of the Deep Ecton Level by the River Manifold was made safe so that it was possible to access the three dive sites. This entrance had been reopened in the 1980s after it had collapsed earlier in the 20th century. The remedial work done then included placing timber supports under two holes in the arched roof and under another area where the roof was in danger of collapse; this infrastructure include three metal Acro-props that prevented access along the passage for any objects as large as the submersibles. In the last five years or so one of the passage walls had developed a worsening bulge and was in danger of imminent collapse. In October-November 2018 the arching and wall were put in good order after a 4m deep hole was dug from above to access the passage, done under archaeological supervision, a necessary prerequisite as the site is a Scheduled Monument of National Importance (Barnatt 2018b; 2019; in press).

Fig. 7.4: The entrance section of the Deep Ecton Level, just above the river level, photographed in Summer 2019, showing the 1980s remedial work, and the recent bulge on one of the walls, before they were removed (Photograph: John Barnatt).

Fig. 7.5: The entrance section of the Deep Ecton Level, just above the river level, showing the October-November 2018 repairs in progress (Photograph: John Barnatt).

Another task was the upgraded provision of safety measures in the ladderway to '*Salts Level*' above, in compliance as a 'working mine' within UK Mines and Quarries Act health and safety legislation, as this was the 'second means of egress' that British law demands (Barnatt 2018a).

A third task was the building of three platforms at the dive sites to allow safe launching of the submersibles, and the installation of electrical, telephone and Ethernet cables, that were brought from surface, via '*Salts Level*' (a mine level from surface on the hillside above Deep Ecton Level) and then down a 35m stretch of the main winding shaft, for use at the each of the launch sites, all carefully designed in such a way that their erection did no archaeological damage.

Mineralisation: The mineralisation is covered in more detail in other parts of the UNEXMIN report; to set the scene for the archaeological assessment, and to define terms used here, a summary is given below.

Ore deposits are common throughout Ecton Hill within the Carboniferous limestones here, and these include ores of copper, lead and zinc. The Ecton Mines have commonly always been referred to as copper mines, mainly because copper fetched a better price, but the other metal ores were also plentiful; they were often found associated with non-metallic minerals, particularly calcite, but with barite and fluorite also common. While all these minerals were mined in many places on the hill, both in mineralised faults and in tilted bedding planes, there were two exceptionally rich deposits, at Deep Ecton Mine and Clayton Mine nearby. Both occur where the bedrock is heavily folded, with the beds often lying near-vertical between the tops and bottoms of these folds. These rich ore deposits are found in the steeply folded rocks where fractures are most common, found particularly at top and bottom of the folds, at points that are intersected by faults, the latter often mineralised as 'vein-like' features. These faults vary in inclination from near-vertical to running at diagonal angles through the bedrock.

For the sake of simplicity the main ore deposits are all referred to here as 'mineralised pipe deposits' and the mine working here as 'pipe workings', with a distinction drawn between 'main pipe workings' and smaller 'side pipe workings'. Both the Deep Ecton and Clayton rich mineralised pipe deposits outcrop near the crest of the Ecton Hill ridge and descended near-vertically in somewhat sinuous fashion too deep below the level of the adjacent River Manifold.

Fig. 7.6: The launch platform, and the adjacent work station, at the pumping shaft, photographed as their installation was being completed (Photograph: John Barnatt).

Recording the Archaeology: It is a common misconception that archaeology comprises the study of artefacts that people used in the past. In fact archaeology is a much broader discipline than this and includes all structures created by people in the past, including such things as mine workings, as well as the impacts people have had on the landscape and environment. At Deep Ecton it is the mining structures and workings observed that are of the greatest significance rather than the artefacts the miners left behind.

The archaeological features seen during the UNEXMIN dives have been assessed by viewing videos compiled from the *c.* 600,000 still images captured by the five cameras on each of the two submersibles used; this included reliable depth data and often problematic information on orientation. The assessment process was augmented by viewing selected sonar point-cloud data acquired during dives, although the use of these was also sometimes problematic due to the navigation issues together with spurious echoes and other vagaries.

Selected features are illustrated in this report, with still images extracted from the dive videos prepared at higher resolution after the curvature resulting from using fish-eye lenses had been rectified (note that the YAWs given in these are often no guide to the real orientation from north). This was only done for some features; in others this was not possible because of poor visibility resulting from the distances the features were from the cameras or because of disturbed sediment particles in the water. These problems were especially apparent in the main 'pipe workings' and in lower parts of the shafts. In other cases only partial views of the features were captured by the cameras in such a way that it was impossible to successfully stitch still images together; this was particularly the case with the larger 'pipe workings' intersected by the shafts. Some sonar images are also used in the report, illustrating the plan views of selected features at specific depth ranges.

The Known and the Unknown: While the Deep Ecton Mine workings above water level have been surveyed in detail, prior to the UNEXMIN dives in May 2019, all we knew of the flooded workings was from sketchy and in some ways potentially unreliable data derived from historic sources. While these sources are good for reconstructing the history of the mine, with the physical structures there were many blanks and uncertainties in our knowledge. We knew of the depths and general character of the workings and shafts that accessed them, but detailed knowledge of what lies below water was virtually non-existent.

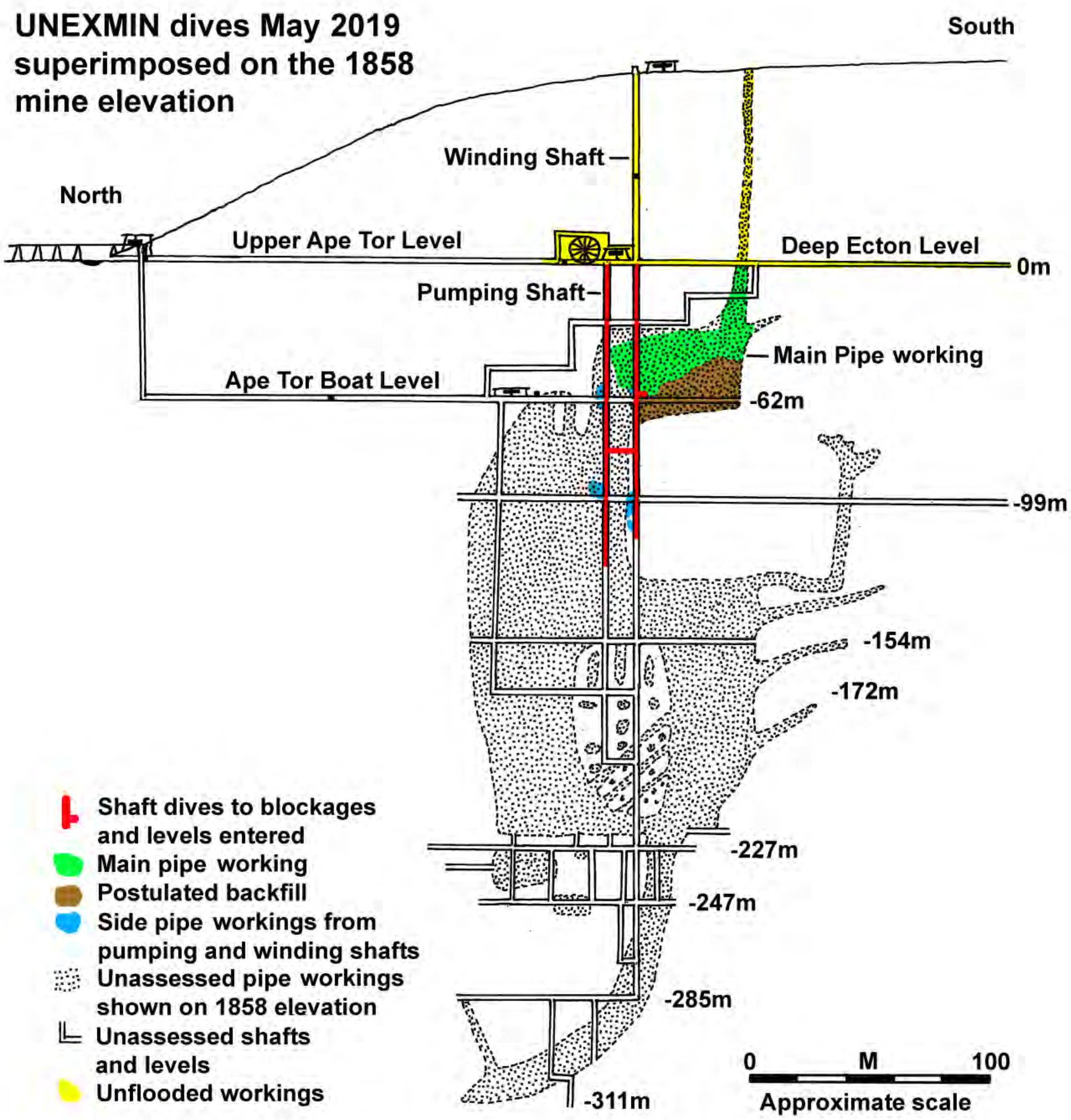
The three launch sites - at the two main shafts and the top of the flooded 'pipe workings' - were positioned so that dives could start to answer research questions, including:

1. At the main pumping shaft, is it of the same character throughout and is there any physical evidence for such things as pumping pipes/rods and a ladderway running down the shaft?
2. Archaeological evidence at the shaft top suggests it was divided into three compartments by timber walls; is this interpretation sustainable at depth and what were these compartments used for?
3. At the main winding shaft, is it of the same character throughout and at what points was ore delivered for haulage upwards?
4. With both shafts, what cross-cuts between them, and levels leading elsewhere, exist?
5. With both shafts, to what extent were they sunk through bedrock or conversely through 'pipe workings'?
6. What is the location, scale and character of the main 'pipe workings' and smaller side 'pipe workings', and do working platforms and ladders remain in place?
7. It has long been thought that the 'pipe workings' will be far more complex and three dimensional than the present evidence in the form of Meads 1858 drawing allows assessment of; to what extent is this true?
8. What is the character of a documented underground canal at about -62m, and associated horse-operated winding engine and stables nearby?
9. Is a documented stepped passage between river level and the canal a ladderway for accessing workings?
10. What is the character and purpose of several long levels and a deep third shaft documented from -99m downwards?
11. What is the character and size of the lower workings below -220m where the main ore deposit is documented as having been lost?
12. In all the workings, are there important artefacts remaining?

The 2019 dives have started to give answers to points 1-7 and 12, but answers to points 8-11 are for the future. The main submerged 'pipe workings' below -58.5m down have not yet been entered and what lies here is still unknown (although there is a strong possibility that some workings that have been entered via the two shafts, and are currently classified as 'side pipe working', may link with these, or in one case may upon further exploration prove to be part of the 'main pipe workings').

The 2019 Dives: While the primary aim of the dives was to test the two submersibles, we were also able explore workings for which our prior detailed knowledge was minimal. The most useful source of historical information on where now-flooded features lie is an 1858 detailed but schematic and over-simplified cross section through the workings (Meads 1858). One thing that was obvious once the dives started, as long suspected, is that the 19th century elevation shows everything on the same plane but in fact there is a conflation of features that in reality are in front 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'. During the ten dives undertaken there was only time for less than 10% of the recorded workings to be entered, with explorations concentrating on the two main shafts and the upper parts of the massive 'pipe workings' in the mineral deposit. Open leads were left and hopefully these will allow future access to unexplored parts of the flooded workings, which are known to include further vast mined caverns, an underground canal level at about -62m down and various tramway levels.

Fig. 7.7: The approximate extent of passages explored during the UNEXMIN dives undertaken in



May 2019 at Deep Ecton Mine, with these superimposed on the schematic 1858 mine elevation drawn by Meads, with feature names and recorded depths and a scale added (the scale bar is only approximate as the drawing shows the lower parts of the workings at a slightly larger scale than those parts above).

The main pumping shaft was explored to about -125m to a blockage, while the winding shaft was choked at about -113m. These shafts are sunk through bedrock, where the bedding was often near-vertical, with the base of saddles in the folding also seen. Both shafts had horizontal levels leading off their sides at various depths, some connecting the two shafts, others going elsewhere. In the pumping shaft there were various substantial timbers, thought to be for helping retain the now-removed pump pipes, entrances to levels and perhaps also ladders. Other features at both shafts included three complex groups of mineral workings in 'side pipe workings' and at the pumping shaft there is a 'level' at or just below the documented underground canal horizon with a walled 'dam' at its entrance.

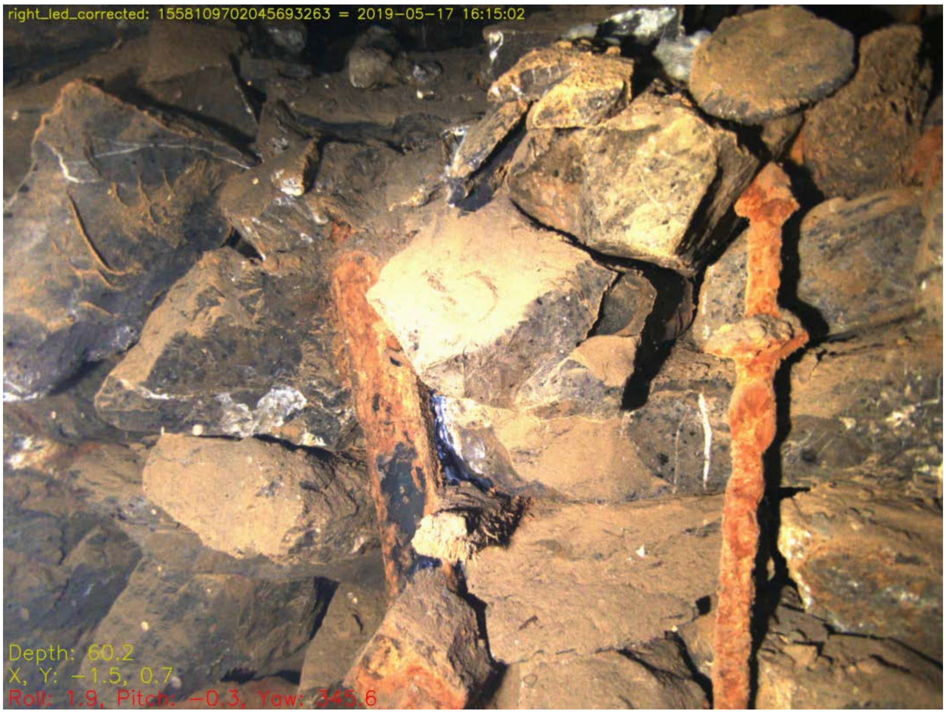


Fig. 7.8: In the pumping shaft there were a large number of archaeological features, including a complex arrangement of timbers and ironwork supporting a partial blocking of a level or 'side pipe working' at about -61m depth (PS9). This image shows a detail, with an iron pin and rotting timber, with crude stone wall at the end of the blocking behind.

Fig. 7.9: In the winding shaft one of the most interesting sets of archaeological features were these displaced timbers in an entrance to a 'side pipe working' at about -57m depth (WS6), located on the opposite shaft wall to a cross-cut from the 'main pipe working'. These timbers may have fallen from within the 'side pipe working' and originally could have been part of a working platform and its supports. Who placed the metal 'drum' there, and at what date, is unknown.

In the 'main pipe working', entered from a launch site in a chamber at river level, a route through convoluted passages led down to a huge 'pipe working' chamber with highly irregular sides that descended from about -20m to a little under -40m. This was massive towards the bottom measuring roughly 20m by 45m across. Below here much of the working had been backfilled with mine waste, but a route on, starting above this, led diagonally down, via two low retaining walls holding back stone dumps, to the present base of this working at about -58.5m. Here a short level led to the main winding shaft, with a part-choked working leading off beyond. No intact timber working-platforms remained in the 'main pipe workings', but on the rubble floors there were scattered displaced timbers and also such items as 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, working 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.

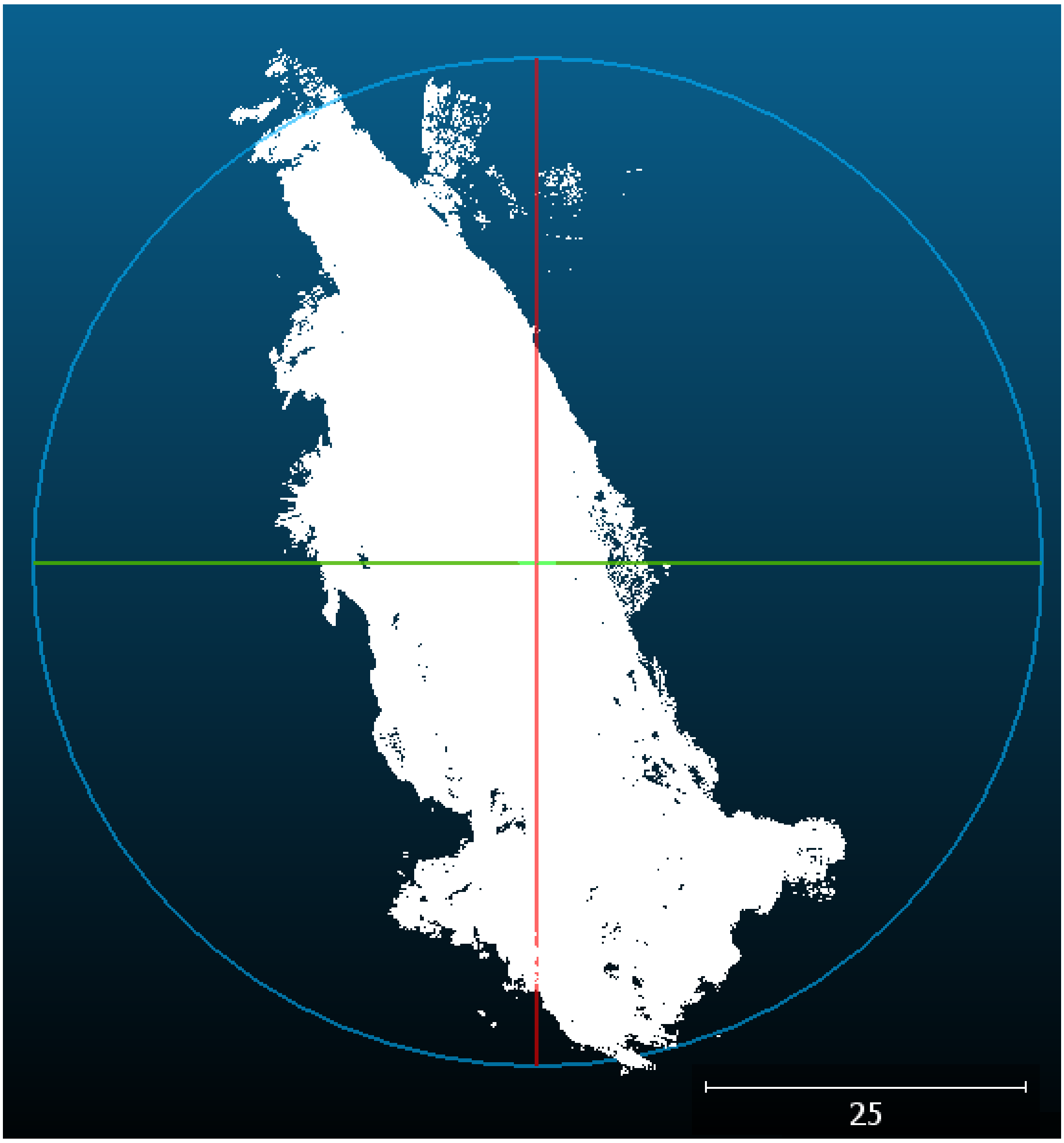


Fig. 7.10: The 'main pipe workings' explored in May 2019 were so large that often little could be seen on the submersible's cameras and general assessment relied upon the sonar point-cloud plots; this figure shows these workings, with data from all depths combined, in plan view (scale bar in metres).

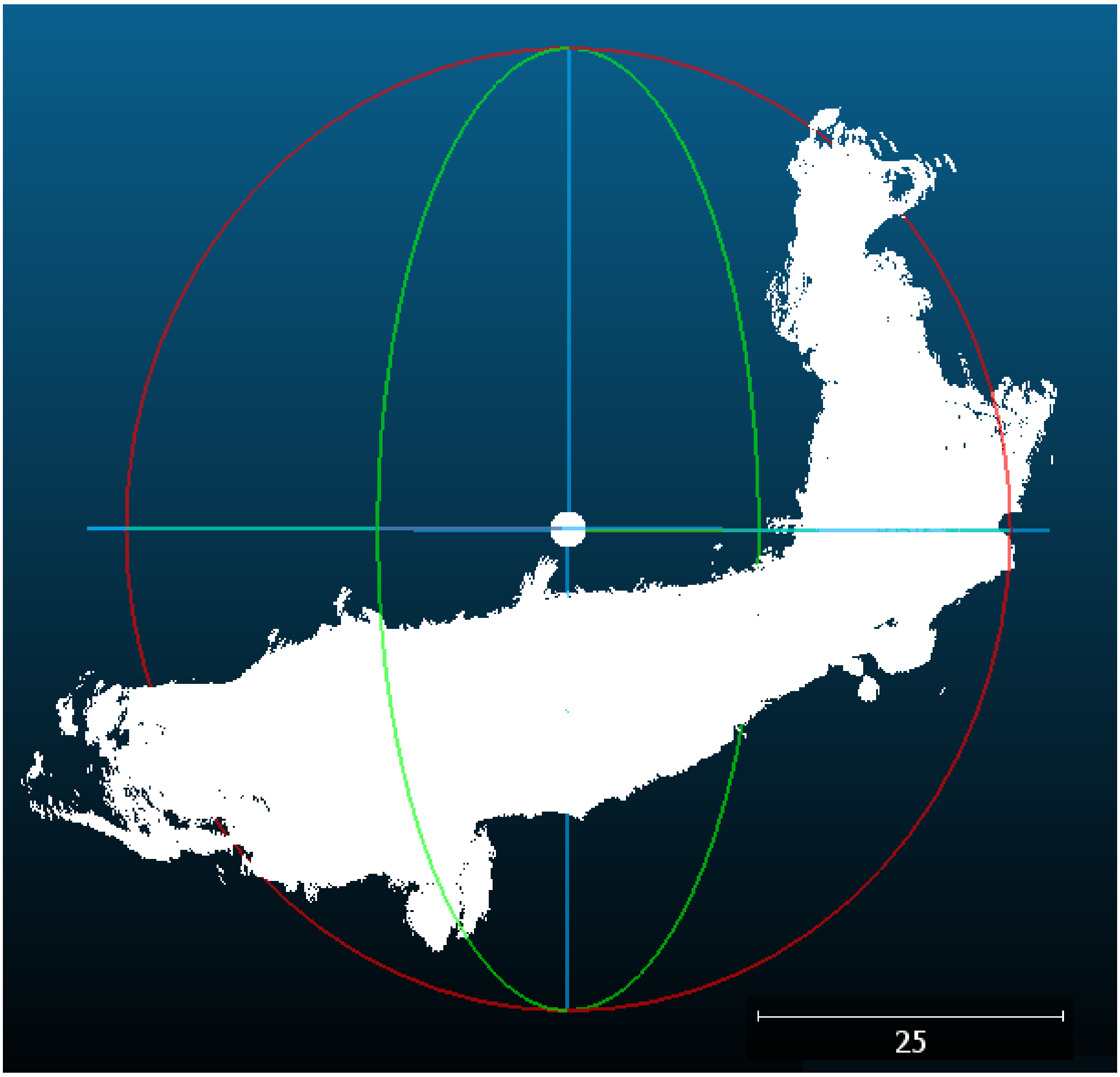


Fig. 7.11: A sonar plot of the explored 'main pipe workings', with data from all depths combined, as an elevation (scale bar in metres).

What Follows: The report continues below with a detailed review of what we know of the Deep Ecton Mine from historical sources, particularly its now-flooded workings. Then it moves on to give the archaeological data on each of the three 2019 dive sites is given in turn, including a summary of the known history and a review of each type of surviving physical evidence. This information is then brought together in a final section to give a review of what we learnt in 2019 and the impacts this has had on our interpretations of the mine, and ending with the prospects for entering further parts of the flooded workings should further dives take place in the future. There are also four appendices, the first three giving detailed descriptions of the 2019 archaeological discoveries for the dive sites, and the fourth giving transcriptions of historical descriptions of the flooded parts of Deep Ecton Mine.

Because of potentially different ways in which the report will be used, sometimes the same data is repeated, but often with different levels of detail, in more than one section.

7.3 Historical Documentation

Sources: Modern descriptions and interpretations of the Ecton Mines have been published from the 1940s onwards, with interpretations being modified through time as more research has been done after further historical documentation has become available, and as assessments of the underground remains have been refined (key texts - Kirkham 1947; Kirkham and Ford 1967; Robey and Porter 1972; Porter and Robey 2000; Porter 2004; Barnatt 2013).

There are also first-hand accounts of the mine written when they were still open; the pertinent ones relevant to the flooded working investigated in 2019 are given here in Appendix 4. The most important of these, where people described their descents of the working, are those by Efford in 1769, by Harper at around the same time, and that by an anonymous writer in 1838.

Another invaluable source of information are the archives of the Dukes of Devonshire in Chatsworth House, particularly the detailed mine accounts that have survived for 1760-1810 (Ecton Mines Account Books 1760-1810). These have many entries for such things as sinking shafts and driving levels, but need to be analysed with care. For instance, a '*new shaft*' in one decade is not always the same '*new shaft*' as detailed a decade later; the results of one such analysis were presented by this author in 2013.

From the 1850s to 1880s a series of mine account books and other documentation has also survived but for the most part these are not relevant to the workings below river level at Deep Ecton Mine as mining here had ceased by 1855. The exceptions are 1850s accounts that give details of mine equipment sold that was used in, or to pump, the below-river workings (Staffordshire Record Office: D3060/7; D 3060/13; D 3060/15).

An invaluable source is a detailed drawing showing an elevation through the mine, produced by Meads in 1858 but based on earlier drawings (Anon. n.d.; Meads 1858).

It should be noted that many of the historical sources give measurements in fathoms (1.829m), yards (0.914m) and feet (0.305m); these have been converted to metres in this report to facilitate comparisons with dive data and are usually given to the nearest metre.

Much of the text below on historical documentation draws heavily on my 2013 publication and the research done for this. The published work has a much broader scope than just Deep Ecton Mine, covering all the mines at Ecton, thus much of the data on Deep Ecton Mine is brought together in one place in this 2019 report to save researchers having to trawl though the long text to find relevant parts.

Interpreting the 1858 Mine Elevation: The mine elevation drawn by Meads in 1858, at a time when the mine was already partially flooded, is based on earlier drawings (Anon. n.d.; Meads 1858). It is discussed briefly here as it was the primary guide to the 2019 explorations and we know that it cannot be taken at face value. We have long suspected that it is oversimplified and this has been confirmed by the 2019 dives. There are some minor features not shown and those drawn are depicted in a somewhat stylised way. More fundamentally, everything is drawn on one plane, whereas in reality some things are in front of, or behind, others.

A classic example of this is the two main shafts that we now know are sunk for the most part through bedrock and only intersected relatively small 'pipe workings' at specific depths. Where the shafts pass through these 'side pipe workings', it is not clear from the dive photographs what came first; the shaft may have come through pre-existing workings, or alternatively mineral was found during the shaft sinking and then extracted. However, in interpreting these workings, it seems the former is usually the case.

In the 'main pipe workings' shown by Meads, it may well be that, in some places, what is shown as one working is in fact more than one overlapping sets of mined cavities; this must be the case in one area between the two main '*opens*' where small isolated workings are shown with no depicted access points to them.

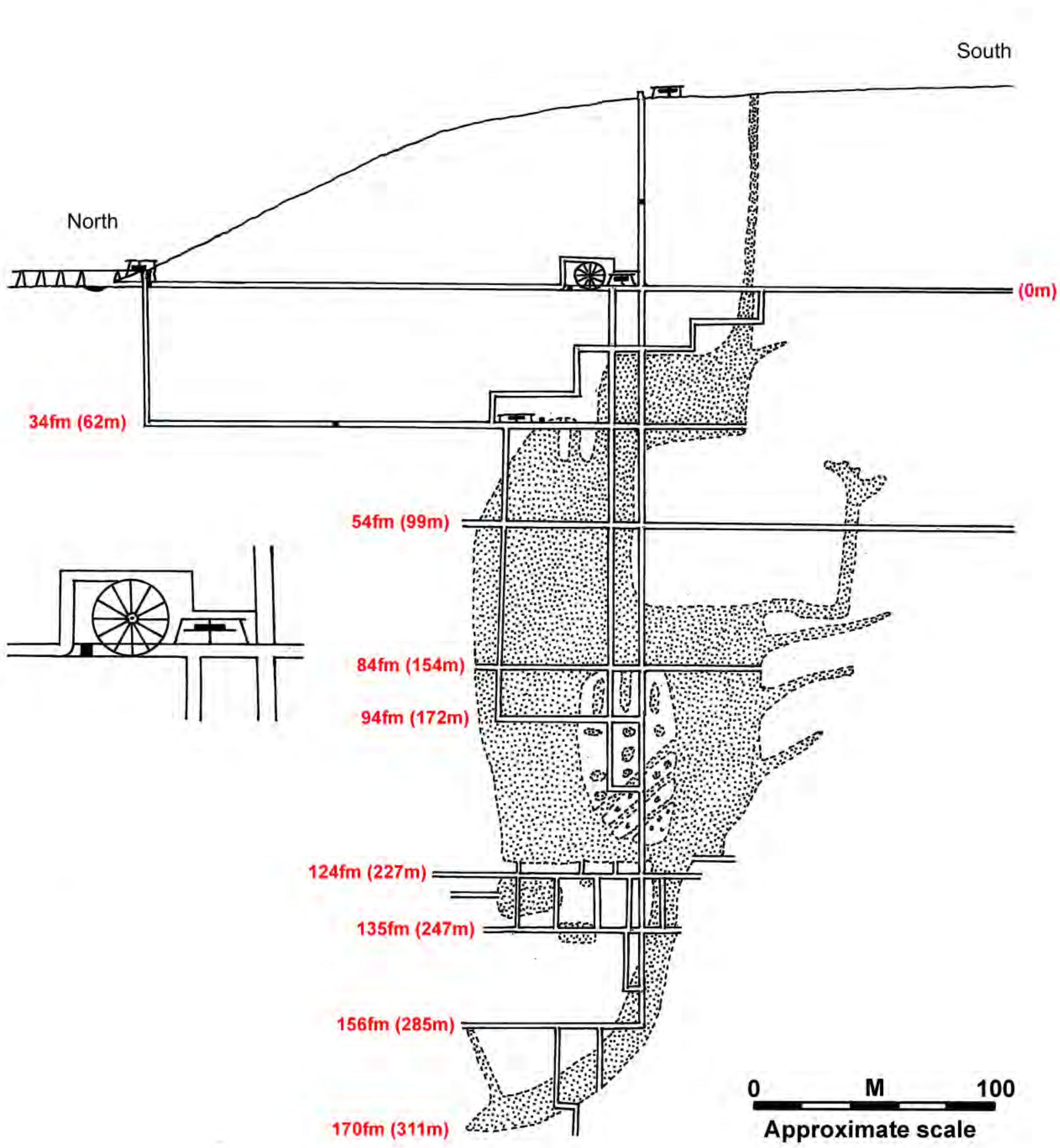


Fig. 7.12: The mine elevation of Deep Ecton Mine drawn by Meads in 1858, redrawn here for clarity, with known depths and scale added (the scale bar is only approximate as the drawing shows the lower parts of the workings at a slightly larger scale than those parts above).

Historical Overview: This section is given to contextualise the flooded workings investigated in 2019. Mining at Ecton in prehistory and the 17th century AD was all above river level and is not discussed here. The following account of mining at Ecton in the eighteenth and nineteenth centuries, when they mined below river level, is based on Barnatt 2013 (pp. 273-75, 284-286).

Mining at Deep Ecton first took on great importance in the 1723-60 period when two successive companies of '*Adventurers*' developed the mine. They eventually made exceptionally rich discoveries of ore well below river level, probably in the 1740s-50s, where the 'pipe deposits' reached huge proportions compared with what had already been found above, which in themselves were already large deposits.

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

During the first twenty years of the Fourth and Fifth Dukes' mining in-house at Deep Ecton Mine, the mining operation grew significantly in size. It is recorded that a little over 100 men were employed at the mine in 1759, whereas by 1772 there were about 260 people working here (Robey and Porter 2000, p. 53). Of these, 154 were working underground, 90 were '*dressing*' ores (concentrating these by removing non-metallic material) and doing other surface work, twelve were carrying coal and four were smelters. They were using horse-drawn engines and underground canal boats to facilitate operations.

Towards the end of the first twenty years of the mine under the Fourth and Fifth Dukes, Robert Shore, who had been the mine agent since 1760, was dismissed for embezzlement (Porter and Robey 2000, pp. 53-54; Porter 2004, pp. 38-40). This was not the first time he attempted this, for he had been caught making irregular entries in the mine accounts in 1768 and paid back £1,090 in instalments over several years. That he was not sacked when first attempting fraud presumably says something about his ability to manage the mine. In 1779 he was replaced by Cornelius Flint; this gave advent to new technological developments and still greater ore output at the mine.

To work successfully a mine that was forever getting deeper, the Dukes invested in ever more ambitious 'state-of-the-art' technology and new infrastructure was installed over the 1760s-80s in order to bring out ore and keep water at bay.

By 1786 production at Deep Ecton had reached its peak, with over 4,000 tons of copper ore raised that year (Porter and Robey 2000, p. 57). Altogether, over 400 people were employed at Ecton and at Whiston where the copper ore was smelted. These included many working underground, some in small companies who took on 6/7 weekly '*bargains*' (contract agreements) for ore extraction and '*deadwork*' (work that produced no ore, such as shaft sinking and driving levels), together with overseers, engine tenders and '*waterdrawers*' (people operating pumps). At surface there were smiths, carpenters and other tradesmen, ore '*dressers*', general labourers, ore and coal carriers, and workers at the smelters. Ecton was now the deepest mine in Britain.

By the beginning of 1789 all necessary plant needed for successful mining at depth at Deep Ecton had been put in place, and no doubt it was thought that extraction would run smoothly for years. The uncertainties of mining dealt a cruel blow, for in 1790 the ore body contracted at the base of the mine to virtually nothing and no profitable reserves could be located deeper down.

The surviving documents show the mine was clearly in trouble, for in March-June 1790 approximately £433 was advanced '*to pay the people discharged*', of which nearly £63 remained unspent at the end of the June reckoning. A further *c.* £114 was given as a '*gratuity to sundry workmen and labourers at ye mine discharged*'. In June 1790, The Times newspaper reported that the mines had '*failed*'. In 1796-98 further workers were to be laid off. In a letter to his father written in June 1796 after a visit to the mine, James Watt Junior observed they '*are got into one of the constrictions of the Vein, which having lasted longer than they expected, they have turned off half their men, not being able to find employment for them*'.

The 1790s was the beginning of a period of radical contraction in the mining operation, concentrating on searching for further viable ore deposits both at the sole of the mine and to the sides of 'pipe workings' that had been previously mined. Large new deposits never materialised, but although the boom years were over, the quantities of ore raised, albeit much reduced, were still large when compared with many mines. However, the real problem was the cost of recovering this when the mine was so deep, with an infrastructure that was expensive to run and maintain. The number of employees that remained is difficult to determine because the accounts often paid small companies of people on '*bargain*' rather than listing all individuals, but it is estimated to have still been upwards of 100 people.

In the 1760s-80s the extreme richness of the mine attracted public attention, bringing visitors from far and wide. The Dukes of Devonshire made a considerable fortune to add to their already substantial coffers gained from their widespread estates, not just from routine agricultural rents but from the mineral wealth, particularly in terms of lead, copper and coal in the Peak District, North-East Derbyshire and the Yorkshire Dales.

The reputation Ecton gained because of the 18th century success of Deep Ecton Mine attracted investment in speculative ventures across the hill throughout much of the 19th century. They were living on past glories, with people hoping to make their fortunes when the fresh ore deposits that they thought were bound to be there were discovered. With the exception of rich finds made by the Duke's miners in Clayton Mine in the early-19th century, all were to be disappointed.

From 1790 into the second decade of the 19th century, large amounts of ore were still produced at Deep Ecton, but given the expense of raising this, eventually the mining was running at an untenable loss and the Sixth Duke wound up this Estate venture in 1825. As is often the case, after the best was gone, they had made the mistake of spending large sums searching between 1790 and 1825 for the further rich deposits around the next corner. Extensive trials in the mine from the 1790s onwards, including trials at river level, failed to find any. From 1804-05 a new outward-looking strategy seems to have been introduced. This involved a concerted attempt to make the mines profitable again by taking an integrated approach to trialling and exploitation across the hill as a whole. In 1804-07, presumably as part of this general initiative, '*Salts Level*' at about 35m above the Deep Ecton level at the river horizon was driven to rationalise how ore was brought to the ore processing floors, by bringing this up the main engine shaft in one lift to the same horizon. Although only fragmentary documentation remains, it is clear that Clayton Mine was the main focus of activity at this time and for a while significant amounts of ore were recovered.

The plans of 1804-05 came to nothing as rich ore in Deep Ecton Mine was 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 at Deep Ecton Mine was replaced by a large waterwheel to operate the pumps. The capstan/horse-drawn engine nearby, also at the main pumping shaft top, was probably also replaced with a new shorter-armed capstan.

Even though Deep Ecton Mine was no longer viable as a large producer, from 1826-27 to 1855 a series of companies worked this, using money from partners or shareholders who invested in the ventures, at a much-reduced scale of operation than previously, with far fewer men. They were employed reworking hillocks and old '*pitches*' (pre-arranged working places) deep down in the 'pipe working', recovering metal ores from poorer ore deposits and using more advanced ore concentration techniques at the Swainsley Stamps a short distance downriver from the mine. However, by the early 1850s all hope of profitable working in the old mine must have been given up and in 1855, after they had failed to find investors to work the mine, the Ducal Estate finally turned off the pumps and let the workings flood. There was no longer a need for a steam engine to wind from great depth, nor the waterwheel used for pumping, and these were sold and then scrapped in 1855-56.

Later, as part of operations at the mines on the hill as a whole, trials were made at Deep Ecton Mine by new 'companies' using shareholders money, sometimes working in desultory fashion, but these included the extension of Salts Level above the top of the 'pipe working' at this horizon from the late-1850s intermittently through to 1868, and there was further work in poor mineralised deposits at its end in the 1880s.

Mining below River Level: In outline, and discussed further below, the significant mining components here are as follows:

- **The 'Main Pipe workings' –** These comprise a series of interlinked 'pipe working' chambers and side workings worked to ever increasing depths between the 1740s and 1790s, with later trial work, that extend down to about -220m. While some were huge, including two at depth known as the '*North Open*' and '*South Open*', their configuration and inter-relationships are poorly understood in any detail.
- **The Lower Workings –** These smaller workings accessed by short internal shafts and levels, and by the main winding shaft, were created from the late 1780s onwards below the rich 'pipe workings', in an attempt to find rich ore continuations downwards.
- **The '*Deep Shaft*' (Winding Shaft) -** This main winding shaft, which comes down from surface high on the ridge top, was sunk in 1767-73 down to close to the then sole of the mine. This was to become the main winding shaft used to bring ore up to river level, and was deepened further in the late-1780s to mid-1790s. From 1806 the ore was taken up to '*Salts Level*' well above the river horizon rather than being unloaded at river level.
- **The '*Great Shaft*' (Pumping Shaft) -** In 1780-84 with the development of radically new pumping arrangements for water from the sole of the mine, they sank '*Great Shaft*' with the

primary purpose of housing the pumps and their pump rods, together with the pump pipes for bringing the water up to the river horizon. As the mine continued downwards, the shaft was periodically deepened through to 1795.

- **The Ape Tor '*34 Fathom Boat Level*', Ape Tor Winding Shaft and '*Footway Shaft*'** – The level at -62m was started in the early 1760s and converted to a canal level later in the 1760s. From here ore, waste stone and water were taken to surface via a shaft at Ape Tor. The '*Footway Shaft*', presumably, given its name, at some stage used as a ladderway down to deep workings, was used in 1780-84 to bring up water in barrels to the canal using a horse-drawn engine and there were underground stables nearby. Earlier it may have brought up ore destined for the Ape Tor shaft.
- **Haulage and Exploratory Levels** – There are a series of other levels at different depths that were used to transport ore and to search for further ore deposits; for the most part these again are poorly understood.

Bringing Ore, Waste Stone and Water to Surface: This section is again extracted, in modified form, from Barnatt 2013 (pp. 277-81). What is about to be discussed is summarised in Fig. 7.13.

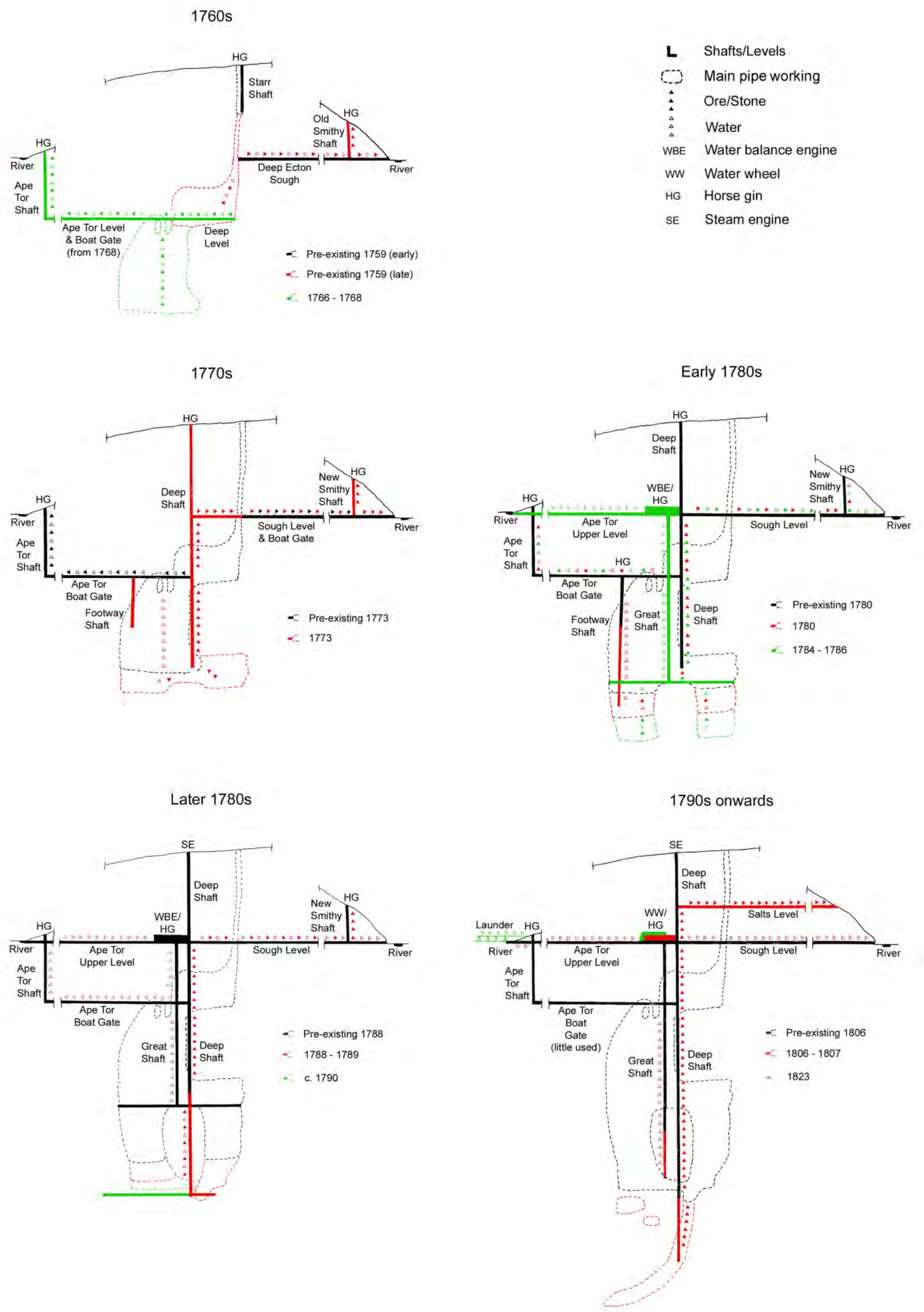


Fig. 7.13: Changes in ore and water extraction through time at Deep Ecton Mine, showing how shafts and levels were added and used in different decades of the 18th and 19th centuries (based on Fig.12; Meads 1858).

The 1723-60 '*Adventurers*' put the mine on a firm footing by driving the '*sough*' (drainage level) to dewater the 'pipe workings'. The first deep engine shaft from the ridge top, probably known as '*Starr Shaft*', was sunk to service upper workings in the pipe. From before 1760 the main route for bringing ore from the increasingly large and ever deeper pipe working at depth was via the main drainage and access level at river level, with ore drawn up by '*stowces*' (hand windlasses) to here; water was brought out in series of short lifts using '*rag and chain pumps*' and '*churn pumps*' (two types of hand-operated pumps). Ore was taken along the access level at the river horizon in small tubs, with some perhaps going straight to surface, but with lower grade ores taken to the upper dressing floor (ore processing area) via '*Old Smithy Shaft*' directly below. All this would have presented a scene familiar to Agricola when he was writing about continental mining in 1556 (Hoover and Hoover 1950).

In 1765, to help with the output, a second ore removal route came into operation, bringing ore along the long Ape Tor 34 fathom level, at -62m, using a wooden waggonway, which ran the full length of the mineralised pipe deposit before passing through un-mineralised ground to Ape Tor. From here ore was then taken up a shaft at Ape Tor not far above river level at the northern end of the hill; water could also be taken to surface using barrels. This scheme had taken years to bring to completion, with work starting at '*Deep Level*' at the beginning of 1762, with the shaft sinking perhaps starting before the Fourth Duke took over the mines in late-1760 but more probably in 1761-62. The fundamental problem to solve, within the limitations of the technology then available, was how to reach the bottom workings as they lay deep below a prohibitively high ridge. An alternative option to using Ape Tor would have been to sink a shaft to a similar depth from the lower dressing floors, which lay close to the river to the south-west of the 'pipe working'. However, the useful space here was restricted and space for ore processing rather than waste disposal was at a premium. This said, to an extent this had already been solved by having an upper dressing floor for lower grade ores and waste stone, above a waste heap part-way up the steep slope above. Looking to the future the mine management may have decided it was foolish to assume that they had room for indefinite waste disposal here. Also, if a new shaft was to be linked to the upper dressing floor then this would need to be somewhat deeper than at Ape Tor. The Ape Tor option, next to the river, was at a similar distance from the mineralised pipe deposit and although an additional task, the ore could be transported easily at surface to the dressing floors. The real reason for choosing the Ape Tor option is perhaps that when the scheme was planned the 'pipe workings' below river level were trending strongly to the north-east. If this trend had continued then the Ape Tor shaft would have been increasingly closer to deposits underneath as mining progressed; in the event the mineralised pipe deposit became more vertical further down and never came closer than the point where it intersected the Ape Tor 34 fathom level.

In what was presumably a measure to further increase the capacity to bring out ore, most probably in 1767-68, the '*34 level*' was converted to a canal for ore-carrying boats, with another installed in the main level at the river horizon above in 1769-70.

After a probable aborted start in the early-1760s, from 1767 an ambitious engine shaft was also sunk from the ridge top to depth, presumably in response to the Ape Tor ore route being unable to cope on its own with the ore output from the then sole of the mine. While the main river-horizon route coming straight from the 'pipe workings' was still in use in the late-1760s, output of ore brought this way, mined from well above the Ape Tor '*34 Fathom Boat Level*' route, must by then have been much reduced. Thus the river level route could be utilised in a different way. In 1769-70 the new '*Deep Shaft*' was linked with '*Main Level*' via a new passage knows as '*Pickering Gate*' and the whole converted to a second canal; the shaft sinking from below the river horizon down too deep in the mine was completed in 1773. Steam engine technology was not far enough advanced to wind ore in the shaft and a large horse-drawn engine was employed at surface; this may have been relatively inefficient given the distance wound, and until the 1780s and the creation of '*Great Shaft*' a significant proportion of the ore probably still came out via Ape Tor. At the upper canal's outer end was '*New Smithy Shaft*', where ore was taken up to the top of the ore processing floors.

In the 1780s first pumping and then ore winding at the mine was revolutionized. In 1780-84 they developed radically new pumping arrangements from the sole of the mine. This included the sinking of '*Great Shaft*', the top of which was in a new chamber at river level, the installation of a water-powered beam engine in this chamber, and the bringing of water from the river via a purpose-driven upper level from Ape Tor at the up-river end of the hill. The shaft was also used in conjunction with a capstan/horse-drawn engine in a new adjacent chamber. The canal at river level was replaced by a raised floor with tramway running over both the pumped- and ingress-water flowing to the river at the downriver part of the hill. While all this was being created, an interim measure was put in place in 1780 at a time when ore output was rising as the 'pipe workings' got deeper. This comprised the installation of a horse-drawn engine underground at the inner end of the Ape Tor '*34 Fathom Boat Level*' to lift water and stone from depth to allow the main engine shaft to be used exclusively for ore. The horses were stabled underground and their feed brought along the canal.

In 1788, to significantly increase winding rates from depth, a Boulton and Watt steam winding engine was installed at surface at the head of '*Deep Shaft*', replacing the large horse-drawn engine here. This was an exceptionally deep shaft, and tapered ropes and a spiral drum for the counterbalance rope were designed especially. Once the steam engine was in place, this made the Ape Tor route largely redundant except for part-time use bringing out some of the waste stone and surplus water; more water and waste stone were also brought out by the steam engine. After 1807 the lower canal at -62m was little used and was probably fully abandoned when the Sixth Duke withdrew from mining in 1825; we now know following the 2019 dives that the inner end of the haulage level here may well have been blocked in the 1790s.

After mining at Deep Ecton Mine contracted from the 1790s onwards the same basic ways of dealing with ore and water continued until the deep 'pipe workings' were allowed to flood in the 1850s. The main change was the 1804-06 creation of the '*Salts Level*' ore removal route above river level that allowed raised ore to be taken straight to the upper ore processing floor, cutting out the ore-removal route at river level and '*New Smithy Shaft*' here. In 1823 the pumping arrangements were modified by the installation of a large waterwheel to replace the bucket-engine but the pumps and water flow routes remained the same, except at either end of the upper level from Ape Tor where modifications allowed the wheel to be used overshot.

In 1855 the Ecton Mountain Mining Company, who worked between 1851 and 1857, was sold the now redundant Boulton and Watt steam engine on the ridge top by the Ducal Estate after the mine pumps were turned off and the mine below river level allowed to slowly flood (Barnatt 2013, pp. 236-40). The boiler from the engine was sold by the company in 1855-56. In addition, they sold a total of 5 ton 8cwt of '*old pump trees and joint pins*' for £30/14/10, getting a further £4/0/0 for four more '*pump trees*', and a total of £1/9/0 for five '*waterwheel arms*'. It is likely that the company was struggling for cash; hence they were selling off inessential assets, unwanted because they were not working at depth. '*Pump trees*' was a commonly used mining term for the pump pipes of the '*rising main*' of a pumping engine shaft and it may well be that these came from Deep Ecton Mine. While the length of the pipes sold is not stated, it is likely that they were each somewhere between 2.5m and 4.0m long, derived from such pipes at other mines where their length are known. Given the prices paid there must have been roughly 30-34 pump pipes sold. Therefore they represent a total of at least 75m to 136m of '*rising main*' that must have been removed (but in addition there may have been more pipes that were not sold). As no iron pipes were found *in-situ* in 2019 between -0m and -125m; this raises the interesting possibility that the pump pipes were removed only down to just below -125m, perhaps because they did not have long enough winding ropes for the capstan at the shaft top to remove others from a greater depth; there may be an *in-situ* wooden maintenance platform at the top of the remaining pipes that has led to the blockage of the shaft at this depth. From 1857 the Ecton Consolidated Mining Company, which was formed in that year and was effectively the same company as the 1851-57 venture under a different name, stripped further old plant from Deep Ecton Mine at the time it was gradually flooding after the pumps were turned off in 1855 (Barnatt 2013, pp. 240-43). This included timbers, ladders and '*whim material*' ('whim is a term for a type of horse-drawn engine) perhaps associated with the 1780s horse-drawn engine at -62m.

Delving Ever Deeper: This section is again modified from Barnatt 2013 (pp. 275-281) and reviews how the 'pipe workings' were deepened through time. Table 7.1 and Fig. 7.14 shows there was a steady increase in the depth of the workings from the late 1750s to the early-19th century when they had just exceeded -305m below river. The mine became a little deeper by the middle of the 19th century, reaching around -323m by the time the 'pipe workings' were allowed to flood. However, the rich ore deposits had diminished at around -220m and everything below here had been largely exploratory or was working in poor deposits.

Table 7.1: The Depth of Deep Ecton Mine through Time: A Summary of the Evidence.

Date	*Depth from river level*	*Source*	*Notes*
1759	210ft (64m)	Roose (Ecton Mines Account Book and Vouchers Boxes - 1760-1810).	The Roose sketch survey notes the workings at 70yd below river level. It is thought the actual depth was a little shallower than this.
1769	480ft (146m)	Efford 1769.	Efford noted the bottom of the mine was 160yd below river level.
1770	Upwards of 420ft (128m)	Shore (Ecton Mines Account Book and Vouchers Boxes - 1760-1810)	Shore who was the mine agent, may well have had a clear idea on mine depth, and his statement of 'upwards of 70 fathom' suggests the real depth was somewhere in the region of 70-75 fathoms (128-137m) suggesting the depths stated by Efford and Geisler are overstated.
1772	480ft (146m)	Geisler (Althin 1971).	Geisler said ore was being worked from 80fm (480ft) below river level (perhaps quoting Efford's depth).
1788	672ft (205m)	Boulton &Watt collection: MS3147/4/4.	The Boulton and Watt calculations book states the bases of the winding and pumping shafts are currently 92fm (552ft) below the level and that the base of the mine is 20fm (120ft) deeper.
1789	[711ft+ (217m+)]	6/7 weekly accounts (Ecton Mines Account Book and Vouchers Boxes - 1760-1810).	Depth of 'Deep Shaft'.
1790	[900ft (274m)]	Boulton &Watt collection: JWP: MS3219/4/12/42.	Letter from James Watt junior to his father after visiting the mine, saying they were working at the bottom at 150fm (900ft) – this is a rounded understatement.
1795	966ft (294m)	Boulton &Watt collection: MS3147/3/429/44.	Flint in a letter to Boulton and Watt stated depth of mine from river level as 161fm (966ft).
1796	[1,050ft (320m)]	Hatchett 1796 (Raistrick 1967).	Hatchett in 1796 said the total depth of the mine from the ridge top was 200fm (1,200ft), of which 25fm (150ft) lay above the river horizon; these are gross approximations.
1802	1,010ft (308m)	Mawe 1802.	Mawe stated workings now to a depth of 220fm (1,320ft). This is presumably from the ridge top - therefore 310ft subtracted.
1811	1,010ft (308m)	Farey 1811.	Farey states the shaft was 440yd (1,320ft) deep - this is an error in that he meant the depth of the mine not the shaft, as shown by Meads 1858. 310ft subtracted to adjust to river level.
1820s?	1,020ft (311m)	Meads 1858 section.	This detailed section, drawn after the workings were flooded, may be based on an old drawing of 1820s date when the Sixth Duke last worked the mine. It states the overall depth of the mine below the 'adit' at river level was 170fm (1,020ft) and 230fm (1380ft) below surface (which is in error by 50ft too much in the distance between shaft collar and Main Level).
1839	[1,340ft (408m)]	Anon 1839.	The mine is said to be 1,650ft deep – this must be from the ridge top and appears to be

			a gross exaggeration - 310ft has therefore been subtracted.
1844	[1,190ft+ (363m+)]	Garner 1844.	Depth of mine said to be upwards of 1,500ft – this appears to be an exaggeration - 310ft has been subtracted.
c. 1846	1,061ft (323m)	Attwood 1883 (Mining Journal 53, 17 Nov. 1883).	Attwood stated that the bottom workings when he ceased work were at 457yd (1,371ft). This must be from the ridge top and 310ft has therefore been subtracted.
1849	[962ft (293m)]	Porter and Robey 2000 (pp. 77-78).	A report made on the state of mines in March 1849 said the depth of Ecton Mine was 1,272ft. This was presumably from the ridge top and 310ft has therefore been subtracted.)

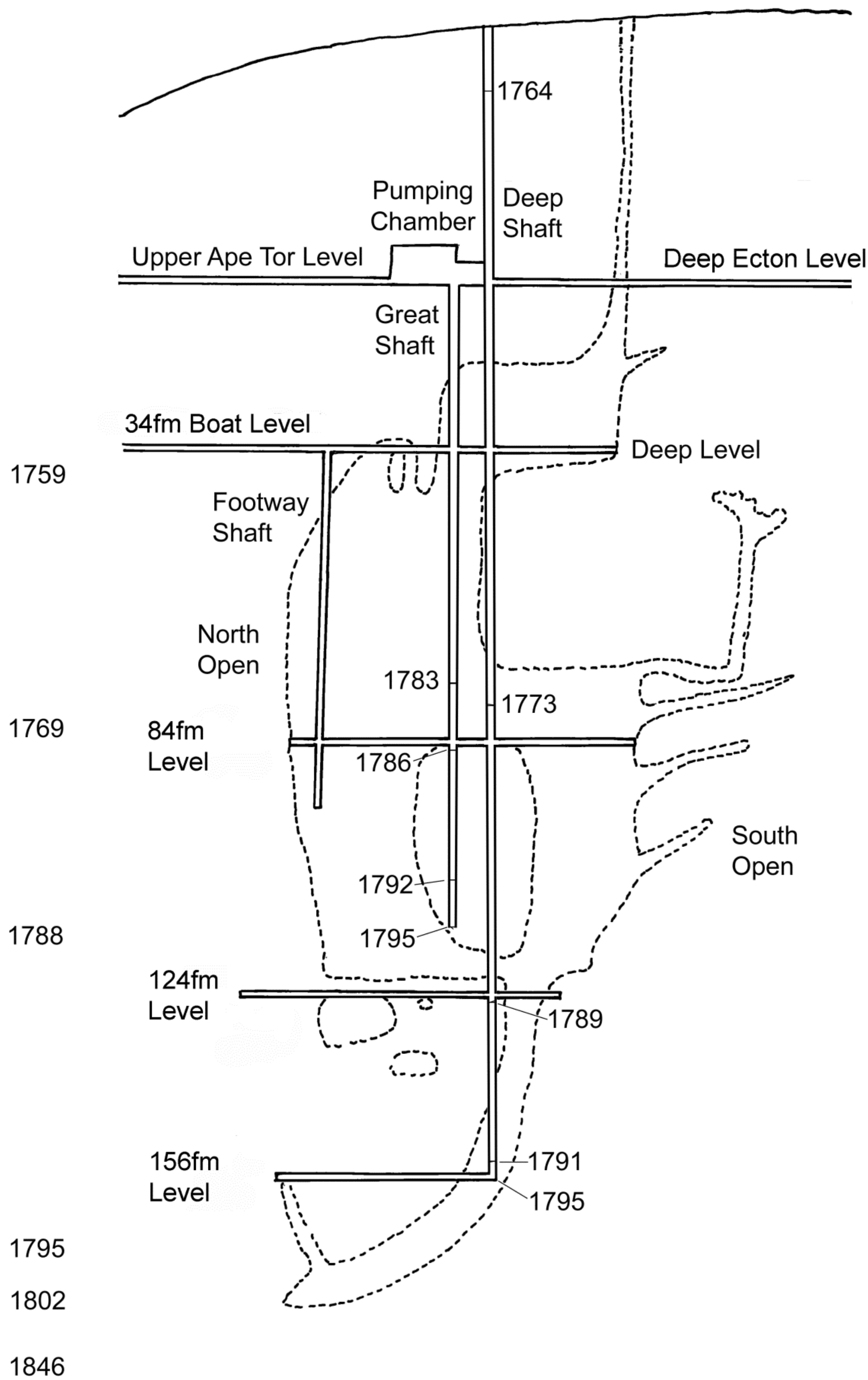


Fig. 7.14: The known depths of the Deep Ecton Mine workings and its main pumping and windings shafts at different dates, using the Meads 1858 elevation (Fig.12).

Looking in more detail at the two main shafts, used as dive sites in May 2019, the depths they reached at various dates are now reviewed, with these given in Table 7.2.

Table 7.2: The depths of '*Deep Shaft*' (winding shaft) and '*Great Shaft*' (pumping shaft) at different dates.

Date	*Depth from river level (to nearest 0.5ft/0.1m)*			
	Total depth below the river	*Increase in depth at end of sinking phase*	*Total depth below river level*	*Increase in depth at end of sinking phase*
	'*Deep Shaft*' (winding shaft)		**'*Great Shaft*' (pumping shaft)**	
Early-1764	-233.5ft (-71.2m)	79.0ft (24.1m)		
Mid-1767	-233.5ft (-71.2m)	?6.0ft (?1.8m)		
Mid-1768	-223.5ft (-68.1m)	-		
End of 1773	464.0ft (141.4m)	689.5ft (210.1m)		
Early-1781			0ft (0m)	
Mid-1783			439.0ft (133.8m)	439.0ft (133.8m)
Early to Mid-1786			507.0ft (154.5m)	68.0ft (20.7m)
Mid-1787	464.0ft (141.4m)	-		
Beginning 1788 (extrapolated from 1794 figure)	570.0ft (173.7m)	-		
End of 1788	733.0ft (223.4m)	269.0ft (82.0m)		
Mid-1789	751.5ft (229.1m)	18.5ft (5.6m)		
Late-1790	751.5ft (229.1m)			
Mid-1791	902.0ft (274.9m)	150.5ft (45.9m)		
Mid-1792			619.0ft (188.7m)	112.0ft (34.1m)
Late-1794	902.0ft (274.9m)			
Mid-1795	906.0ft (276.2m)			
Mid-1795			663.0ft (202.1)	44.0ft (13.4m)

Note those depths given as negative values are heights above river level.

The overall depths compare well with the detailed 19th century section of the mine drawn by Meads in 1858, which was based on earlier 19th century data, possibly from 1820s (anon. n.d.). This gives (in fathoms) the depth of the level at the bottom of the winding shaft as -281.6m, which is only 18ft greater than the depth stated in 1795. Similarly, it shows the bottom of the '*Great Shaft*' as just over midway between the -154m and -227m haulage levels, which scaled off the drawing is at about -190m; this is only about 6m more than the cumulative documented depth after a last sinking here in 1795. These slight discrepancies are perhaps explained by work undertaken after 1810 in the period where detailed accounts for work at the mine do not survive.

The Flooded Working - Known Historical Details: This section gives more detail on the different flooded mining components introduced above, taking each in turn; it again is based on texts in Barnatt 2013 (pp. 160-85, 210-11), given here in somewhat modified form. All of the extensive passages below river level, which descend to about -320m below the main level at the river horizon, have been flooded since the late 1850s and cannot be entered except by diving.

The 'Main Pipe workings' – The main mineralised deposit, with side trials and cross-cuts to branch deposits, comprises an often spacious working dropping steeply and sinuously from surface to depth. From the '*Salts Level*' horizon down to river level, the mineralised pipe deposit was worked in the 1720s-

50s, with later minor trials here of later-18th and 19th century date, as indicated by shot holes of various sizes (see Barnatt 2013, pp. 111-13). When the mine was reopened in the 1720s-50s the workings following the main mineralisation downwards could only have been substantially deepened below river level from the 1740a, at the earliest, when the drainage level reached the 'pipe workings'.

By 1759, almost certainly in the 1740s-50s, the 'main pipe working' was worked down to between about -55 and -65m below river level; in the 1760s extraction was facilitated by the creation of the Ape Tor level at -62m, and a shaft to surface at its far end (see below).

In the late-1760s or early-1770s the 'pipe workings' had reached -146m below river level and Boulton and Watt recorded a depth of -205m in 1788. The main 'pipe' mineralisation at depth was '*lost*' in 1790, with a restriction in the size of the ore deposit from about -220m downwards.

In the 1790s trials above the -220m horizon were made at the sides of the 'pipe working' and some ore extracted, taking poorer grades of ore, and working areas with small quantities of ore that earlier generations of miners had disregarded whilst there were richer deposits to hand; it is thought that this trial work was relatively systematic, stripping the 'pipe working' back to bedrock in a search for deposits leading off that had previously been missed.

In the 1840s it was noted that the 1823 waterwheel was ineffective in that it did not always keep the mine fully clear of water, thus the lowermost parts may have been prone to flooding. From 1846 the 'pipe working' was only mined down to -165m below river level. However, in contrast, late in the 1840s miners had been sinking workings in unproductive ground at the base of the mine, presumably on a seasonal basis. In 1850 it was reported that no work was being done below the -146m level.

In 1850 to 1855 miners were on tribute below river level, but the 'pipe workings' here were then allowed to slowly fill with water from 1855 when the pumps were turned off. These were entered in early-1858 down to the -55m level, but by 1860 all was flooded to the river horizon.

As the Duke of Devonshire's account books usually only give details of the location of the '*deadwork*' (non-ore bearing tasks) where no ore was obtained, we have few details of the ore extraction in the mineralised pipe deposit. What we do know is that from before the 1750s productive mining largely took place below river level, following the unmined parts of the mineralised pipe deposit downwards, and clearly this was where the main profit was to be had. Thus, workings were sunk inexorably deeper and deeper below river level. However, our understanding of the details of the workings below river level from the documentation, in terms of their distribution and size, is patchy at best.

The most useful source of information is the detailed but schematic source, discussed above, is the elevation drawn by Meads in 1858 based on earlier drawings (Anon. n.d.; Meads 1858).

This shows:

- A relatively small working between -0m and -25m that was about 5-10m wide.
- A large chamber approximately between -25m and -65m that is about 60m wide and 40m high.
- A massive chamber, known as the '*North Open*' approximately between -60m and -219m, which is up to about 160m high and is 70m wide in its upper half and 40m wide in its lower half.
- A massive chamber, known as the '*South Open*' approximately between -130m and -220m, which is up to about 90m high and is 30-40m wide in its upper half and gradually becomes narrower towards the bottom.
- Where the two '*Opens*' are linked the total length of the works are about 120m at the top and 90m at the bottom.
- An 'island' of rock between the two '*Opens*', with the latter linked top and bottom, which has three small inclined workings and a number of isolated pockets of workings. The latter must have been linked to the rest in some way but these passages are not shown. This area is particularly hard to understand from the drawing, which is clearly schematic and clarification is not possible in the current absence of three dimensional data.
- Four relatively small branch workings to the southern end of the '*South Open*', the uppermost of which, after about 30m, ascends nearly vertically to about -70m.

- Lower workings between -219m and -311m that are smaller and linked by horizontal levels and short shafts. While the drawing shows a continuous 'pipe working' going downwards and trending northwards at depth, which is about 10-15m wide, and also three small isolated workings, it is known that these were relatively unproductive.

With all of these mined cavities the drawing only gives their lateral extent in one plane and gives no indications of their widths.

The drawing also shows:

- The main winding and pumping shafts, '*Footway Shaft*' (un-named) and a series of levels, including the -62m canal level and its extension through the pipe workings known at the time it was driven as the '*Deep Level*'. In the lowermost workings there are also a series of '*winzes*' (internal shafts).

The data shown by Meads is supplemented by various first-hand 18th and 19th century accounts of the workings, mostly given by visitors to the mine (given in full in Appendix 4).

In 1769 William Efford published an account in 'The Gentleman's Magazine' of the workings at a time when these went down to somewhere between about -130m and -145m. He stated that in the pipe at river level '*there is a spacious lodgement of timber, for landing and receiving the Ore from below, which is drawn up by a man at a winch…. Thus far into the mountain, with the aid of light, tis easy enough of access. The late Duke of Devonshire ventured to this platform, took a cursory view of the works, gave the miners ten guineas to drink, but returned immediately, not choosing to descend below. Indeed, such a horrid gloom, men boring of rocks under your feet, such explosions in blasting, and such a dreadful gulph to descend, present a scene of terror, that few people, who are not versed in mining, care to pass through.*'

'*From the platform the descent is about 160 yards* [146m], *through different lodgements, by ladders, lobs (steps), and cross-pieces of timber let into the rock, to the place of action, where a new scene, ten thousand times more astonishing than that above, presents itself; a place as horrible to view, as imagination can conceive – On the passage down, the constant blasting of the rocks, ten times louder than the loudest thunder, seems to roll and shake the whole body of the mountain. When at the bottom, strangers are obliged to take shelter in a nitch cut in the rocks, to avoid the effects of blasting the rocks, as the miners generally give a salute of half a dozen blasts, in quick succession, by way of welcome to those diabolical mansions.*'

'*At the bottom of this amazing work, the monstrous cavern or vacuum above, the glimmering light of candles, and nasty suffocating smell of sulphur and gunpowder, all conspire to increase your surprise, and heighten your apprehensions.*'

He then noted the Ecton ore deposit '*runs not in regular veins, or courses, but sinks perpendicular down, widening and swelling out at the bottom, in the form of a bell.*'

'*suppose yourself now upwards of 200 fathoms* [from the ridge top] *deep in the bowels of a large mountain, in a great hollow of immense diameter, then suppose around you an impenetrable wall of lime-stone rock, interspersed with small veins of Copper-ore, yellow, black and some brown, intermixt with Spar, Marcasite, Mundic, and other sulphureous compositions, of all colours……*'

'*There is no timber made use of, except for lodgements, or platforms, ladders, or steps set into the rocks, for ascending and descending into the mine; neither is there any quantity of water to retard the works, notwithstanding it is at least 150 yards* [137m] *below the bed of the river.*'

'*The timber-works about the Mine are very ill contrived and worse executed. In descending from the principle lodgement you pass thirty ladders, some half broken, others not half staved; in some places by half cut notches, or steps in the rock; in others you must almost slide on your breech, and often in imminent danger of tumbling topsy-turvy into the Mine; nor are the shores which support the lodgement below in better condition.*'

What Efford describes is supplemented by unpublished notes in John Harper's 1767-70 diary (Derbyshire Record Office: 2375M/63/55), probably made in about 1769-70 and if so written by him shortly after Efford visited the mine. He again noted ladders and '*bundings*' (platforms) and that '*some of ye vaults are quite dry – in others springs break in*'. More interestingly Harper described a series of seven '*vaults*' or '*chambers*', one roughly above the other, from river level downwards to the then sole of the mine at between about -130m and -145m, where an eighth chamber had been started.

Details of the chambers include:

- The first chamber at river level, circular, about 30 yards (27m) wide, '*ye sides and roof of it all stone and spar with holes or places in it from whence ore taken away pretty much alike*'.
- The second circular chamber at the north-east end of the first at about 80 yards (73m) below the first and nearly 30 yards (27m) high, with holes on the north and north-eastern sides, '*with some 'a yard or two high and sev^l yards obliquely as ye ore is dug in one part ….. some of them near as big as a room of ten or 12 feet some smaller like cupboards*'.
- The third chamber circular, with its floor at the Ape Tor 34 fathom level (-62m). This was said to be the largest chamber and about 100 yards (91m) high and about 60 yards (55m) across.
- The fourth to eighth chambers are oval in plan or in one or two cases nearly triangular, some 30 or 20 yards high (27-18m), but the lowest one not above 15 yards (14m), with these 30-60 yards (27-55m) wide. The eighth chamber was in the process of being sunk.

Comparing this account with Meads 1858 drawing, the first three chambers fit tolerably well, if allowance is made for Harper significantly overstating the dimensions of the chambers, at least in the case of their heights. Harper's third chamber must be the upper chamber shown by Meads. However, Mead's plan shows the upper part of the North Open down to about -150m, the depth of the workings in Harper's time, as one large open space rather than five separate chambers; these must overlap with each other and must be conflated on the drawing.

In 1770 Robert Shaw, the Duke's mine agent at the time, writing soon after Efford and Harper, wrote an unpublished account of the workings (Chatsworth Manuscripts - Devonshire Collections –Ecton Vouchers Box 1760-74), stating '*The Copper Vein at Ecton goes down pritty near in a Perpendicular direction at this time, is now sunk from the Sough or Levil which is taken from the River Manifold, upwards of 70 fat^ms* [128m] *and all the conveniancys completed to the depth and now ready for sinking afreash. The work upon the s^d Bothams is not so large a Compass as they have been nor able to raise such large quantitys as they have hear to fore, but the quality much better*.' This account may suggest the depth for the bottom of the workings quoted by Efford was overestimated and it was actually about -130m to -135m.

In 1772 Eric Geisler (published in Althin 1971), when touring Britain, visited Ecton and stated that at river level there was '*a wide room, created by ore being removed from there as well as higher up and still* [in work] *80 fathoms* [146m] *under the adit. Where stocken is now mined 15 fathoms* [27.5m] *in one diameter, east to west, and 10 fathoms* [18.5m] *in the other, all equally good, only mixed more or less with quartz* [he meant calcite] *and lime* [limestone]'. Perhaps he was quoting Efford regarding the depth of the workings.

In 1790 James Watt (junior) wrote to his father (Boulton & Watt collection: MS3219/4/12/42.), saying that *The vein frequently bulges out into large bellies of 50 to 100 fathoms* [91-182m] *breadth then again becomes contracted to 2 or 3 feet* [*c.* 1m]' and that '*They are now working at the depth of 150 fathoms* [275m] *and are got into one of the constrictions of the Vein, which having lasted longer than they expected, they have turned off half their men, not being able to find employment for them.*'

In 1839 an anonymous writer of a book on the local area (anon. 1839) reported that at Ecton there was '*the deepest mine in Great Britain*' that was descended upon ladders that had sides '*formed of wood, and the staves chiefly of iron, some of which are loose, and others so worn away by the repeated treading of the miners*'. Also there were '*iron hooks and stays, which in the most hazardous situations have been driven into the rocks to assist descent*'. He and a friend, accompanied by miners, descended '*what appeared to us an almost interminable number of ladders, and after groping our way through several cavernous passages, hewn out of solid rock, and scarcely high enough in some places, to admit of our standing erect, we landed within forty* *yards* [36.5m] *of the bottom of the mine, in a gloomy excavation of great extent, and very considerable height. In the dense and overwhelming obscurity which reigned around us, scarcely broken by the feeble glimmer of our lights, we were unable to for any probable estimate of its proportions; if we state its altitude to be in some parts not less than fifty or sixty feet* [15-18m], *it is certainly not overrated.*' What the author meant by the bottom of the mine is not made clear, but presumably he meant the bottom workings that were actively being mined rather that the lowest workings ever made. He also observed '*Our guides next led us through a narrow passage on one side of the cavern, to the mouth of a shaft leading to the bottom of the mine; but being told that the passage was insecure, we did not risk a further descent. Proceeding a short distance, we arrived at the great perpendicular shaft; on looking upwards the sky at the summit of the mountain was distinctly visible.*' The latter shaft was clearly the main winding shaft, but whether the other was the pumping shaft or an internal winze used as a ladderway is not clear.

In 1850 an anonymous writer reported in the Mining Journal (Vol. 28, 13 March 1858 p. 167) that '*In the 30 fathom level* [-55m, but perhaps he meant the 34 fathom level at -62m], *which is reached by convenient ladders, the mine was very productive and the excavations are of immense scale. From this to the 50 fathom level* [91m] *the workings are larger; but still lower from this to the 80 fathoms level* [146m] *the workings are truly extraordinary. A light being placed in one of the upper openings (the 30 fathom level), and one lower down at the 50, produced a striking effect. Here there is probably a clear opening of upwards of 350 feet* [107m] *in height, by an average width of 150 feet* [46m], *some parts being wider, the whole of which has been worked out.*' Clearly his dimensions are approximate.

In 1858 John Dickinson Brunton reported in the Mining Journal (Vol. 20, No. 786, 14th Sept. 1850, p. 433 that '*Yesterday I went through the old workings down to the 30 fathom level below adit* [-55m, but perhaps he meant the 34 Fathom level at -62m]. *From the small extent of the workings on the pipe vein at this part it is evident that the great ore deposit of Ecton was not above the 30* [thus he must have descended a ladderway that bypassed the large chamber above this depth and this may be the stepped passage shown by Meads]. *At about this depth an intersection took place of a cross load with the pipe greatly increasing the productiveness; but it was not until the 50* [-91m], *at which another cross load came in, that the immense gulf of ore commenced which has never yet been equalled. From the 50* [-91m] *down to the 80* [-146m] *is now a cavern of 300 yds* [275m - clearly overstated] *long, 100 yds* [91m] *wide at bottom and 20 yds* [18m]*wide at top, showing how the pipe increased as it went down: this enormous cavity was once a mass of lead and copper ore. Between 80 and 90* [-149m to -165m] *the pipe narrowed but opened out again and thence down to 200* [-365m – clearly overstated] *continued to yield ore in immense quantities.* The account of the workings below *the '30 fathoms level'* must have been second hand as these workings were already flooded at the time of his visit. While the dimensions are only approximate and some at least are significantly overstated, interestingly they suggest the 'pipe workings' had a section part-way down that was restricted in width after having become very wide near the bottom of the upper part, but that they opened out again lower down. From Brunton's account we can see that the 'main pipe workings' above the Ape Tor '*34 Fathom Boat Level*' and the associated '*Deep Level*', both at the -62m horizon, were mostly or all still open in 1858 but in contrast we know these were flooded by 1860. While he describes descent to 30 fathoms (-55m), the various depths given in this account are clearly only approximations and it may be that the 34 fathoms level (-62m) could still have been accessible.

<u>The Lower Workings</u> – These workings, which comprised a series of trial shafts, levels and areas of ore removal, were created from the late 1780s onwards below the rich 'pipe workings' in an attempt to find rich continuations downwards. The main winding shaft was deepened to facilitate this work in 1790-91 and again in 1795, when it reached -285m. By the first years of the 19th century at the latest, trials had reached their final depth, at about 15m below the base of the shaft, without finding further economically viable ore deposits. By the 1850s, when the mine was allowed to flood, ore deposits had been followed down to -311m, and trials went below to a stated total depth of -323m. None of these 1790s-1850s workings produced significant deposits that rivalled what was found above.

<u>Early Winding and Pumping Arrangements</u> - Until the early 1770s, bringing the ore up from the sole of the mine to the drainage level at the river horizon was probably done in short stages using hand windlasses. One unloading place is still visible near the 'main pipe workings' at river level, where there is a small drawing shaft with a top '*striking house*' (ore unloading chamber) that goes downwards and is now flooded. Similarly, water was removed using hand pumps in a series of short lifts.

The '*Deep Shaft*' (Winding Shaft) - This shaft comes from the ridge top next to the Boulton and Watt engine house. It was started in 1767 at the latest, after a probable aborted start in 1762-63, and reached the then sole of the mine at -141m in 1773. It was sunk with the aid of a horse-drawn engine at surface and reached '*Pickering Gate*' at the river level horizon in 1770, the point where ore was unloaded once the shaft was finished (until 1806 when '*Salts Level*' above was brought into commission for this purpose). A major change to extraction infrastructure came in 1788, with the installation of a Boulton and Watt winding engine. This was placed at the collar of the 1760s '*Deep Shaft*' high on the ridge above the mine, which previously had been operated using a large horse-drawn engine.

The winding shaft was periodically deepened as workings went ever further below river. The first episode was in 1787-89, coinciding with installing the 1788 Boulton and Watt winding engine at the shaft top, and the shaft bottom was at -229m by mid-1789 when they has finished this deepening. Of the documented 1787-98 sinking in the '*Deep Shaft*', 82m was completed by the end of 1788 when the steam engine was put to work. After a break of less than six months a further sinking of only *c.* 5.5m was undertaken, probably as a minor adjustment to increase the depth of the sump below the '*striking house*' (ore loading chamber), a job presumably put on hold after the balance weight in the shaft broke in December 1788 nearly killing three men, and resumed after a new shaft for the balance weights on the ridge top had been completed and these moved to here. A minor adjustment was made in March 1789 when they were '*cutting and widening the deep shaft where the barrels meet*'.

The second deepening was in 1790-91, when the winding shaft was taken down to what had become the sole of the mine at -275m, at a point below where the rich mineralised pipe deposit had failed. The shaft was in continuous use until the 1850s when the steam engine was scrapped at the time the pumps were turned off.

The '*Great Shaft*' (Pumping Shaft) - A radical departure in how the mine operated was brought about in 1781-84 with the creation of a chamber at the river horizon, located deep under the ridge top, for the engine put in use here, which operated pumps in the newly created pumping shaft descending from here to great depth. To the west side there is the large conjoined chamber created for a capstan/horse-drawn engine used to lower heavy equipment down the shaft.

The pumping chamber originally contained a 1783-84 water-powered beam engine, with a large water bucket that swivelled as it hit the floor at one end of the rocking beam and the pump rods attached at the other. The new engine was operated by water brought from the River Manifold at Ape Tor through a purpose-driven level started in 1780. It operated rods to pumps at depth that brought water up the new shaft. A counterbalance beam was added in 1786 and the water engine had its original timber beam replaced by a cast iron one in 1814. This engine was replaced by a large waterwheel in 1823, at which time the chamber was heightened and the reservoir at the end of the upper Ape Tor level was ripped out as it was in the way of the new wheel. These changes were made in advance of the mine being leased, done to put things in good order. The waterwheel continued in use for over three decades but was sold on in 1855 and scrapped in 1856; thereafter all workings below river level gradually flooded.

The '*capstan*' chamber has a very distinctive shape, with sides high enough for men standing at long capstan arms and a central area with a raised roof for a winding drum, with this cavity extended to the shaft top to allow for winding ropes going to headgear. We know from documentation and archaeological evidence that this unusual machine, usually referred to simply as the '*capstan*', was used as both a man-operated capstan and a horse-drawn engine from the 1780s until at least 1795. While its main purpose was to lower heavy equipment down the shaft, in the 1780s documented tasks also included supplementary ore winding. However, the original capstan/engine was almost certainly subsequently replaced as the outer parts of the chamber have been filled with waste stone. This may well be stone from the roof heightening in 1823 when the waterwheel was installed, when presumably they also put in a new, more conventional capstan with shorter arms. At the north side of Capstan Chamber the 1823 the pack of waste stone contains a small stepped hearth, with much soot on the chamber roof above. We know from 1839 documentation that this was built for drying capstan ropes and this is unparalleled elsewhere in Peak District mines.

The pumping shaft, known to the miners as '*Great Shaft*', or sometimes '*Water-Shaft*', was sunk in 1781-83 for water removal from depth and for taking equipment into the mine. The recorded sinkage by the time it was 'finished' in 1783 was -141m. In March to May 1783, at the shaft base they were '*sinking and cutting room for a lodge*' in the shaft bottom that presumable held a pump. Shortly after the shaft sinking was completed, related work continued at its base, including driving a short '*cross cut from shaft to the vein*' in May 1783 and '*driving a gate from the Great Shaft to the northwardly part of the vein*' for *c.* 25.5m in May to December 1783. In August to November 1783 they enlarged the base of the shaft for a '*striking house*' (ore-loading chamber) '*betwixt the shafts*', and for a dam and a large cistern. Clearly, this was seen at the time as the 'permanent' shaft bottom. In September 1783 they put seven '*bundings*' (platforms) in the shaft, presumably for a ladderway for access and/or for support/maintenance of pump rods and pipes. They put the pumps down the shaft in December 1783, and in February to March 1784 they added '*lacing*' (vertical partitions).

The pumping shaft was periodically deepened, in 1786 to a total depth of -155m, and in 1792 and 1795 to a total depth of -205m. Archaeological evidence shows this shaft was divided into three parts, with a large central compartment being used for lowering equipment into workings below with the aid of the '*capstan*'. Another compartment at the north-west end of the shaft contained pump rods and pump pipes, and a third at the other end was presumably for a ladderway. From either 1784 or 1786, until 1789, the '*capstan*' was also regularly used as a horse-drawn engine to bring ore up the lower part of '*Great Shaft*', to then be transferred to '*Deep Shaft*' to be brought up to main level at the river horizon using the horse-drawn engine high on the ridge.

The Ape Tor '*34 Fathom Boat Level*', '*Footway Shaft*' and Stables, and Ape Tor Winding Shaft - The Ape Tor shaft at the northern end of the Ecton ridge, was probably sunk in 1761-65; a level from its base to the 'main pipe workings' was probably completed in 1765-66. Initially they used this 34 fathom level (-62m), and its extension known as '*Deep Level*' through the 'pipe workings' themselves that here were about 110m long, for ore haulage to the shaft, presumably using mine waggons. However, in 1767-68 they widened the level to increase capacity for ore removal, and this is probably the date of its conversion into an underground canal. Subsequently this part, running for a little over 180m through unproductive ground from Ape Tor and probably coming only to somewhere in the vicinity of '*Footway Shaft*', was referred to as the '*34 Fathom Boat Level*'. This canal allowed water as well as ore and waste stone to be taken out to the north of the 'pipe workings' at Ape Tor, supplementing ore movements along the main drainage level going southwards at the river horizon. It also allowed a significant reduction in men employed as '*waterdrawers*' (hand-pump operators), with some at least of the water now brought up in barrels in Ape Tor shaft at the northern end, with water thus only having to be pumped up to the canal from workings below to the -62m horizon rather than to river level. As the 'pipe workings' got ever deeper, more water had to be removed from the mine.

The '*Deep Level*' may well have continued to be used as a tramway to the canal for regularly for bringing out ore until after the completion of the '*Deep Shaft*' in 1773; much of this must have been raised from below -62m once ore removal was finished above it sometime in the 1760s. One unknown is to what extent ore was brought up the '*Footway Shaft*' in the late 1760s and early 1770s before the completion of the main winding shaft down to -141m and whether there was a horse-drawn engine rather than a hand-windlass at its top in this period to facilitate this; we know there was such an engine here in the early 1780s used for bringing up water (see below). By the early 1770s the 'pipe workings' cannot have extended deeper than about -170m but in the mid-1760s these cannot have extended down much below something like -70m; as the 'pipe working' got deeper in this period, they must have needed a horse-drawn engine unless windlasses were used to bring up the ore slowly in a series of lifts.

After 1773 the canal continued in use for the frequent bringing of surplus water up Ape Tor shaft, together with occasional raising of ore and waste stone that presumably came from trial reworking in the 'pipe workings' at around this horizon; this continued into the 1790s, but after 1807 the Ape Tor shaft and canal at its base were little used.

A horse-drawn engine was introduced underground at the inner end of the boat level, probably in 1780, to draw water from the bottom of the mine via the pre-existing '*Footway Shaft*', which in its final form went down to -172m. This shaft, as the name suggests, may well at some point have contained a ladderway to access the then deep workings in the mine and it has been suggested above that it may have been used to draw up ore. The 1780 horse-drawn engine here is thought to have been a stop-gap measure, to be used until the water-powered beam engine in a chamber at the river horizon was completed in 1784; it allowed a further reduction in men working pumps between 1780 and 1784. There was an underground stables somewhere nearby; records for the use of the horses stabled, and provisioned underground via the boat level, for drawing water started in August 1780 and continued until February 1784 when the new pumping arrangements at '*Great Shaft*' came into operation. From this date the underground engine and stables would not have been needed as much of the water was brought straight up to river level, and the Ape Tor shaft was used only to supplement water removal when needed.

Haulage and Exploratory Levels – A series of levels are shown on Meads elevation of 1858, most of which are undocumented and of unknown date. The main exception is the '*34 Fathom Boat Level*' and the associated '*Deep Level*', both at -62m and dating to the 1760s; these have been described above. A series of '*cross-cuts*' and other drivages are documented as made at '*Ape Tor Level*' in 1792 to 1795, which are also likely to have been at the -62m horizon.

The three short levels above this horizon, linked together by short internal shafts, are undocumented but are likely to be a ladderway dating to the 1740s to 1760s.

Below the -62m horizon there are three long levels shown on the 1858 elevation in the 'main pipe workings'. That at -99m extends well beyond the 'pipe workings' suggesting this in part at least was driven for exploratory purposes at an unknown date. That at -154m must date to 1769 or later, given the depth below the river horizon. That at -172m links the base of the '*Footway Shaft*' with the main pumping and winding shafts and is likely to date to the *c.* 1775-80 period, given the depth below river and that it is well below the depth the main winding shaft reached in 1773, and because the '*Footway Shaft*' was used for removing water in 1780-84. Late in the 1840s a level at -146m is documented as being driven horizontally for 142m from '*Deep Shaft*' in search of the '*Dutchman Lode*' (a presumed third main mineralised pipe deposit in Ecton Hill that was never found); this does not appear on the Meads 1858 elevation, presumably because he based his elevation on drawings that were made before the level was driven.

In the lower trial workings below the -220m where the mineralised pipe deposit '*failed*' in about 1790 there three levels. The level at -227m is likely to have been driven in 1789-90 after the winding shaft was deepened to this point in mid-1789, as there are short shafts down to this from the 'main pipe working' that are likely to have been for dropping ore down for transport to the main winding shaft before mining in this rich deposit came to an end. The levels at -247m and -285m are likely to date from the 1790s and the lower of these runs from the base of the winding shaft, which was taken down to this depth in 1795.

7.4 The 2019 Dives: The Pumping Shaft

Introduction: This section describes that part of the pumping shaft entered in May 2019 and the archaeological features identified here, prefaced by relevant historical data. Seven dives were made from the launch platform (17th, 18th, 20th, 24th, 25th, 26th, 28th May). Detailed descriptions of all archaeological features found here are given in Appendix 1; what follows here is a synthesis and interpretation of this information.

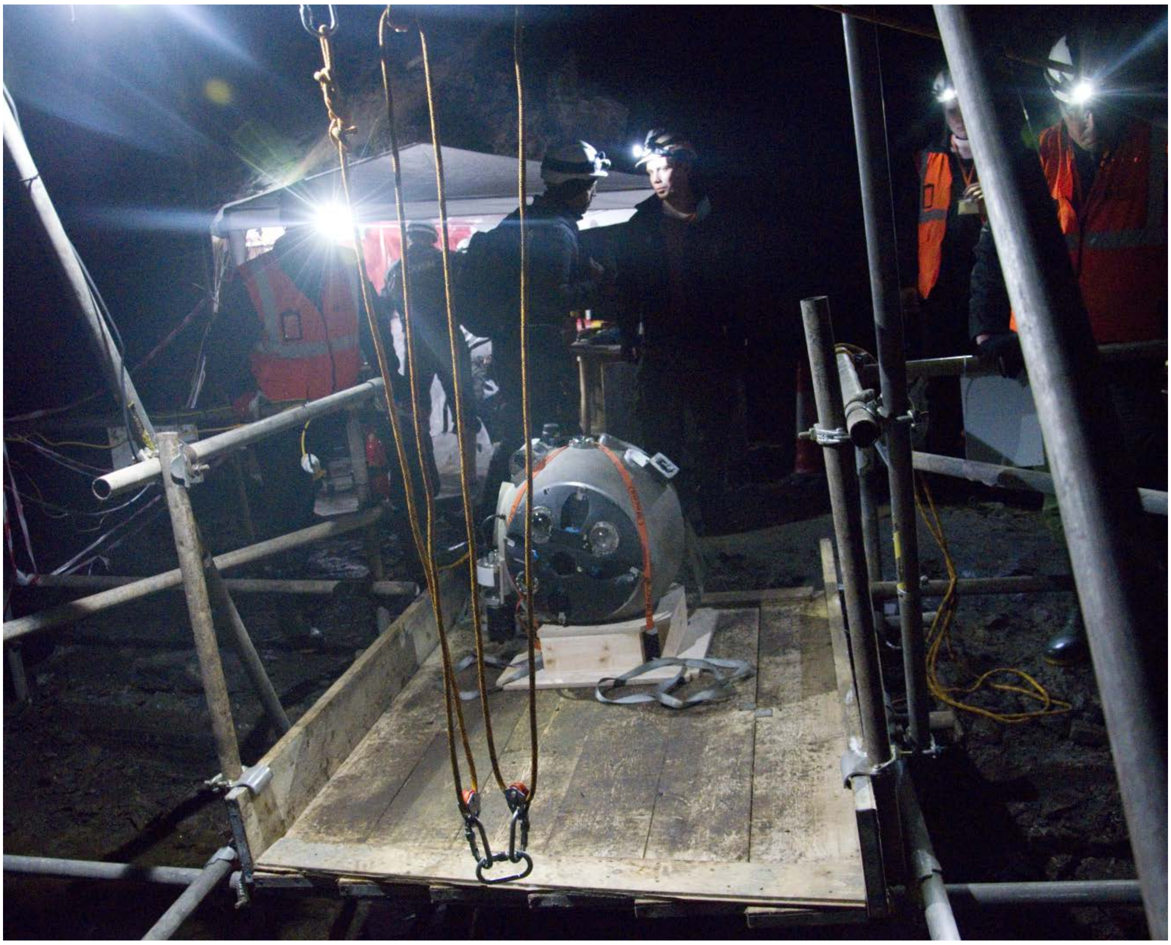


Fig. 7.15: The dive platform at the pumping shaft, photographed just after a submersible arrived for the first time (Photograph: John Barnatt).

Known History of the Pumping Shaft: The data from historical sources given above, and using knowledge derived from other mines of how such shafts were used, indicates that the following information, given here in summary, is pertinent when interpreting the pumping shaft:

- The total depth of the shaft below river was -205m (but it is now blocked at *c.* -125m).
- This shaft was first sunk in 1781-83 to a depth of -141m, but it was deepened in 1786 down to -155m and deepened again twice, in 1792 and 1795, to a final -205m; with these episodes reflecting the need for more depth as the 'main pipe workings' were extended downwards.
- The shaft was used for pumping water up to river level and this would have been achieved by using pumps at depth to force water into pipes rising upwards, usually known as the '*rising main*'. What is undocumented is whether or not the pump rods that operated the pumps at depth were iron rods placed within the pump pipes for bringing the water up, or alternatively were a separate set of timber beams, each strapped to the next, that were placed close by in the shaft; both systems were commonly used at other mines.
- At the base of the shaft it is documented that, when it was first sunk to -141m, there was a chamber for a dam to hold back the water collecting here and a large cistern where the base of the pump pipes drew out water.

- The pumping equipment in the shaft was powered from the chamber at river level where the launch site was located. This water-operated bucket engine comprised a beam arm that was connected to the pump rods at one end and a large bucket at the other. When the bucket was filled with water it tilted the beam until the bucket hit the floor, swivelled and emptied, whereupon this end of the beam went up again because of the weight of the pump rods. This engine was replaced in 1823 by a large waterwheel that operated the beam. The pump rods were also connected to at least one '*balance bob*' (a counterweight device) placed in the chamber.
- There would have been two or more cisterns, each with a pump, placed at its base and part way up the shaft. Because of the depth of the shaft it may well have been impossible to bring the water to river level in one lift, but how many lifts there were in the Ecton pumping shaft is undocumented; it seems likely there were two or three. Often, but not always, cisterns were placed in chambers or other openings in the shaft walls so that these were not in the way.
- The shaft would also have been used for lowering heavy equipment down the central part of the shaft using the capstan/horse-drawn engine at the shaft top in the wide side chamber at the launch site.
- The shaft may also have been used as a ladderway, but this is undocumented.
- There would have been '*bundings*' (platforms) at intervals down the shaft to one end, or both ends, which were used to support and maintain the pump rods and pipes, and perhaps cisterns and ladders. When the shaft was first sunk to -141m, it is documented that seven such platforms were installed in 1783; how may were added when the shaft was deepened is not known. In the top 125m of the shaft entered in 2019, evidence for five of these platforms was found.
- It was common in multipurpose shafts, as at the pumping shaft at Deep Ecton, to add timber '*lacing*' (vertical walls of boards) down the shaft to separate the compartments. It is documented that when the shaft was first sunk to -141m, '*lacing*' was added but it is not made clear if this was at one or both of its ends.
- There was at least one, and possibly more, documented cross-cuts between the winding and pumping shafts, with a certain example show by Meads at -205m at the final shaft depth. It is documented that previously there was probably another at the -141m shaft base as the working chamber created here is described as between the two shafts. In 2019 it was found there are other cross-cuts that do not appear in the historical documentation, which is unsurprising, as such details were often not commented upon.
- At least two of the three cross-cuts found in 2019 are interpreted as being made when the pumping shaft was being sunk as temporary air-ways. These would have been necessary to ventilate the new sinking because of poor ventilation at the 'blind' base as progress in sinking was being made; the pre-existing winding shaft would have provided an easy way of achieving air circulation.

The Shaft to -124m to *c.* -126m Depth: The shaft itself (PS0), whose top is in a large chamber created to operate equipment in it, is rectangular in plan, measuring about 2.0m by 4.0m at its top. It originally dropped vertically to about -202m, but there is now a blockage at -124m to *c.*-126m (PS21 in Appendix 1), which prevented explorations below this point; here there is a pile of rubble across the shaft, perhaps resting on an original platform with open shaft below. As the shaft is descended from the top its sides are relatively irregular but with the rectangular shape retained, with ends that are narrower than the longer sides. Gunpowder shot hole scars in the shaft were frequently observed, often facing downwards and sometimes found at regularly-spaced intervals that reflect its sinking, with the shaft bottom taken down about 0.5m each time it was deepened.

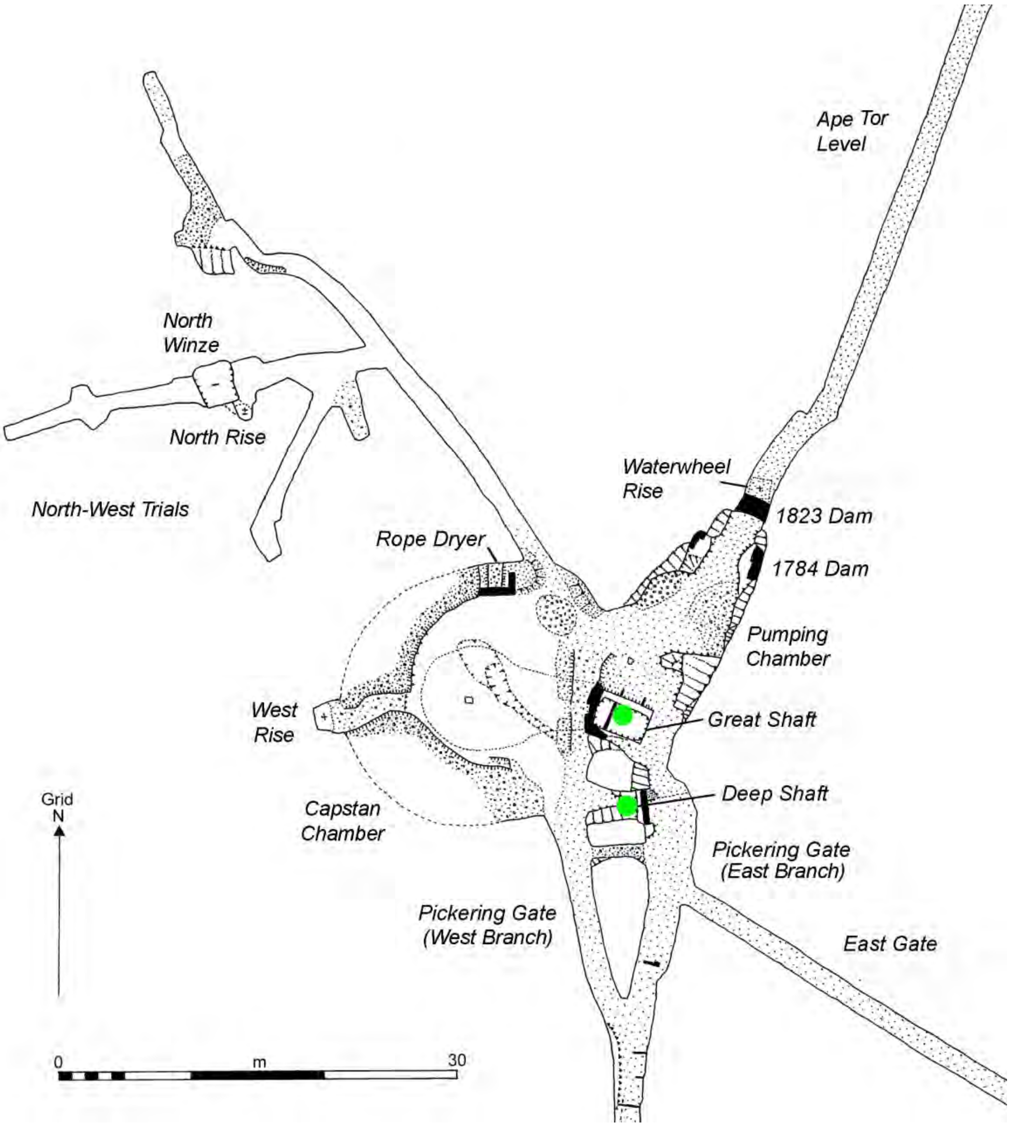


Fig. 7.16: The location of the dive platforms at the winding and pumping shafts, known respectively to the miners as the '*Great Shaft*' and '*Deep Shaft*', shown as green dots.

Fig. 7.17: The pumping shaft, photographed in 2008, showing parts of the pumping chamber and Pickering Gate behind (left) and the capstan chamber (right) (Photograph: Paul Deakin).

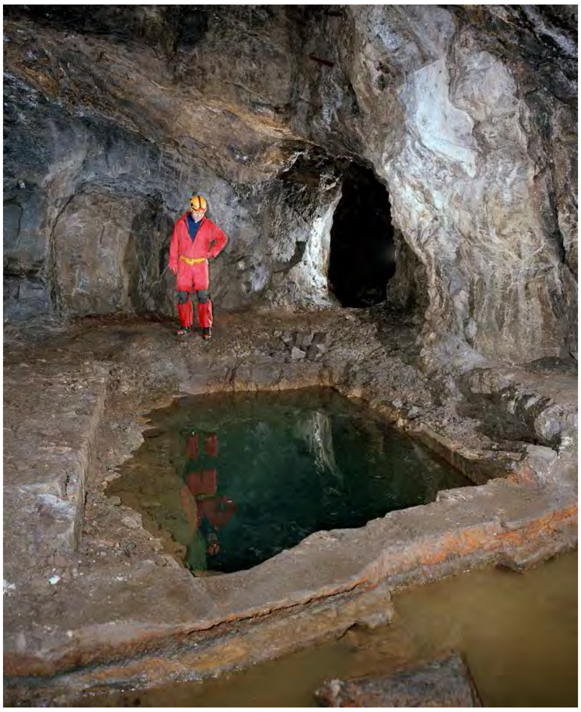


Fig. 7.18: The top of the pumping shaft photographed in 2008; the channel in the foreground is where the pump pipes discharged water from the shaft to let it down the level to the river (Photograph: Paul Deakin).

Fig. 7.19: A detail of the pumping shaft wall at -86m, showing three downward-pointing gunpowder shot hole-scars placed at regular intervals, which date to when the shaft was being sunk in the early 1780s.

The shaft contains several cross-cuts and levels, some certainly interpreted others less so, going off the shaft, one of which has been carefully dammed by a wall. There are also large timbers and sites of timbers across the shaft near its ends that retained platforms and/or supported equipment and timber partitions, and 'side pipe workings' that are intersected, two with associated levels or possible levels leading from them. Displaced timberwork is found in three places. These are all described in the sub-sections below.

This shaft would originally have contained a '*rising main*' and perhaps an independent set of pump rods, located at the north-west end, as indicated by a drainage channel here at the shaft top. We know that some of the pump pipes were taken out and sold in the mid-1850s and it may be that below the blockage at *c.* -125m they remain intact.

'Side-Pipe workings': The positions and depths of these are given in Table 7.3.

Table 7.3: 'Side Pipe workings' leading off the Pumping Shaft

Feature	*Depth*	*Orientation*	*Character*
PS8	-53.0m to -59.3m	north-east	Moderate-sized but tall single cavity with a level leading off at the back (Figs. 7.20, 7.23, 7.65).
PS9	-58.0m to -61.5m	south-east	Possible 'side-pipe working' of unknown size with its entrance largely backfilled behind a blocking of timber and stone (Fig. 7.21).
PS12	-62.5m to -65.0m	north-east	Possible modified 'side-pipe working' of unknown size, behind a walled-up entrance.
PS15	-90.3m to -96.5m	north-east	Moderate-sized entrance but becoming significantly larger inside in its upper part, with parts that were not visible (Fig. 7.22). A lower part is narrower; here a level leads off north-eastwards.
PS16	*c.* -95.5m to -99.0m	north-west	Small 'side pipe working' that was not explored, which may have been part of PS15 before it was intersected by the shaft
PS18	-115.0m to -117.5m	south-east	Small opening to a small 'side pipe working' or level that was not clearly visible and was not explored (Fig. 7.23).
PS19	-121.0m to -123.0m	south-east	Small opening to a small 'side pipe working' or level that was not clearly visible and was not explored (Fig. 7.23).

The 'side pipe workings' were found at two horizons in the shaft, at *c.* -50m to -65m (PS8, 12) and at *c.* -90m to -100m (PS15, 16). At the latter the workings are larger and more complex, with this zone possibly extending down to -123m (PS18, 19); these two zones match the depths of those in the winding shaft. All the pumping shaft 'side pipe workings' are mostly aligned towards the eastern half of the shaft and thus have potential for being linked with the 'main pipe workings'.

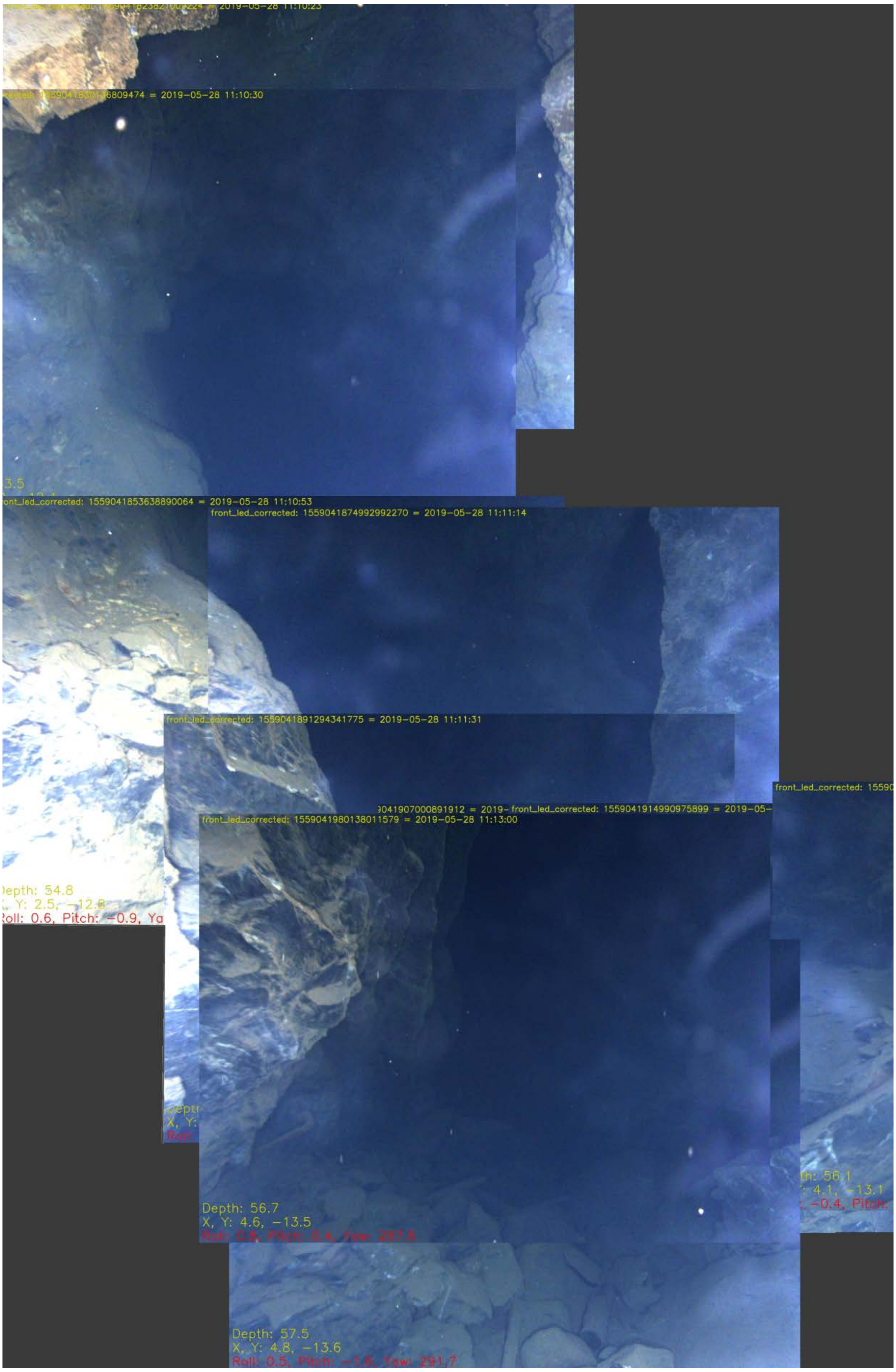


Fig. 7.20: The tall 'side pipe working' at PS8 at the north-east side of the pumping shaft. The level leading off the back is just visible above the rubble floor.

Fig. 7.21: At the base of 'side-pipe working' PS8, to the right-hand side, there is a separate passage at PS9 that the videos suggest is not interlinked; however, no clear view beyond was available to determine whether this was a level of a further 'side pipe working'.

Fig. 7.22: In the large 'side pipe working' at PS15, in its upper part, there is an ascending slope of rubble to the right hand side, and also at the back, both visible in the gloom; visibility was not good enough to see into the area to the left how far back and upwards the working extends.

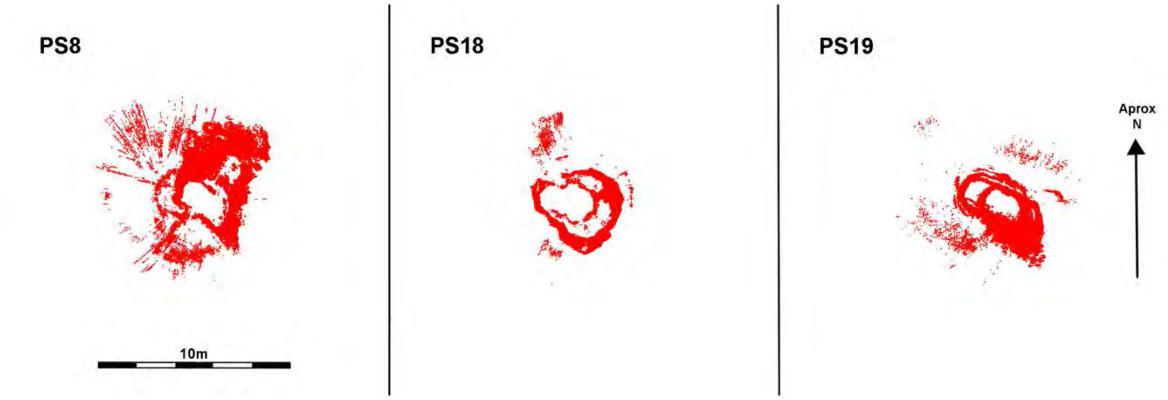


Fig. 7.23: Plans from the sonar point-cloud data. The plot for PS8 shows 'side pipe workings' to the north-east side of the shaft (but with a jump in submersible position so that the shaft appears in two places). The plots for PS18 and PS 19 are uncertainly interpreted from the sonar (with a jump in submersible position at PS19 so that the shaft again appears in two places). All three plots include echoes and other uncertainly interpreted data making them difficult to read; north is estimated because the directional data was in error by significant amounts and there is uncertainty, even in general terms, with PS18-19. The 'side pipe workings' at PS 15/16 were not illustrated because of problems with interpreting the sonar data for this complex area, again compounded by sideways movement of the submersible as it went down.

Cross-Cuts and Levels: The positions and depths of these are given in Table 7.4.

Table 7.4: The disposition of cross-cuts and levels in the pumping shaft.

North-West End

Feature	*Depth*	*Destination*
PS3	-8.0m to -8.9m	Choked and destination unknown (Fig. 7.26).
PS5	-25.8mm to -27.2m	At the same depth as WS2 in the north end of the winding shaft, so there was probably a cross-cut link to here that did not follow a straight line (Fig. 7.25).
PS15	-95.5m to -96.5m	A level going roughly north-eastwards from within the lower part of the large 'side pipe workings' here has an unknown destination.

		It may be that this was linked with a level running roughly north/south that is shown on Meads 1858 elevation through the mine at -99m depth.
PS17	*c.* -108.0m to -111.0m	Possible level going roughly westwards from the north-west end of the shaft; destination unknown.
North-East Side		
PS8	*c.* -57.0m to -59.0m	A level running from the back of a 'side pipe working' with an unknown destination, but possibly a cross-cut to the documented '*Deep Level*' at -62m.
PS12	-62.5m to -65.0m	A level with a carefully-built dam wall sealed with clay, with what appears to be a 'side pipe working' behind (Fig. 7.27). The 'level' has an unknown destination, possibly associated with the documented '*Deep Level*' at -62m. Or, more probably, it was a cistern for the '*rising main*', or a dam made to contain a nearby spring.
South-East End		
PS9	-58.0m to -61.5m	Level or 'side pipe working' with unknown destination, but possibly 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 'Timberwork' below)
PS18	-115.0m to -117.5m	A level or 'side pipe working' that is uncertainly oriented but in the south-eastern half of the shaft and possibly extends towards the winding shaft.
PS19	-121.0m to -123.0m	A level or 'side pipe working' that is uncertainly oriented but in the south-eastern half of the shaft and possibly extends towards the winding shaft.
South-West 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 towards the winding shaft its destination is unknown
PS13	-79.7m to -82.0m	In the south-west side and north-east 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 (Figs. 7.24, 7.35).

As can be seen from the table, there are cross-cuts to the winding shaft at PS13 and probably PS5. The upper link to the pumping shaft (PS5) is small and irregular and may have been designed as an air-way used to bring ventilation to the pumping shaft from the finished winding shaft while the former was being sunk. That at PS13 is larger but it may also have been used in the same way. Given that both 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 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. The possibility that possible levels at PS 18 and PS19 enter the winding shaft below its current blockage, rather than other 'pipe workings', cannot be discounted.

Fig. 7.24: The cross-cut to the winding shaft at PS13, has had rubble dumped on the floor after it became disused. The iron ‘eye’ on the wall presumably dates to when it was still in use.

Fig. 7.25: The small level at PS5, at the north-west end of the pumping shaft, may well be a cross-cut to the winding shaft that was created to bring air to the pumping shaft whilst it was being sunk. As with PS13, which was explored, it must have taken a circuitous route between the two shafts.

Another level (PS3), located near the top of the shaft and 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 to the north-west. At a greater depth possible/probable levels at the back of 'side-pipe workings' (PS15,-18, 19) run to destinations unknown from the north-east side and south-east end of the shaft; it is likely these destinations were other 'pipe workings' and they are roughly in the right direction for the 'main pipe working'. At PS15 it is possible that, in addition, it linked with a level running roughly north/south that is shown on Meads 1858 elevation through the mine at -99m depth, which is shown extending significant distances beyond the 'main pipe workings' in both directions.

Fig. 7.26: The small level at PS3, near the top of the shaft at its north-west end, has been choked with rubble in such a way as to suggest this material came from behind the entrance, but the character of the working here is not known.

A 'level' of particular interest (PS12) is that at -62.5m to -65.0m, which has a carefully built dam of limestone blocks and slabs with the interstices sealed with clay, which comes up to *c.* 1m from the roof; this was very probably designed to hold back water. This level may be associated with the documented Ape Tor '*34 Fathom Boat Level*' and its continuation southwards into the vicinity of PS12 as '*Deep Level*', with the wall originally built as a dam, but with its base at -65m it is below the stated depth in historical records of -62m this interpretation is problematic. Therefore, it is more likely that the walled-off passage was either a cistern for a lift of pump pipes, with the passage behind being an old 'pipe working' that was modified to be 'level-like' at the shaft side to make the dam, or alternatively that it is a 'pipe working' that was later modified for the dam, made to contain a spring of water that was breached in the workings nearby; from here the water could be removed in a controlled way via the shaft. When the shaft was first sunk, down to -141m, then it may well be that the water in the '*rising main*' was taken up the shaft in more than one lift given the nature and thus power of the pumping engine used; the half-way point for a cistern, assuming there were two lifts as seems potentially likely, would have been at about 70m, thus the -62.5m to -65.0m level and dam are not particularly well positioned, but no features related to a possible cistern at -70m were identified, thus a position at about -65m should be considered.

Fig. 7.27: The carefully-built dam across the passage at PS12, with what appears to be clay in the interstices, looks to have been built as a dam to hold water back; the text explores several potential explanations for why this was created.

Another level (PS8), running back from a 'side pipe working', and a further possible example (PS9), are both a short distance further up the shaft than the last described and are roughly at the right horizon to provide links with '*Deep Level*', but it is unknown whether they do so. That PS9 had a strongly built timber structure at its base where it meets the pumping shaft could suggests it was designed for heavy sustained use, but what this use was is unclear; however, that the level here was largely backfilled may indicate the timbers are more likely to have been added simply to retain this backfill.

Some of the levels and cross-cuts are open and only have had sufficient backfill added to create a flat floor (PS5, 13 and probably PS7, 18). Others are partially or fully choked with waste rock that was added after they became redundant (PS3, 9, 19 and possibly PS12), while at two leading back from 'side pipe workings' the extent to which they are open is unclear (PS8, 16).

Timberwork: The positions and depths of timbers set horizontally across the shaft are given in Table 7.5.

Table 7.5: The disposition of horizontally-set timbers in the pumping shaft.

North-West End

Feature	*Depth*	*Character*
PS1	-0.9m to -1.1m and -1.6m to -1.9m	A substantial beam, *c.* 0.3m high and *c.* 0.2m wide, with the site of another above defined by notches in the shaft walls, 0.20m wide and *c.* 0.12m high, with these set *c.* 1.5m vertically apart (Fig. 7.30).
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 that the remaining timber, so that 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.
PS4	-11.5m to -11.8m	Two substantial timber beams at the same horizon, 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 with timber planks but these have not survived (Fig. 7.32).
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 (Fig. 7.31).
PS14	-84.3m to -84.5m	Substantial timber beam that is *c.* 0.2m high and *c.* 0.2m wide (Fig. 7.66).
PS17	-111.3 to - 111.6m	Two substantial timber beams, set horizontally, that are each *c.* 03m high and *c.* 0.2m wide; these were presumably surmounted by a platform with timber planks but these have not survived. Above there is what appears to be a wall of ashlar blocks laid horizontally in two courses, built below the right side of a level or small 'side pipe working' going off.
PS20	-123.5m to -123.8m	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.
South-East End		
PS2	-1.6m to -1.9m and -2.5m to2.8m	The sites of two sets of timbers defined by notches in the shaft walls, each with a timber set above another, with these *c.* 0.3m horizontally apart, with the upper ones at the same horizon as the lower timber in PS1 (Fig. 7.34). Those 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 and 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.
PS6	-50.3m to -50.6m	Four timber notches for substantial timbers for two timbers at the same horizon. All are rectangular with base and sides defined. The outer ones were set in the NE and SW walls of the shaft about 0.5m from the shaft end, as were the other two but with these against the shaft end. Each would have held timbers that were *c.* 0.3m high and *c.* 0.2m wide. They would presumably have held a platform made of boards but these have not survived.
PS9	-58.0m to -61.5m	The level leading off here has a complex arrangement of timbers below its current floor, with a two-timber platform at the base and others placed on this and set above each other, and with a vertically-set iron bar in front of them near the centre line of the passage (Figs. 7.8, 7.28, 7.33); these 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.
PS11	-62.1m to -62.3m	Two substantial timber beams set horizontally about 1.8m below the base of the timber beam at PS10 and further into the shaft (Fig. 7.29). The two horizontal timbers are each *c.* 0.2m high and *c.* 0.2m wide. They would perhaps have held a platform made of boards but these have not survived (but see below). A vertical timber, set between the two beams, rises upwards that has fallen north-westwards and now rests diagonally on PS10 near its top; this timber is more rotted than the other two and may be a different type of wood. It may perhaps be a vestige of a timber '*lacing*' between the side and main shaft compartments.

All the timberwork lies to the ends of the shaft as expected, and where the horizontally-placed beams are substantial they appear to comprise pitch pine (PS1, 3, 4, 10, 11, 14, 17). Although little survives (but see PS11), it is documented that '*lacing*' (vertical timber partitions) was placed in the shaft after it was completed down to -141m in 1783. '*Bundings*' (platforms) are also documented as installed in 1783 and thus much of the timberwork observed in the shaft may well date to its completion in this year.

Fig. 7.28: The base of the timber platform below the level or 'side pipe working' at PS9, with both supporting beams visible, lies at the south-east end of the pumping shaft. Directly above these two beams there is a complex series of timbers and ironwork that hold back the rubble in this part-backfilled passage.

Fig. 7.29: Nearly two metres below the timberwork at PS9 the south-east end of the shaft, there are two more support beams, for a second 'platform' across the same end of the shaft at PS11. Between these beams there is a timber that now lies at an angle, but once was placed vertically and rose for at least 2.5m; this may be a vestige of a vertical partition between the central area of the shaft and a small end compartment. The stones on the timbers may well have come to rest later, when rubble from above fell down the shaft.

Those timbers in the north-west end of the shaft may well have been at the edge of a side compartment in the shaft that held the '*rising main*' cast-iron pumping pipes, and possibly also independent timber pump rods; it is documented that in the part of the shaft explored in 2019 these were removed in the 1850s as the shaft as being abandoned. Presumably the shaft compartment was '*laced*' with timber planks that have not survived, presumably made of wood that was not as durable as the main beams. The only places where there is more than one beam at the same horizon comprising 'platform' supports are at PS4 and PS17, with the last at the entrance to a level; there would presumably have been another at the shaft top, placed to prevent falls down the shaft. 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, is that these pipes were no more than *c.* 20cm in diameter. The mine was a relatively dry one and did not need massive pump pipes; 1880s iron pipes from Clayton Mine survives and these are also of relatively small diameter.

Fig. 7.30: One end of the timber at PS1 at the north-west end of the pumping shaft, showing that it is set into a carefully cut notch in the shaft wall; the shaft-end compartment for the '*rising main*' iron pipes lies behind the timber to the left.

Fig. 7.31: One end of the timber at PS10 at the north-western end of the pumping shaft; the timber resting on it is the once-vertical one at PS11 that lies at the other end of the shaft, which has fallen across the shaft and come to rest on the PS10 timber above. The end of the PS10 timber has been shaped to fit into a small cut '*eye*' in the shaft wall.

Fig. 7.32: One end of the outer timber at the PS4 platform at the north-western end of the pumping shaft; the end of the visible timber has been placed in a rectangular notch cut into the shaft wall.

The depths down the shaft that these timbers at the north-west end were placed is far from regular, with narrow spaces near the top of the shaft between PS1 and PS3 (measuring *c.* 7.m) and between PS3 and PS4 (measuring *c.* 3m). 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), suggests there was at least one, and possibly two timbers, have that have been lost without trace.

The timber beams at the south-east end of the shaft may well define a second side compartment. It has been suggested previously that this contained a ladderway (Barnatt 2013). However, with only three or four timbers potentially defining this compartment, this interpretation needs questioning. The beams of PS9 had a different function as noted in Table 7.5. This said, if the south-east compartment was not for ladders it is hard to know what its function was. If the beams were just to support '*lacing*' then they are again significantly too far apart; the only potential survival of '*lacing*' is the one collapsed timber at PS11. One possible interpretation is that there were other beams down the shaft that have disappeared without trace between PS2 and PS6 and again below PS11 to the shaft blockage at *c.* -125m.

Fig. 7.33: Part of the complex arrangement of timbers above two support beams outside the base of the passage at PS9 at the south-eastern end of the pumping shaft. One of these support beams is just visible at the bottom of the photograph, with further timbers above, including a panel of planks near the shaft wall. The long iron pin was presumably also placed here to help support the crude stone wall that retains the backfilled part of the passage.

Fig. 7.34: Notches for four timbers in the pumping shaft wall at PS2, near its south-eastern end; one, at the outer edge of a platform, has had an iron pin inserted to help hold the now-lost timber in place. These timbers lay close to the shaft top and an atypically complex platform arrangement at two horizons may have existed here, unless one set of timbers was replaced by another at a slightly different depth down the shaft.

The only place where timberwork occurs in close proximity at both ends of the shaft is at PS10 and PS11, showing the timbers were out of synchronisation to either end, with regard to the depth placed down the shaft, by *c.* 2m at this horizon.

Artefacts: Iron 'eyes', hooks and pins are found at the entrances to levels, cross-cuts and 'side pipe workings' (PS2, 5, 7, 8, 9, 13, 19), which relate to the use of these passages, although just how they were employed is unclear; possibilities include attachment points for ladders and chains, and handholds to facilitate entry or exit to these passages. There is also an iron 'eye' associated with the timber platform at PS14. In other cases (PS3, 9, 11) iron pins were used to help keep structural timbers in place.

Fig. 7.35: An iron 'eye' set into the rock wall at the entrance to the cross-cut from the pumping shaft to the winding shaft at PS13. Such 'loops' are suitable for holding ropes or the tops of chain ladders, but exactly how they were used is not known.

There is displaced timberwork in two cross-cuts and a 'side pipe working' (PS5, 13, 15). It is unclear whether these timbers have fallen from above, or have been discarded here by miners at a time when the features that they lie within were disused.

7.5 The 2019 Dives: The Winding Shaft

Introduction: This section describes that part of the winding shaft entered in May 2019 and the archaeological features identified here, prefaced by relevant historical data. Only one dive was made from the launch platform (29th May). Detailed descriptions of all archaeological features found here are given in Appendix 2; what follows here is synthesis and interpretation of this information.

Fig. 7.36: The launch platform at the winding shaft ready for use (Photograph: John Barnatt).

Known History of the Winding Shaft: The data from historical sources given above, and using knowledge derived from other mines of how such shafts were used, indicates that the following information, given here in summary, is pertinent when interpreting the winding shaft:

- This shaft was very different in character to the pumping shaft because of its different function. Here what was needed was a single vertical space that was unencumbered by obstructions that would impede the '*kibbles*' (ore buckets) used to bring up the ore. Thus, the winding shaft was smaller in compass and carefully made so that there were no significant protrusions in the shaft walls, nor any fittings that might constitute obstacles.
- The total depth of the shaft below river was -275m (but it is now blocked at *c.* -113m); above river level the shaft continues upwards to the ridge top.
- This shaft was first sunk in 1767-73 (but possibly started earlier in 1762-63 and for reasons unknown sinking stalled) to a depth of -141m, but it was deepened in 1787-89 down to –229m at the time when a Boulton and Watt engine was placed at the shaft top (see below). It was deepened again in 1790-91, with a minor further sinking of just over a metre in 1795, to a final -275m. All these episodes reflect the need for more depth as the 'main pipe workings' were extended downwards.
- In 1789 the shaft was widened slightly at half way down its then depth (excluding the sump), and thus at about -30m, at the point where the '*kibbles*' met, presumably because previously they had a tendency to hit each other (no evidence for this widening was found in 2019).
- The shaft was used for bringing ore up from depth for removal from the mine. At first this was unloaded at river level and taken down the main level to two short shafts that took it up to the ore processing floor at surface on the ridge-side. From 1806 the ore was taken further up the main winding shaft and unloaded at '*Salts Level*' from where it was taken straight to the ore processing floors.
- At the base of the shaft it is documented that, when it was first sunk to -141m, there was a chamber created for loading '*kibbles*'. Presumably there were others created later at -229m and –275m after the shaft was deepened.
- It is normal for pumping shafts to have a sump below the '*kibble*' loading chamber that allowed for collection of water that came down them, and these were periodically pumped dry as and when necessary. Thus, it is unclear whether or not the chambers were at the levels stated in the last point, or whether the sumps extended below the given depths.
- Winding equipment in the Deep Ecton winding shaft comprised two '*kibbles*' on ropes, at any one moment in time there was a full one going up, while an empty one went down. These were at first operated at the ridge top from a large timber-built engine that was horse operated, but from the end of 1788 this was replaced by a steam engine built by the famous firm of Bouton and Watt; this was one the first rotative engines in the world. The horse-drawn engine was retained as a back-up to be used whenever the steam engine was under repair.
- There were cross-cuts between the winding and pumping shafts, with a certain example shown by Meads at -205m at the final pumping shaft depth. It is documented that previously there was probably another at the -141m pumping shaft base as the working chamber created here is described as between the two shafts.
- It is anticipated that other cross-cuts would have been made when the pumping shaft was being sunk in 1781-83 as temporary air-ways to ventilate the new sinking. It is likely that there would have been poor ventilation at the 'blind' base as progress in sinking was being made and the pre-existing winding shaft would have provided an easy way of achieving air circulation; however, these air-ways are undocumented.

The Shaft to -112.5 to -113.5m Depth: The shaft itself (WS0) is rectangular in plan, measuring just over 1.0m by 2.0m at its top, and originally it dropped vertically to about 285m, but there is now a blockage at -112.5m to -113.5m (WS14 in Appendix 2), which prevented explorations below this point; here there is a pile of rubble and smaller material. As the shaft is descended its sides are somewhat uneven but with a rectangular shape with rounded corners usually retained, with a more oval plan only occasionally observed. Gunpowder shot hole scars often face downwards and sometimes are found at regularly spaced intervals that reflect its' sinking, with the shaft bottom taken down in stages by about 0.5m each time.

There are several cross-cuts and levels going off the shaft, a timber beam across the shaft and possible sites of removed timber beams, and 'side pipe workings' that are intersected, three with associated possible levels leading from them. Artefacts such as displaced timberwork, tramway rails and small diameter pipes are found in various places. These are all described in the sub-sections below.

'Side-Pipe workings': The positions and depths of these are given in Table 7.6.

Table 7.6: 'Side Pipe workings' leading off the Winding Shaft

Feature	*Depth*	*Orientation*	*Character*
WS6	-56.5m to -57.5m	west	This 'side pipe working' has only a small entrance, but almost certainly gets larger inside where it extends upwards, with a complex set of collapsed support timbers below (Figs. 7.9, 7.37, 7.38, 7.45). 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 (Figs. 7.37, 7.39), and with a level or small 'side pipe working' leading off northwards at the back, perhaps going to the pumping shaft. WS11 is effectively part of the same 'side pipe workings' as WS12, with a walled-off section between the two.
WS12	*c.* -99.0 to -103m+	east 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 (Figs. 7.37, 7.40, 7.67). One of the cavities leading off at the back may be a level or small 'side pipe working' leading off north-eastwards. WS12 is effectively 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 small opening to a shallow 'side pipe working', which may extend upwards out of sight (Fig. 7.37). There is a probable level heading straight on westwards. WS13 may link upwards to the workings at WS11/12.

The 'side pipe workings' were found at two horizons in the shaft, at *c.* -55m to -60m (WS6) and at *c.* -95m to -105m (WS11, 12). The workings in the latter are larger and more complex, and this zone probably extends down to *c.* -110m (WS13). These two zones match the depths of those in the pumping shaft. The orientation of the 'side pipe workings' from the shaft varies but the main ones (WS11, 12) run north and east, and thus have potential for being linked with the 'main pipe workings', with openings from the 'side pipe workings' here leading roughly in the right direction; that at WS13 to the west and south but may originally have been part of those at WS11/12. The uppermost 'side pipe working' (WS6) lies to the west of the shaft but is linked with the 'main pipe working' via a cross-cut running eastwards.

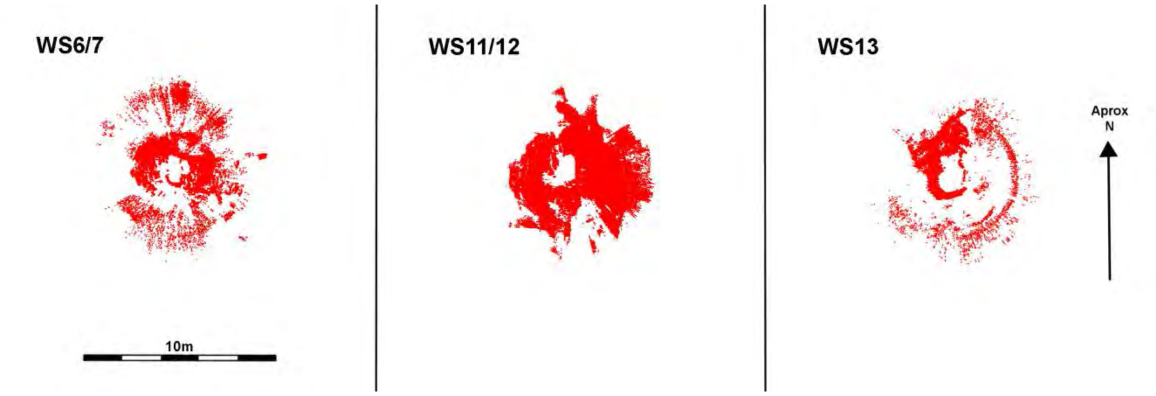


Fig. 7.37: Plans from the sonar point-cloud data. That for WS6 and WS7 has the 'side pipe workings' to the west side of the shaft, and cross-cut to the east. That for WS11 and WS12 has the former to the west side and north end of the shaft and the latter to the eastern side and northern end of the shaft. WS13 lies to the western side and northern end of the shaft. All include strong echoes and other uncertainly interpreted data making them difficult to read; north is estimated because the directional data was in error by an uncertain amount and there is uncertainty even in general terms with WS11-13.

Fig. 7.38: The 'side pipe working' at WS6, with collapsed support timbers and a metal drum within its entrance, photographed from within the winding shaft. The timbers are likely to have fallen from higher within the 'side pipe working', with the drum placed here at a later date.

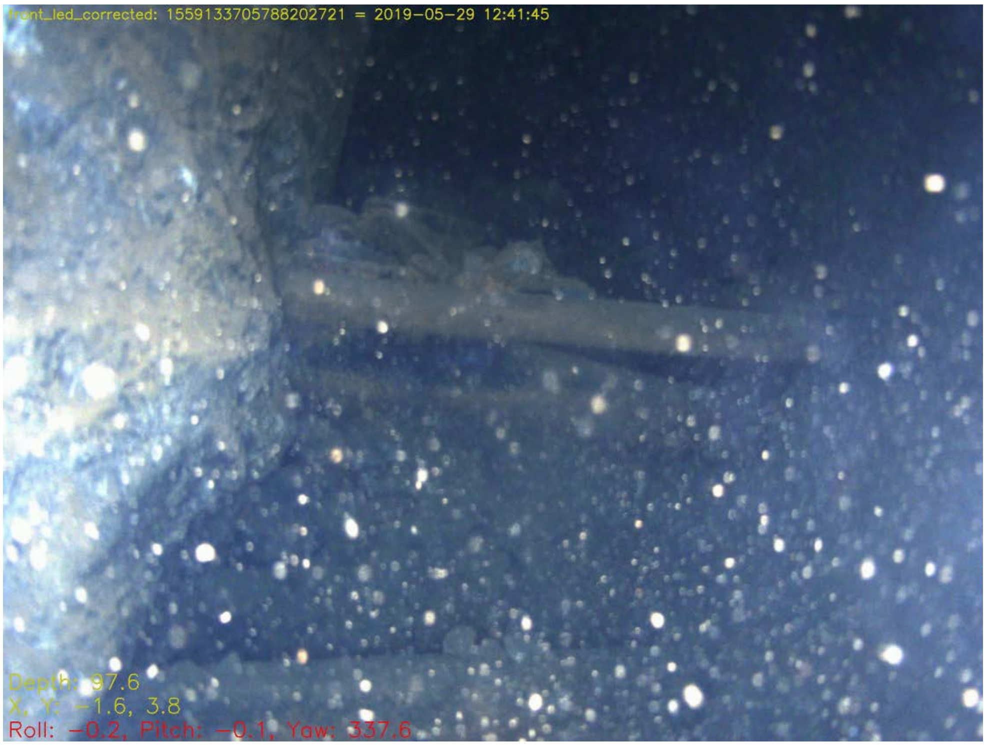


Fig. 7.39: One of the working platforms on sturdy timbers within 'side pipe working' WS11 to its left side, glimpsed only briefly through the general gloom and falling sediments; this one has waste rock above and some of its planks missing.

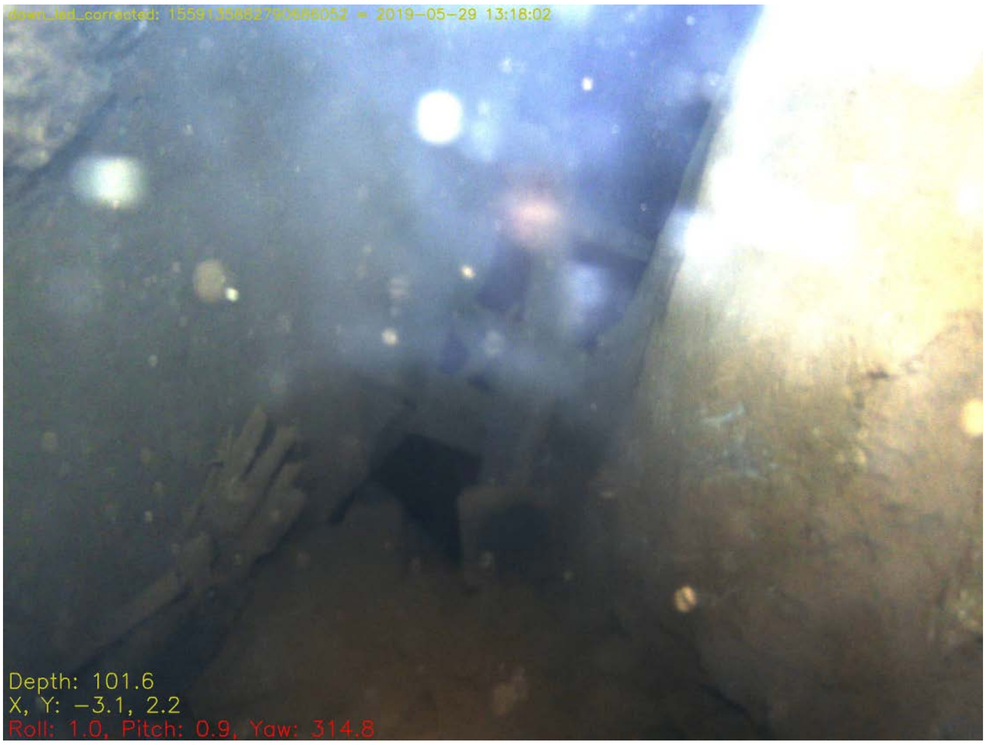


Fig. 7.40: Within the lowermost part of 'side pipe working' WS12, seen through the gloom, there is a part-choked narrow 'vein-like' working with horizontally-set substantial timbers across it and unexplored open workings below.

Cross-Cuts and Levels: The positions and depths of these are given in Table 7.7.

Table 7.7: The disposition of cross-cuts and levels in the winding shaft.

Feature	*Depth*	*Destination*
North End		
WS1	-5.00m to -6.70m	Unknown (Fig. 7.43).
WS2	-26.2m to -27.2m	At the same depth as PS5 in the north-west end of the pumping shaft, so probably there was a cross-cut link to here that did not follow a straight line (Fig. 7.41).
WS13	-109m to -110.5m	Probable level (or 'side pipe workings') going from the 'side pipe working' here to an unknown destination.
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, which was reshaped to prevent loose rocks falling down the shaft.
WS7	-57.5m to -59.0m	Entered and shown to go to the 'main pipe working'. This level 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.
WS11	*c.* -95.0m to -97.5m	Possible level (or 'side pipe workings') going from a 'side pipe working' here to an unknown destination.
WS12	*c.* -100.5m	Possible level (or 'side pipe workings') going from a 'side pipe working' here to an unknown destination.
West Side		
WS8	-79.0m to -81.4m	Entered and shown to go to the pumping shaft at PS13 (Figs. 7.42, 7.46). The route between the two changes direction part way along.

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 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; while that at WS8 is larger it may also have been used in the same way. Given that both are not straight line links between the two shafts, it is tempting to suggest their first parts from the winding shaft were earlier and there were later extended to the winding shaft; however, it is hard to see why short blind levels (known at WS8 and assumed at WS2) would have been driven if was not the intention from the outset to reach the pumping shaft.

Fig. 7.41: The small level at WS2 leading off the northern end of the winding shaft, that may well lead to the pumping shaft as a cross-cut, that came here via a circuitous route and entered this at its north-western end. It can be seen to get wider, or possibly turn left, and may have been driven from the pumping shaft to bring air to the winding shaft as it was being sunk.

Fig. 7.42: The cross-cut at WS8 in the winding shaft, which was explored from PS13 in the pumping shaft and shown to link the two together. As with WS2 higher up the winding shaft, it also changes direction part way along and it may again have been used as an air-way. This said, it has been partially backfilled and given a flat floor (later with rubble dumped here at the far end). One of the two iron 'eyes' at its entrance sides is visible and these may have been for ladders that gave access to the passage, but whether the cross-cut was used for other things as well as air and access is not clear.

Another level, with a timber beam at the shaft that was possibly part of a platform, runs northwards to a destination unknown at WS1, and although this is the direction of the pumping shaft it does not enter this. At a much lower depth, three possible/probable levels running north and east from within 'side pipe workings' also have unknown destinations; it is likely at least two of these entered other 'pipe workings' as they are roughly in the right direction for the 'main pipe working'; WS12 may also access the long level documented by Meads in 1858 at -99m.

Some of the levels and cross-cuts are open and only have sufficient backfill to create a flat floor (WS1, 2, 5, 7 and WS 8 that had a pile of waste rock placed here in one part). Others are partially or fully choked with waste rock that was added after they became redundant (WS11, 12), while at one leading back from 'side pipe workings' the extent to which it is open is unclear (WS13).

At WS1 there is a small sloping '*garland*' (cut water channel) above it in 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 chamber at river level. All were created to take water running down the shaft sides into the adjacent passages in order to help keep the hemp winding ropes dry and thus reduce their weight.

Fig. 7.43: The apex of the 'garland' in the winding shaft walls above the level at WS1. This small cut-channel was made to capture water running down the shaft sides and take it away via the level. Thus, it helped keep the hemp winding ropes dry, which was important because long wet ropes were significantly heavier and thus put more load on the winding engine.

Timber Beams: 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, 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 be fortuitous shaft-sinking scars. Further down, at WS4 there are one or possibly two picked rectangular notches, 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*' (ore buckets), 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 -86m down the shaft, there is an *in-situ* timber beam at the south end of the shaft which may have been placed to secure loose material in a possible alcove above and behind the beam; this must have been close enough to the shaft end to be out of the way of the '*kibbles*'.

Fig. 7.44: The timber purposefully set across the shaft at WS10 (left), with other timbers and rubble above that has come to rest here after coming down the shaft from above; why the lowermost timber was initially placed here is unclear. The tangled divers line to the far left fell here from above after a diver got into difficulties and died several decades ago.

Artefacts: Iron 'eyes' and pins are found at the entrances to levels and cross-cuts (WS1, 7, 8), which relate to the use of these passages, although just how they were employed is unclear; possibilities include attachment points for ladders and chains, and handholds to facilitate entry or exit to these passages. In the 'side pipe working' at WS11 there is a U-shaped iron bar and a nearby iron pin, both fastened to the wall and almost certainly used to support a horizontal timber. Elsewhere in the same 'side pipe working' there is a timber beam, secured by two iron pins, supporting part of the roof running into the workings, with its near end attached to what appears to be a second beam set vertically and running down to the floor on the rock buttress. There is also an iron 'eye' high in the 'side pipe working' side.

As noted above, there are discarded artefacts scattered throughout the workings. These include displaced timberwork (WS1, 5, 6, 9, 10, 12, 13), some substantial, others smaller. There are also displaced narrow-gauge tramway rails of flat-bottomed type (WS5, 9 and possibly WS1) that are of 19th century date. In the case of the timbers in WS6 they look to be parts of a substantial structure that has fallen from higher in the 'side pipe working' and these were perhaps part of a frame to retain the working sides or to support working platforms. In some other cases it is unclear whether the timbers and rails have fallen from above, or whether some or all have been discarded here by miners at a time when the features that they are in were disused.

At WS9 and WS14 there are several lengths of small diameter metal pipe that have clearly come down from above; taken together it may be that they are all part of the same pipe. One possible interpretation is that they have fallen from above and were parts of the documented pipe that brought water up to the 1788 Boulton and Watt steam winding engine on the ridge top for use in its boiler.

Other items include an iron drum-shaped object in WS6 of unknown function, and at WS8 a long iron bar with short attached curved end bars at right-angles; this may be a displaced tie rod used in conjunction with a timber structure.

Fig. 7.45: The iron 'drum' at the WS6 'side pipe workings', resting on one of the collapsed timbers. Its position may suggest it has been purposefully placed here rather than coming to rest on the timber after falling down the shaft.

Fig. 7.46: The iron bar with two curved end pieces, behind a metal pipe, at the winding shaft edge in the WS8 cross-cut from the pumping shaft. This may have fallen down the shaft and was perhaps a tie-bar that was once fastened to a large timber structure. There is also an iron 'eye' above that is fastened to the wall at the level entrance.

At WS9 and below, at -80.5 to -112.5m down the shaft, there is a tangled diver's line in the shaft that has come from above (perhaps from WS5 at -53.9m) and this is associated with a diving incident several decades ago, when a diver got into difficulty and died.

7.6 The 2019 Dives: The 'Main Pipe workings'

Introduction: This section describes that part of the 'main pipe working' entered in May 2019 and the archaeological features identified here, prefaced by relevant historical data. Two dives were made from the launch platform (27th, 28th May). Detailed descriptions of all archaeological feature found here are given in Appendix 3; what follows here is synthesis and interpretation of this information.

Fig. 7.47: The launch platform at the 'main pipe working' ready for use (Photograph: John Barnatt).

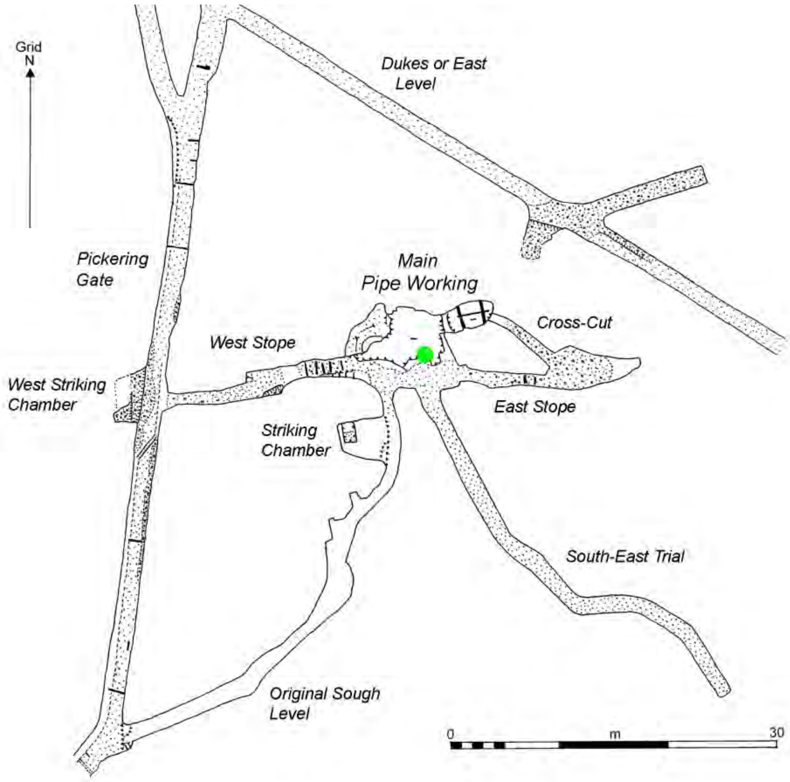


Fig. 7.48: The location of the dive platform at the 'main pipe working', shown here as a green dot.

Fig. 7.49: The 'main pipe working' just above river level above the flooded workings, just visible at the bottom of the image, with a window into a side passage just above the water, and the 'pipe working' at the top of the image ascending steeply upwards from the chamber (Photograph: Paul Deakin).

Fig. 7.50: The permanent pool of water, here since the late 1850s when the mine pumps were turned off, in the 'main pipe workings' photographed in 2008; this was the site of the launch platform for dives here in 2019 (Photograph: Paul Deakin).

Known History of the 'Main Pipe workings' located between river level and the Ape Tor '*34 Fathom Boat Level*': The data from historical sources given above shows the following points are pertinent to interpretation, given here in summary, for those parts of the 'main pipe workings' entered:

- This section of the 'main pipe workings' was mined in the 1740s to 1760s, with ore and water presumably removed in short lifts, using hand-operated windlasses and pumps; no details of these arrangements are documented.
- Meads 1858 drawing shows a relatively small working between -0m and -25m that was about 5-10m wide and below this a large chamber approximately between -25m and -65m that is about 60m wide and 40m high, which extended down to just below the Ape Tor '*34 Fathom Boat Level*' at -62m
- Meads also shows three short levels connected by short shafts between the river horizon and the -62m level. As these are mostly set away from the 'main pipe workings', it is assumed this was a ladderway, probably passing through 'side-pipe workings'. It is likely that John Dickinson Brunton descended into the workings this way in 1858, as he saw only small 'side pipe workings' and thus missed the large chambers between -0m and -62m that we confirmed exist in 2019.
- Harper's 1769-70 description of the mine fits tolerably well with the Meads 1858 drawing. He described three chambers between river level and the Ape Tor '*34 Fathom Boat Level*', the second below and to the north-east of the first, and the third below the second, with the last being largest. The second had various holes leading off the side to the north and north-east.
- It is documented that, after the rich mineralised pipe deposits were lost in 1790 at -220m, there were extensive trials looking for more economically viable ore deposits and that these extended from the sole of the mine up to the river horizon. Details of exactly where they were working at any point in time are hard to establish from the mine records as those specific places named cannot now be identified.
- We do not know whether further trials were ever made in the first half of the 19th century in the workings between -0m and -62m, as detailed mine records for 1810 onwards have not survived. We do know that four successive private mining companies between 1826 and 1850 were extracting some ore from Deep Ecton Mine, some at least probably below river level but specific locations are not recorded, while in 1804-25 and in 1850-55 miners were certainly working somewhere below river level.
- An access level at 34 fathoms (-62m), known by the miners' at the time as '*Deep Level*', was probably created in 1761-65 and used to transport ore for removal from the mine in the mid-1760s via a shaft at Ape Tor at the northern end of the Ecton ridge.
- Part of this level was converted to a canal in 1767-68 and thereafter was known as the '*34 Fathoms Boat Level*'; thereafter ore, waste stone and water was drawn up the shaft until 1807. The canal is unlikely to have extended to the main winding and pumping shafts, but to have come from Ape Tor only as far as the '*Footway Shaft*' at the northern end of the 'main pipe workings'. Ore destined for the Ape Tor shaft to take it to surface was either brought up the '*Footway Shaft*' or from further south in the workings/ It may be that the '*Deep Level*' extending through the 'main pipe workings' was kept open after ore above it was depleted in the 1760s until the main winding shaft was completed in 1773. Perhaps this level continued in use after this date; it could be that the small amounts of ore brought out at Ape Tor after 1773 came from small-scale reworking in the upper parts of 'pipe working' below river level, with this taken out here so as not to interrupt the constant flow or rich ore coming from depth in the main winding shaft. Similarly, while surplus water continued to be drawn up the Ape Tor shaft for many years after the main pumping shaft was completed in 1784, we do not know if any of this water was brought from below after 1784; it may be that all this water came through the upper workings down to -62m. While we know from the 2019 dive that there is certainly no link between the '*Deep Level*' and the main winding shaft, we currently do not know whether it was ever linked by cross-cuts to the main pumping shaft; however, it may be that no such link was needed as '*Deep Level*' was redundant. While a link between the pumping shaft and the canal purely for access may perhaps have been desirable, it again is not clear whether it was needed, as it may well be that there was a separate ladderway down to the '*Footway Shaft*' area from the river horizon, as hinted at by the 1858 Meads drawing.
- Working platforms and ladders between them are likely to have existed, put in as the rich ore deposits were being mined, but few details are documented. Efford writing in 1769 noted that there was a large timber platform over the 'main pipe working' at river level but its primary purpose is likely for unloading ore brought from below and to prevent accidental falls by careless miners. Below here he noted descent into the workings to the then base of the workings

using platforms, ladders, cross-pieces of timber let into the rock and notches cut into the rock for feet; Harper also noted platform and ladders. An anonymous writer noted in 1839 that the ladders had wooden sides and often iron rungs. In the late 1760s when Efford and Harper were writing, the then base of the mine was at about -130m to -145m and Efford noted thirty ladders between here and the river horizon above. Thus, something like 10 ladders between working platforms at different horizons must then have existed in the workings explored in 2019.

The 'Main Pipe workings' Entered to -58.5m Depth: The 'main pipe working' was explored down to *c.* -58.5m in May 2019 (Figs. 7.10, 7.11, 7.60, 7.61), but with this working perhaps continuing downwards but left unexplored (PW11). The workings explored comprise a chamber at -0.0m to -11.5m (PW1), with a second larger one below starting at about –22m (PW 4/6). Between the two, and to the side of the upper chamber, there is a complex series of smaller but sometimes still spacious passages, some with rock bridges and pillars between them (PW3) (see Fig. 7.63), which were left unexplored with the exception of the way down taken by the submersible. The lower chamber also has openings to its sides that were not fully explored (PW4). In the uppermost workings there are occasional *in-situ* timbers set across passages (PW1, 3) whereas in the lower chamber (PW4, 6) none were observed.

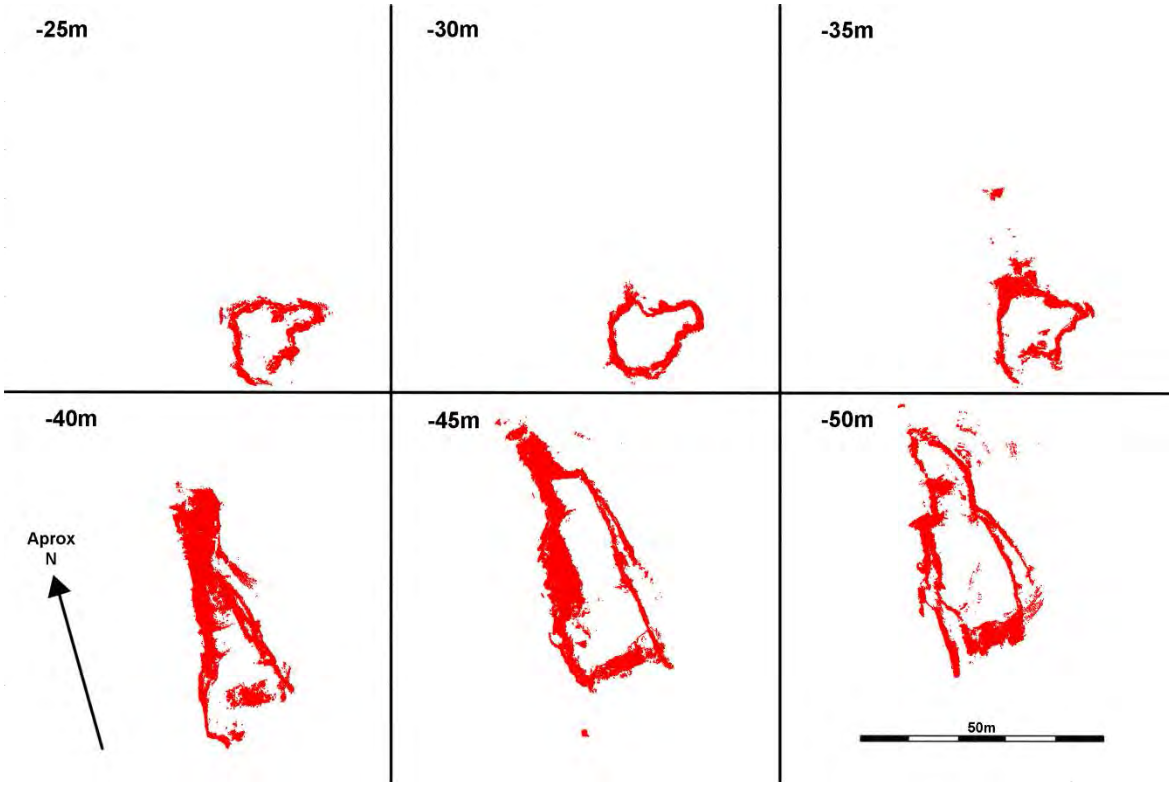


Fig. 7.51: Plans of the 'main pipe workings' walls at chamber PW4/6 at various depths, produced from the sonar point-cloud data (including echoes and other uncertainly interpreted data), with each including +/-1m from the stated depth. Each of the six squares in the image have the same spatial centre point, showing how the workings extend northwards at depth, while to the south at-40m and below the working is filled with rubble (north is estimated because the directional data was in error by an uncertain amount).

There are iron pins and 'eyes' to the sides of passages (PW1, 3, 10). At the bottom of the explored 'main pipe working' there is a short cross-cut to the winding shaft (PW10) and there are artefacts scattered on floors and ledges throughout (PW2, 5, 6, 9); these are described in the sub-sections below.

Fig. 7.52: An iron pin, at the top of a steeply descending passage within the complex series of passages (PW3) entered below the upper chamber, presumably installed to hold a ladder or rope.

The first chamber comprises a large irregular cavity, the lower part of which is below water; at the water surface it measures *c.* 5m north/south and *c.* 9m east/west. To the west the rubble-covered floor is a relatively shallow broad rock ledge below the water, which slopes down eastwards for up to *c.* 3m in plan to where the chamber end goes vertical, while to the east end and both sides of the chamber the walls go down vertically from the water level. At the east end of the floor it is up to *c.* 11.5m down at the lip of the main way down in PW3.

The second chamber near its top is roughly oval in plan and very irregular in shape with a large extension lying roughly to the east that it is not as wide as the rest. In its upper parts it measures roughly 10-15m by 20-25m. Below the chamber becomes larger in size from *c.* -35m down to 39.5m and it is roughly 20m across east/west, with a long extension running roughly northwards, with the long axis in this direction measuring roughly 45m.

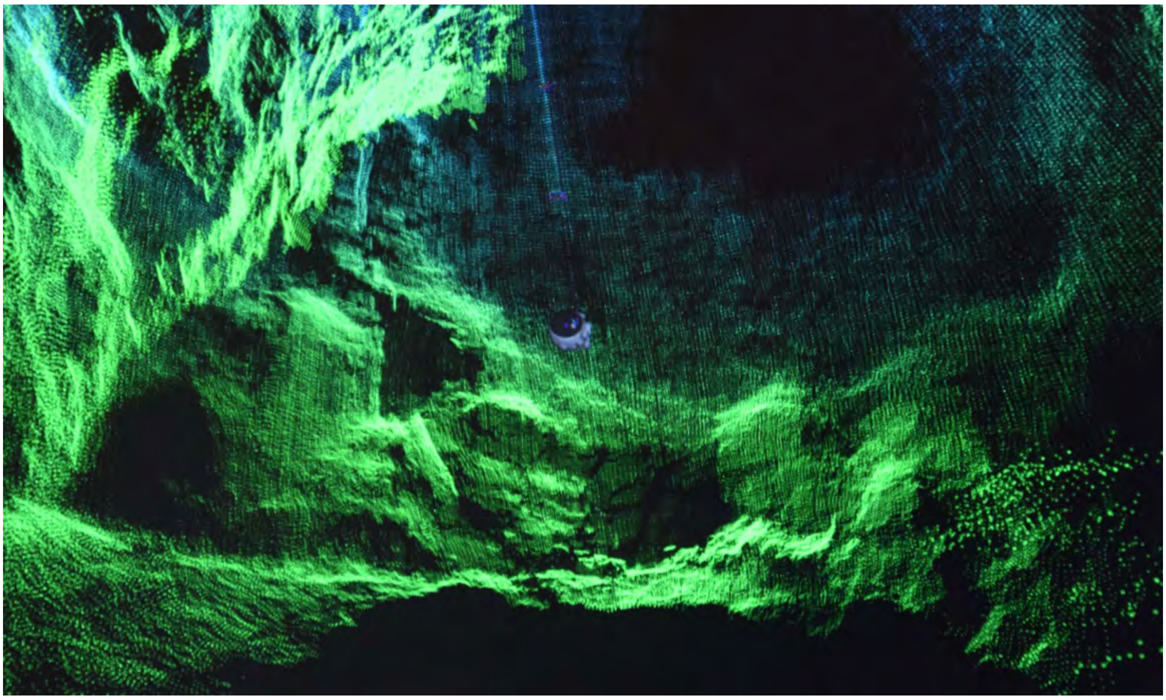


Fig. 7.53: A sonar point-cloud image photographed from one of the dive monitors in the control room in late May 2019, showing part of the second chamber down in the 'main pipe workings' (WS4), centred at about -35m, showing the scale of the working and examples of side passages that have yet to be explored (the submersible at the centre is a graphic that allows its location to be identified).

This cavity has been partially backfilled from the southern end with a heap of waste stone, which here may be 25-30m deep as shown by a comparison with Meads 1858 drawing. The floor of the passage, at -36.9m to -39.5m, comprises a large amount of mine waste, mostly rubble, with large heaps of this across the central section of the chamber. To the south-west, near the end of the chamber, a large hollow appears to be blind. In contrast, a second hollow at the north end of the chamber continues down as passage PW6. The floor at WP6 runs steeply downwards from the southern side of the PW4 chamber, running roughly northwards above the backfill of waste stone down to -58.5m. As with the upper part of the PW4 chamber, its walls and roof are irregular. The roof to the south end is at about -35m that continues roughly horizontally from here northwards, dropping by less than 10m by the time the far end of PW6 is reached. The passage has an approximate width of 15m, with a height at the southern end of about 12m, with this increasing to about 25m at the northern end by PW10. The chamber was explored down to a floor outside this cross-cut at -58.5m, but to the east side there is a narrower extension northwards (PW11) that was not properly looked at.

Part way down the slope of PW6 there is a retaining wall (PW7), built of roughly-coursed limestone slabs and blocks, with its *c.*1.0m wide flat top at -51.5m crossing the whole passage. On the upslope side the rubble does not quite reach the top of the wall. On the down-slope side this wall is up to *c.* 1.5m high. It was presumably built to prevent rubble running further down and blocking the cross-cut at -58.5m (PW10).

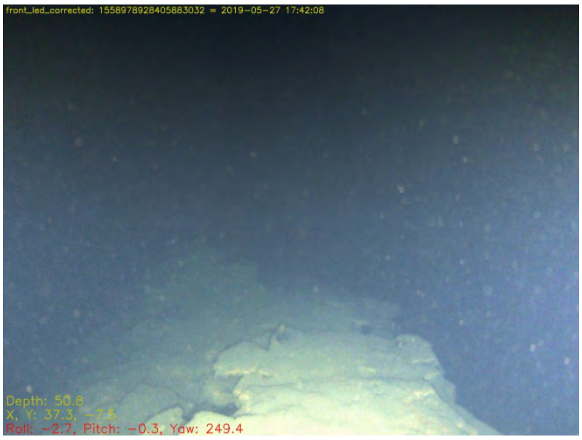


Fig. 7.54: The silt-covered top of Wall PW7 disappearing into the gloom, with the way on down PW6 to the right.

Fig. 7.55: The PW10 cross-cut to the winding shaft, with the retaining wall PW8 to the right that was built to keep the passage clear of rubble coming down the steep slope of PW6 from above.

Near the base of the explored working, there is a large hole in the rubble floor with drystone retaining walls (PW8), which keep clear a relatively small flat sub-rectangular area at the current base of the working outside the cross-cut (PW10). A lower wall stands to approximately the same height as the level on both sides, and is well-built with limestone slabs and blocks to the two sides of the cross-cut entrance, but in the central area between it is less regularly built and of variable height. Behind and above the wall just described there is a near-vertical crude wall of blocks that is about 2-3m high. Together the two walls have a total height of 5m or more.

Two small side-passages were seen to the north side of the main passage of PW6 at between *c.* -51.0m and *c.* -54.0m, a short distance above the top of PW8. One to the right looks 'level-like' but very soon enters the winding shaft (at WS5); this may well be an accidental breach of an 'alcove' in the pre-existing 'main pipe working' made when the shaft was sunk, which was tidied up so that rocks did not fall into the shaft. The other to the left side was not entered and appears to be another irregular 'side pipe working'.

Fig. 7.56: The right-hand side passage within PW6, between *c.* -51.0m and *c.* -54.0m down. Although this superficially looks 'level-like', the 'alcove' here almost immediately enters the winding shaft, here not clearly identifiable in the gloom but seen as the submersible went forward.

One important observation about the 'main pipe working' is the dearth of timber working platforms and ladders; this is interpreted as the result of miners stripping back the walls of the 'pipe workings' in the 1790s, dropping waste rock as they went upwards into already searched workings below and smashing redundant timberwork here.

The -58.5m Cross-Cut (PW10): this runs roughly westwards to the main winding shaft. The entrance is cut into a steep slope of rock in PW6 and is *c.* 1.2m high and *c.* 1.0m wide with a flat floor. The cross-cut was perhaps designed to transport ore from PW4 and PW6 to the winding shaft for haulage towards surface, but as there is no loading chamber here it may never have been used in earnest in this way and its real purpose may well have been for access to side pipe workings beyond the winding shaft at WS7.

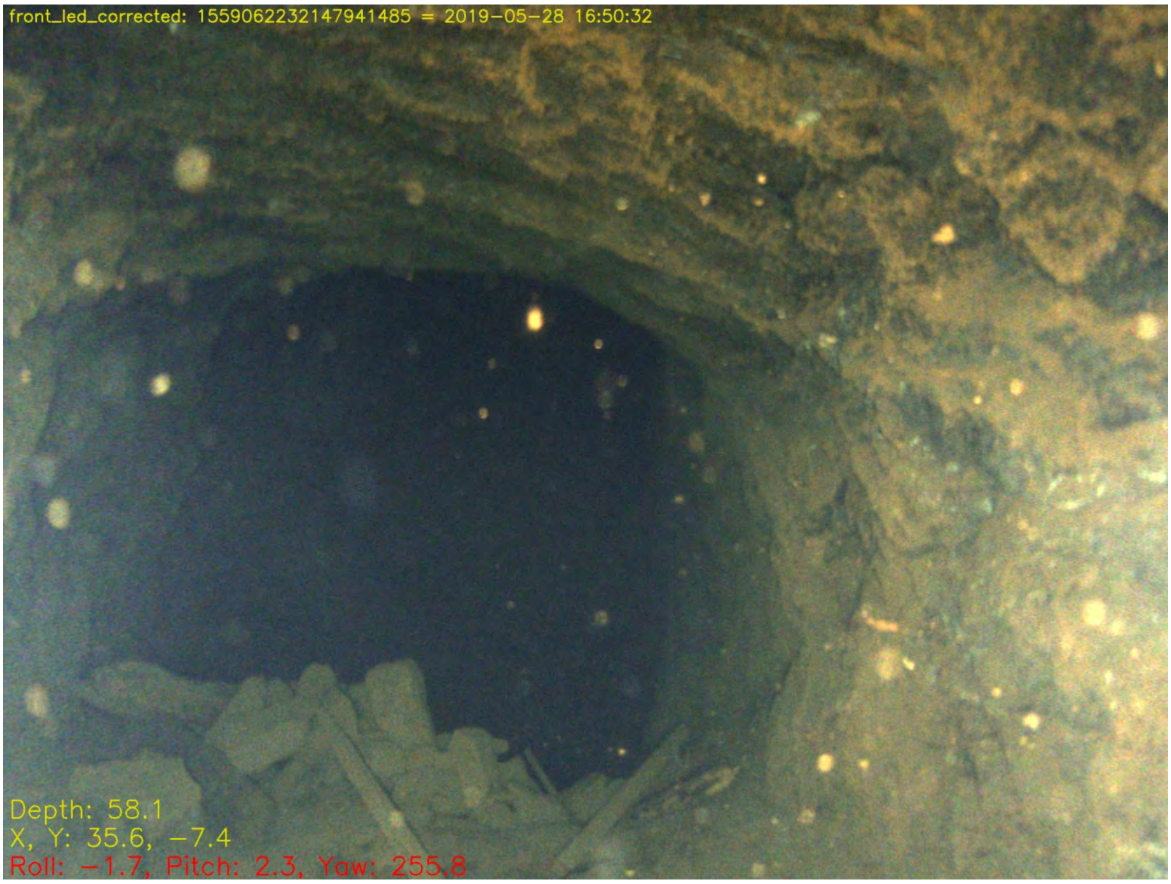


Fig. 7.57: The short -58.5m cross-cut (PW10) between the 'main pipe workings' and the winding shaft (PW10). The pile of rubble on the floor contains displaced timbers and a metal tramway rail.

Artefacts: There are iron pins and 'eyes' that were observed in various places in small numbers (PW1, 3, 10), which relate to the use of these passages, although just how they were employed is unclear.

As noted above, there are discarded artefacts scattered throughout the workings (see Fig. 7.64). The most significant is the displaced timberwork (PW2, 5, 6, 9, 10), some substantial others smaller, some of which at least may well relate to collapsed working platforms demolished in the 1790s. There are also several displaced narrow-gauge tramway rails of flat-bottomed type (PW5, 6, 10), which are of 19th century date. It seems likely that these had been reused by the miners as part of retaining structures above, to hold back waste that subsequently collapsed. Other items (PW2, 5, 6), many of which may be relatively modern in date, including three metal grills, four metal frames, and an iron ring, probably reached their present positions after having been dropped down from above the water level. Of debatable interpretation are several small-diameter metal pipes (PW2, 5, 6); some may date to the mining era, perhaps reused in the same way as the tramway rails, others may be modern scaffold poles dropped from above the flooded workings.

Unexplored Workings to -58.5m Depth: Various workings have been mentioned above as not explored, notably those at the 'bottom' of the lower chamber (PW6), between the two chambers (PW3) and to the side of the upper chamber (PW1). In the second chamber (PW4/6) there are various openings to the sides, some of which may be the '*alcoves*' described by Harper in 1769-70, while others may lead off to passages that we as yet have no knowledge of.

Fig. 7.58: To the right-hand side of the cross-cut to the winding shaft (PW10) at the 'bottom' of the lower chamber (PW6), with the adjacent protection wall (PW8) at its entrance seen here to the left, there is a large working continuing down (PW11). That this goes downwards as well as horizontally is not obvious on the sonar point-cloud data and this area need exploring more thoroughly.

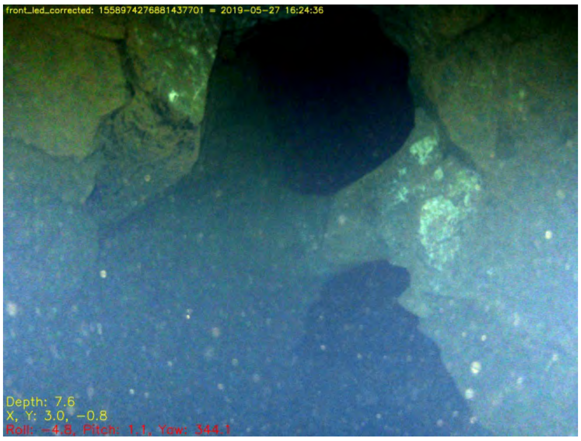


Fig. 7.59: At the eastern end of the upper chamber (PW1) there is a honeycomb of passages leading off that have mostly not yet been recorded; this image shows two of these.

At a slightly lower horizon, at -62m, it is anticipated that the '*Deep Level*' of the 1760s ran through, or to the side of, the 'main pipe working' described above; this, or any entrances to cross-cuts to it, are most likely buried in the backfill of the lower half of the second chamber.

7.7 The 2019 Dives: Overview and Interpretations

Discoveries and Interpretations: This section reviews what was learnt in 2019 and how this alters or confirms previous interpretations of Deep Ecton Mine.

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. These relationships are presented here as schematic drawings because of difficulties in presenting the sonar data because of 'drift' during the dives and the uncertainties in the point clouds as to what was real and what were false data resulting from spurious echoes and deflection due to silts that interfered with the plots.

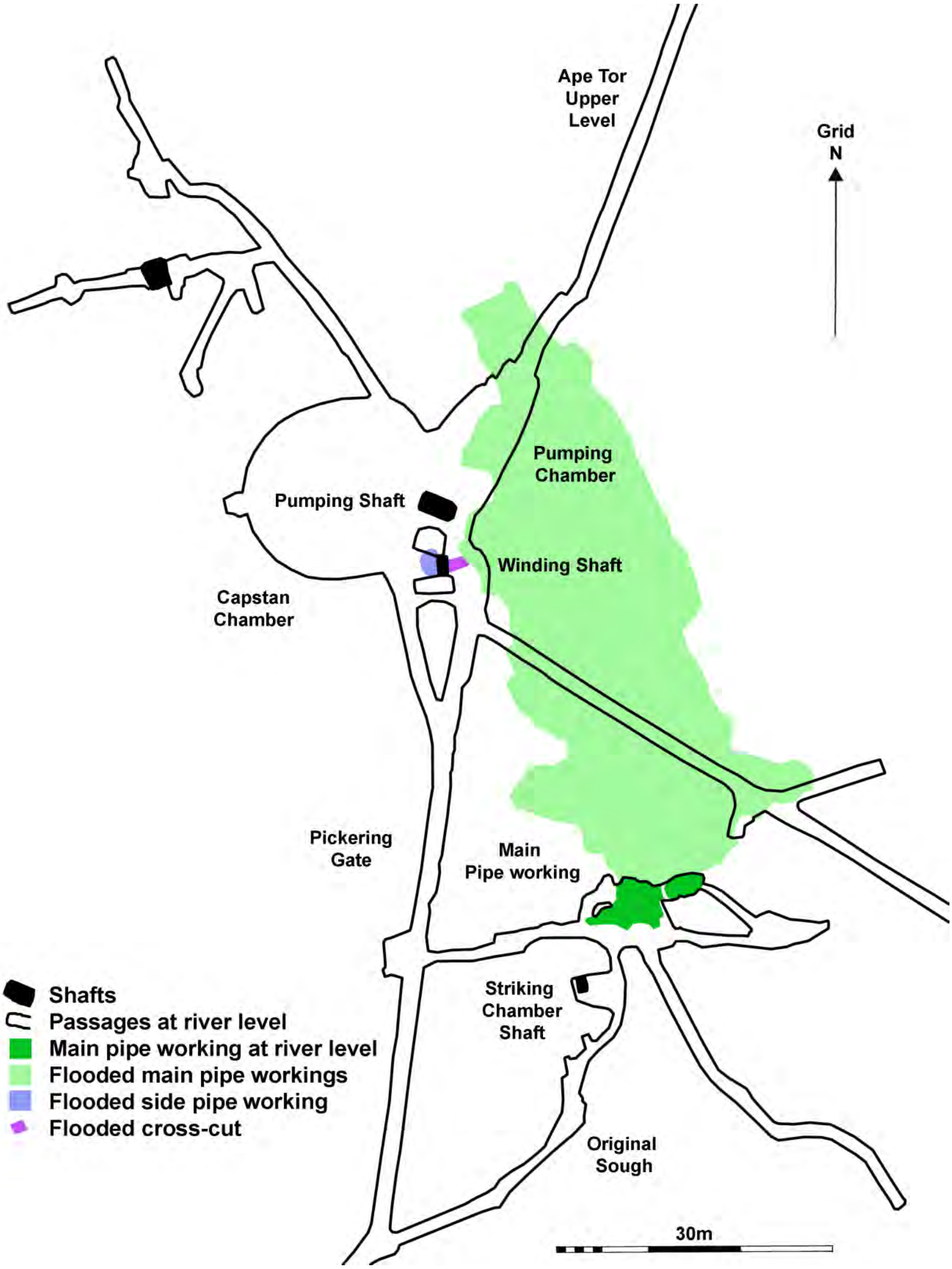


Fig. 7.60: Plan showing the approximate position and shape of the flooded 'main pipe working' explored down to c. -60m and 'side pipe working' WS6, both estimated from the sonar point-cloud plots. These are shown in relation to the pumping and winding shafts, and the cross-cut WS7/PW10 at -58m. The 'main pipe working' at river level as shown in green depicts the top of the pools of water here.

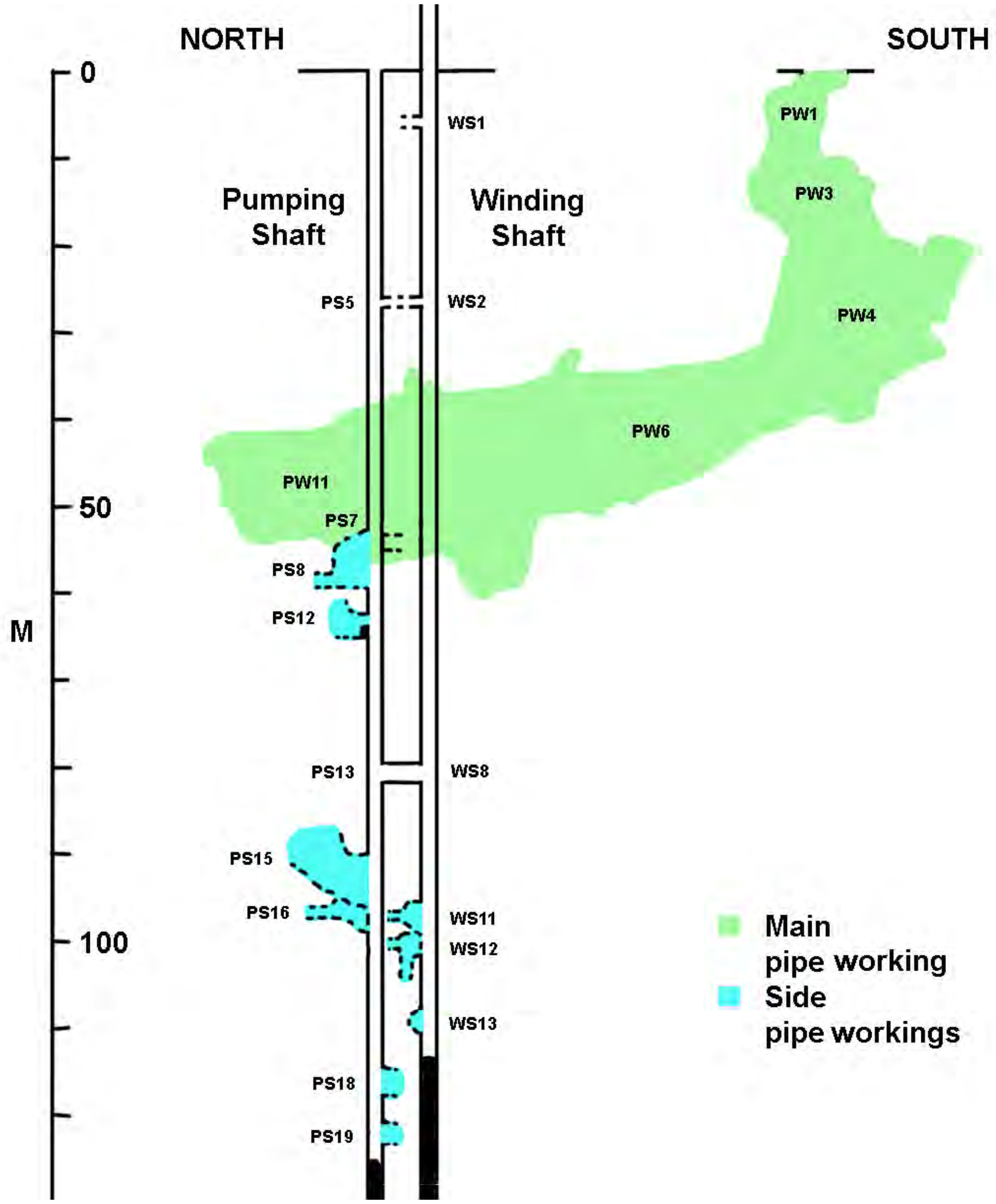


Fig. 7.61: North-south schematic elevation through the explored workings at all three dive sites, showing the inter-relationship between shafts and the 'main pipe workings', with 'side pipe workings', cross-cuts and other levels also shown (with the orientation of the pumping shaft skewed to show the shaft sides).

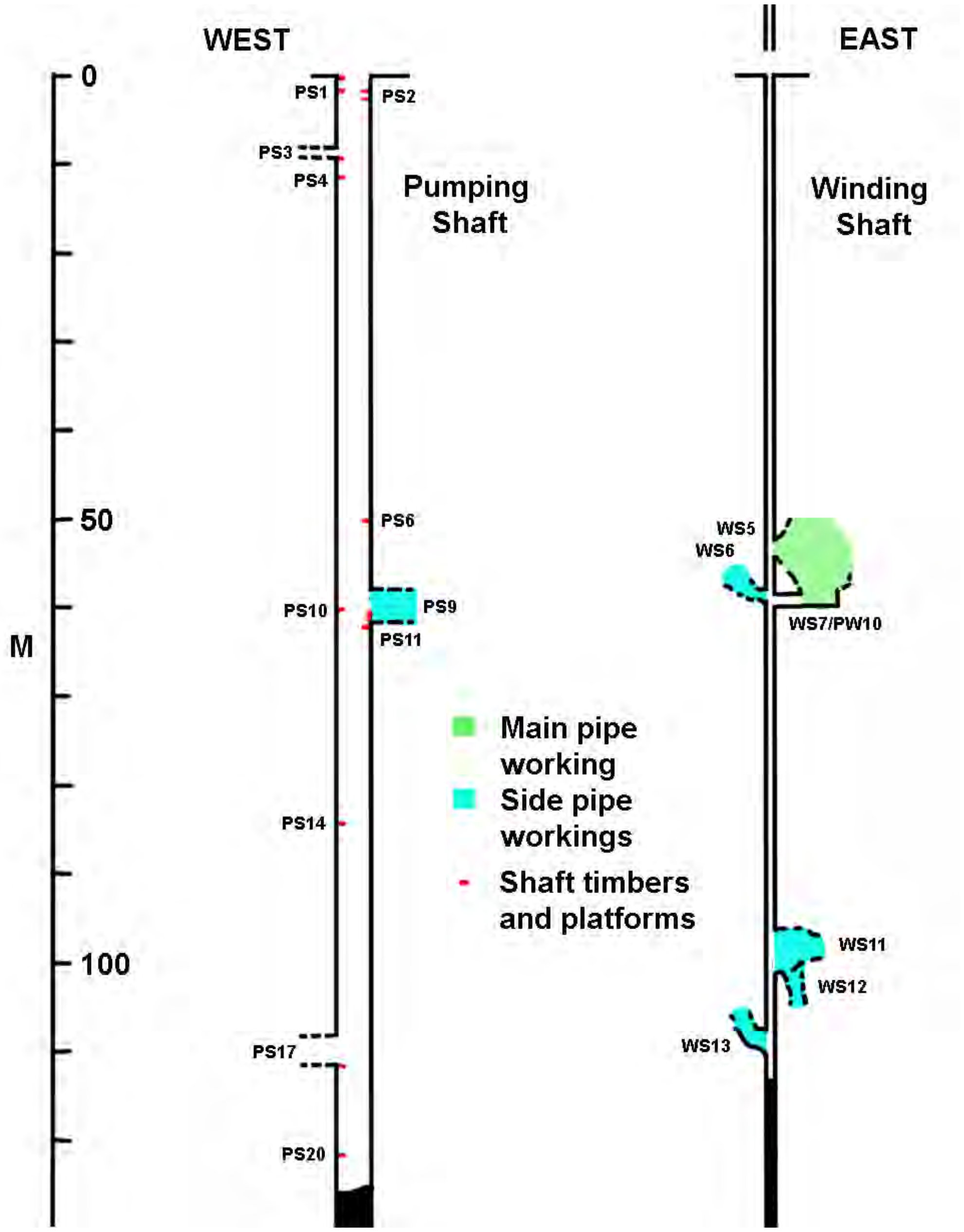


Fig. 7.62: East/west schematic elevations through the pumping and winding shafts, as two separate drawings, showing the explored 'pipe workings', cross-cuts, levels, and shaft timbers (with the orientation of the pumping shaft skewed to show the shaft ends)

Of the twelve research questions raised in the Introduction we have started to address many of these (questions 1-7, 12). This section on interpretation is presented below in four parts.

General Interpretation

The three dives have elucidated several general interpretative issues that relate to the flooded workings.

- As long suspected, the 1858 elevation through the mine drawn by Meads, while detailed, is only 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 west of the 'main pipe workings' to the east. The same displacement may well apply within the 'main pipe workings'. 'Side-pipe working' may have been ignored by Meads, or more probably were subsumed within the general depiction of the workings. In other cases the 'main pipe working' chambers may potentially overlap and this is not shown on the drawing.
- This said, once the problem of overlapping features is taken into account, there is a general approximate correlation between what Mead depicted in 1858 and what was explored in 2019; this has important implications for understanding the waste stone dumped in the second main chamber in the 'main pipe workings' that is returned to below.
- Reappraisal of the historic documentation related to the '*34 Fathom Boat Level*' and the associated '*Deep Level*' of the 1760s at -62m, and their relationship with the two main pumping and winding shafts of the 1770s-80s, has led to a more nuanced interpretation of how and even if these were interlinked. It has now been realised from the 2019 dives that the levels certainly did not link with the winding shaft and this may also be the case with the pumping shaft. Both shafts were created after the boat level had fallen out of use as the main route for transporting ore to surface, whilst water removed via the canal after the main pumping shaft was finished may have been just from springs within workings local to it. One implication of this for future explorations is that we may well need to find another way to access this important feature. It may well be that the southern end of this -62m level was backfilled in the 1790s when the lower chamber in the 'main pipe workings' above was partially backfilled, thus a route entering it further north needs to be sought.
- Archaeological details, previously recorded above river level, include a variety of iron pins, hooks and 'eyes' at shafts and 'pipe workings'. Similar iron fittings were found in 2019 below river level at the entrances to levels, cross-cuts and 'pipe workings', which relate to the use of these passages by miners, although just how they were used is unclear; possibilities include attachment points for ladders and chains, 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.
- Narrow gauge iron tramway rails found in the 'main pipe working' and the winding shaft, both created in the 18th century, are of 19th century date and possibly indicate a continuing presence in the workings between -0.0m and -58.5m up until 1855 when the mine below river level was abandoned. However, it is more likely that they fell from above, from old workings being trialled at and above river level, and thus they cannot be used as dating indicators in the workings explored in 2019.

The 'Main Pipe workings' down to -58.5m

The two dives here have entered these 'pipe workings' for the first time since the 1850s (except for visits by two divers in the mid-20th century who did not live to detail what they saw). The following points summarise what we now know:

- The parts of the 'main pipe workings' entered in 2019 probably date to the 1740s to 1760s, but were significantly modified in the 1790s. Much of the ore mined from here is likely to have been taken to river level using hand windlasses as the workings at this horizon predate the main winding shaft.
- There is a rough match between what was discovered in 2019 from -0.0m down to -58.5m and what is shown on Meads 1858 drawn elevation through the mine as well as accounts of the workings given by Efford in 1769 and in the diary of John Harper in about 1769-70. That Harper describes three chambers between the river horizon and the boat level at -62m, rather than the two we found in 2019, may be simply explained as Harper drawing a distinction between the smaller upper part of our second chamber down and its larger lower part.
- What was not clear in the 1769-70 accounts, nor on Meads 1858 drawing, is that there is a part between the two chambers explored in 2019, at -0.0m and -11.5m, and at –22.0m and -58.5m, that comprises a convoluted section with many interconnected passages where bedrock has been left *in-situ* between them; this has implications for lower parts of the 'pipe workings' at depth that have not yet explored, in that there may be other similar areas there.

Fig. 7.63: A detail, captured in the gloom, of the complex area of passages at PW3 between the upper and lower passages with many interlinked passages, here with a small rock bridge left by the miners at the top of a fold in the limestone beds.

- 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 by Meads in 1858. While we knew of one above river level, used in the 19th century (and today) as a ladderway, we now know these may have been common throughout the flooded workings.
- The implication of the presence of a central complex section in the 'main pipe workings', in combination with several 'side pipe workings' found in 2019 at various depths in the two main shafts, is that the workings are far more complex than Meads drawing and the 18th century descriptions of the 'pipe workings' would suggest.
- It may well be that the 'side pipe workings' found when exploring the two main shafts are all connected to the 'main pipe workings', although this still needs to be confirmed by exploration.
- There is a strong possibility that 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 first being mined in the 1740s-60s and the shafts dated to the 1770s-80.
- A comparison of Meads 1858 drawing of the large chamber, still partially open above -58.5m, with the filling of waste stone found in 2019, shows that at its southern end the second chamber down (PW4/6) has a fill that is likely to be about 25m-30m deep. This may well be associated with the 1790s reworking of the 'pipe working' sides, with rubble dropped 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. We now think that many of them may well have been destroyed when the sides of the 'pipe workings' 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, it is likely that some mining below river level took place in the first half of the 19th century. However, given what we found in 2019 this is likely to have been mostly somewhere below *c.* -60m; it is documented that at least one exploratory level was driven here and thus platforms and ladders dating to, or reused in, this period may still exist at depth.
- A passage leading from the top chamber in the 'main pipe workings' to the south-west may well be a cross-cut to the shaft in a small '*striking house*' (ore unloading chamber) at river level to the side of

the drainage level passage close to the chamber. This horizontal passage and shaft may be the uppermost parts of the postulated ladderway, as shown but not named on Meads 1858 drawing as having three short shafts between horizontal passages on the way down to the '*34 Fathom Boat Level*' at -62m; its continuation north of the first chamber was not identified and presumably runs from the side passages here that have yet to be explored.

- The cross-cut from the 'main pipe workings' to the winding shaft found in 2019 at -58.5m has no '*striking house*' (ore loading chamber) at the shaft, so this begs the question was it used for loading ore into '*kibbles*' (ore buckets)? This may well not be the case. 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 using hand windlasses using short lifts in the workings. Any ore found from the later 1760s to the end of the 1780s is likely to have been taken along '*Deep Level*' to the -62m boat level and then taken up the Ape Tor shaft. The main winding shaft that intersects the cross-cut was only sunk below river level in 1770-73 and much or all of the rich ore deposits above -58.5m may well have been removed by this date. Therefore, the cross-cut's initial purpose, for it is likely to be early in date given the lack of ore loading facilities, may well have been to access the 'side pipe workings' just beyond the winding shaft. While the cross-cut was purposefully kept open in the 1790s, with retaining walls around its entrance to protect it, presumably to allow for the possibility for more ore removal once the -62m level below had become choked, it was probably never used for this.
- Other than the displaced timbers and tramway rails, no artefacts of consequence were observed and many may well be modern, having fallen from the un-flooded parts of the workings above.

Fig. 7.64: A pile of typical artefacts found in the 'main pipe workings', here comprising displaced timber and a metal pipe resting on a wedged slab of rock close to where the submersible went vertically downwards from the base of the upper chamber (PW1) through the complex series of passages below (PW3).

<u>The Pumping Shaft</u>

A great deal was learnt in 2019 about the shaft itself and the disposition of passages that lead off from the shaft down to the blockage at *c.* -125m, together with details of the infrastructure installed in the shaft itself. The following points summarise what we now know:

- The part of the shaft entered in 2019 was created in 1781-83.

- From its top to the blockage point the shaft is mostly sunk through bedrock and is of the same basic character throughout, created as large rectangular opening with vertical sides going to depth.
- The shaft intersects previously unknown 'side pipe workings' at two different horizons; these may well have been linked with the 'main pipe workings', which at this upper part of the flooded workings may pre-date the sinking of the shaft, created in the two decades before the main pumping shaft as created. Within these 'side pipe workings' there are levels leading off in the right direction for the 'main pipe workings' and none are certainly isolated from them (see below).

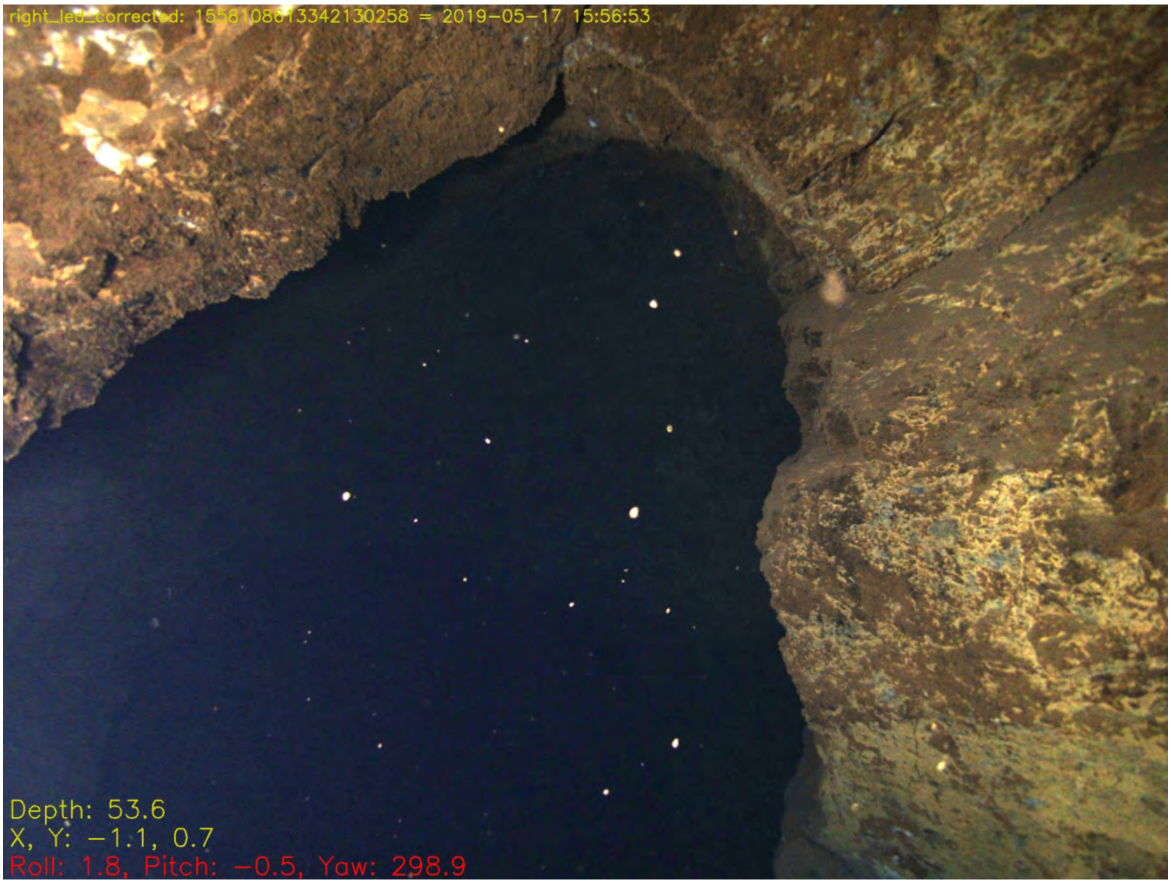


Fig. 7.65: The top of 'side-pipe working' PS8, which was the first of these to be seen during the dives at Deep Ecton Mine in May 2019; this was an exciting moment.

- Two cross-cuts to the winding shaft, one certain the other probable, have been found, none documented before 2019, although their presence at depths unknown was previously suspected; two at least of these are interpreted as air-ways created when the pumping shaft was being sunk in the early 1780s. The uppermost cross-cut has a '*garland*' (cut water channel) above it in the shaft sides that took water from here into the level, created to take water running down the shaft sides into the adjacent passages in order to help keep the hemp winding ropes dry and thus reduce their weight.
- There are also between two and six other levels leading off 'side pipe workings' to currently unknown destinations (and a seventh is given in the next point). These presumably went to various points in the 'pipe workings' rather than to unknown shafts and levels; four lead off towards the 'main pipe workings' to the east side, while two lies to the west side. Two other levels lead straight from the shaft to points unknown.
- One of the levels, at -62.5m to -65.0m, is particularly interesting as it has been carefully walled off as if to retain water behind it. While the possibility that this relates to the documented '*34 Fathom Boat Level*' and its continuation southwards as '*Deep Level*' at -62m cannot be fully dismissed, it seems more likely that the walled-off passage was either a cistern for a lift of pump pipes, with the passage behind being an old 'side pipe working' that was modified to be 'level-like' at the shaft side, or alternatively that it is a level that was later modified to contain a spring of water that was breached in the 'pipe workings' nearby. When the shaft was first sunk, down to -141m, then it may

be that the water in the '*rising main*' was taken up the shaft in two lift and while the half way point would be *c.* -70m, no features potentially related to a cistern were found here, and a cistern at *c.* -65m should be considered.

- Various sturdy horizontally-placed timbers and platforms at the two shaft ends have been found in 2019, located at irregular intervals down the shaft. Timbers in the pumping shaft ends can be observed at the shaft top and these were reported upon previously (Barnatt 2012; 2013); the 2019 dives confirm that matching shaft-end timbers, and sites of others where the notches in the shaft sides remain, continue down the shaft.

Fig. 7.66: Timbers at the north-western end of the pumping shaft were found down much of the depth explored, as here at PS14 at about -84.5m.

- The presence of these timbers confirm that the shaft was partitioned into three parts (see Barnatt 2013), interpreted as a large central space for lowering heavy equipment down the shaft; a north-western part for the '*rising main*' pump pipes that brought pumped water up to the river horizon and possibly independent rods that operated the pumps (alternatively these could have been within the pump pipes); and a the south-eastern part that is tentatively interpreted as for a ladderway. It may well be that the two shaft partitions were '*laced*' by walls of timber planks, but these have not survived, with the possible exception of one collapsed timber at *c.* -60m to *c.* -62m.
- From their appearance the surviving timbers in the pumping shaft look to be of high quality pitch pine, which partially explains their better survival compared with other timberwork here and elsewhere in the flooded workings (but also see the section on the 'main pipe workings').
- It may well be that much of the timberwork in the part of the shaft seen in 2019 dates to documented installation of platforms and wooden partitions in 1783.
- The character 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 the removal of features in the shaft by miners after they became redundant, who placed them in passages that were disused.
- It is strongly suspected that the shaft below *c.* -125m has not been fully backfilled, but comprises material that has fallen from above when rubble fills collapsed from areas immediately adjacent to the shaft in passages leading off, coming to rest here on an original platform or another obstruction at this horizon; the shaft below the blockage may well still be open.

<u>The Winding Shaft</u>

A great deal was learnt in 2019 about the shaft itself and the disposition of passages that lead off from the shaft down to the blockage at *c.* -113m. The following points summarise what we now know:

- The part of the shaft entered in 2019 was created in 1770-73.
- From its top to the blockage point the shaft is mostly sunk through bedrock and is of the same basic character throughout, created as a relatively small rectangular opening with vertical sides going to depth.
- No places were found in the shaft with chambers designed to load ore into '*kibbles*' (ore buckets) for transporting this to the river horizon above. The historical documentation would suggest the first of these would have been at about -141m and no discoveries were made above that would refute this.
- The shaft intersects previously unknown 'side pipe workings' at two different horizons; these may well have been linked with the 'main pipe workings', which at this upper part of the flooded workings may pre-date the sinking of the shaft, created in the two decades before the main winding shaft was created. Within these 'side pipe workings' three have possible levels leading off and none are certainly isolated from other workings. One of the 'side pipe workings' intersected by the shaft has surviving timber working platforms and other timbers that held up the roof.

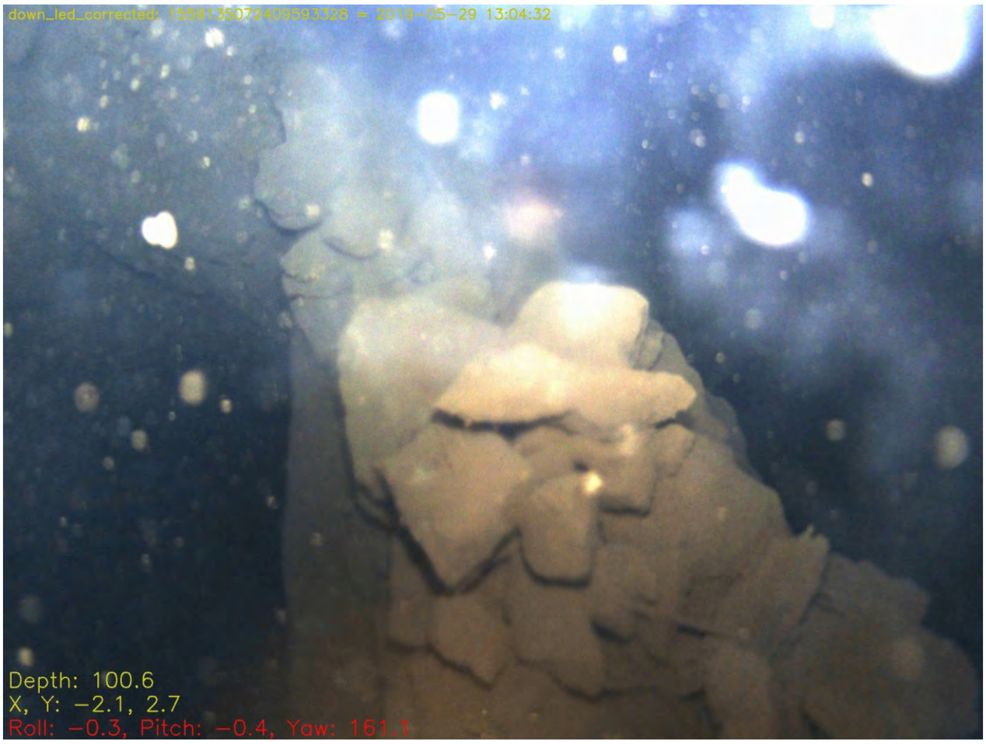


Fig. 7.67: A narrow ridge of rock at 'side pipe working' WS12, between the shaft (left) and workings going down (right). The most likely explanation of this configuration is that the shaft was sunk through a pre-existing cavity.

- Two cross-cuts to the winding shaft, one certain the other probable, have been found, none documented before 2019 and these are covered above under the pumping shaft heading.
- Another level or cross-cut has been identified that leads to the 'main pipe workings' at -58.5m, and this is covered above under the 'main pipe workings' heading and there is a breach in the shaft wall a short distance above, where the shaft clipped the side of an 'alcove' in the 'main pipe working'.
- There are also between one and four other levels leading to currently unknown destinations, presumably at various points in the 'pipe workings' rather than to unknown shafts and levels; two out of the three uncertain examples lead from 'side pipe workings' towards the east where the 'main pipe workings' lie, while another heads west and the certain example above heads northwards.
- In the lower part of the accessible shaft there are several lengths, some long, of small diameter metal pipe, one with a flanged end; all have fallen from above. These may well belong to the same pipe and one possible interpretation is that they were parts of the documented pipe that brought water up to the 1788 Boulton and Watt steam winding engine on the ridge top for use in its boiler.

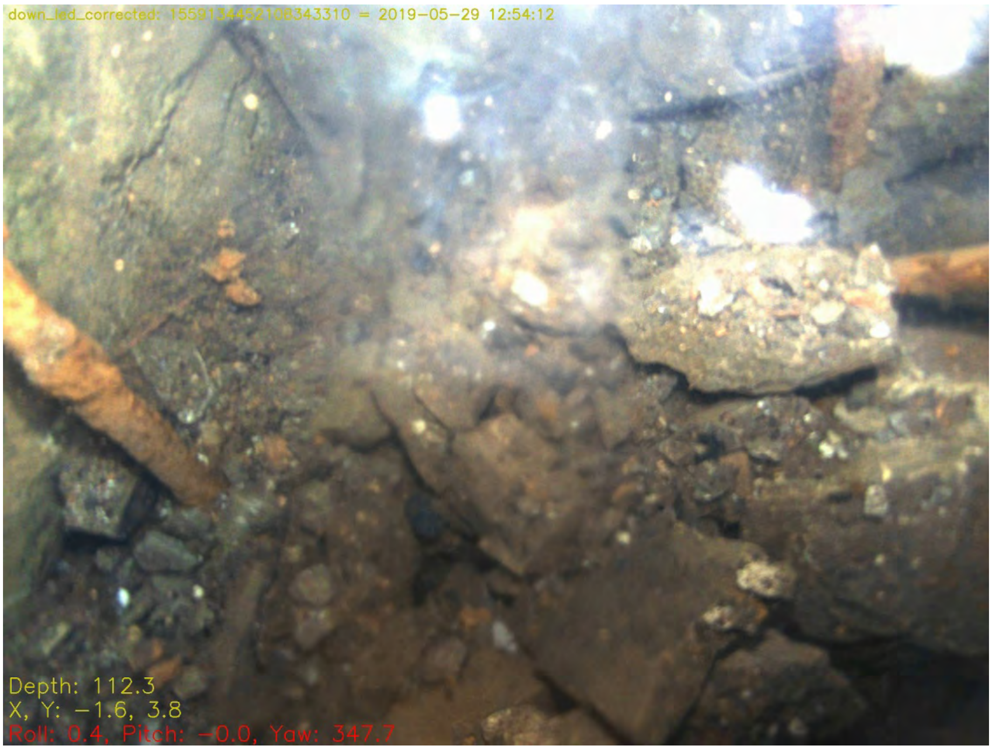


Fig. 7.68: The rubble choke (WS14) at the bottom of the accessible part of the winding shaft contains long lengths of small diameter metal pipes that have fallen down the shaft; originally they may have been part of the long set of 1788 pipes that were set on the shaft side and took water pumped up to the engine house on the ridge top for use in its boiler.

- The character 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 river level. Other artefacts may well be modern, also dropped down the shaft from above.
- It is strongly suspected that the shaft below *c.* -113m has not been fully backfilled, but comprises material that has fallen from above when rubble fills collapsed, from areas immediately adjacent to the shaft in passages leading off, either in the flooded part of the shaft or from above river level, coming to rest here on an original platform or another obstruction at this horizon; the shaft below the blockage may well still be open.

Future Explorations: If future explorations by submersibles were made at Deep Ecton Mine there are various open leads to investigate, which were not adequately explored in 2019. These are listed in Table 7.8, with three prime objectives identified.

Table 7.8: Places to explore in the future where there is potential to gain entry to places not yet explored in Deep Ecton Mine.

A: To access workings at depth

Feature	*Depth*	*Observations*
PS15	-90.3m to -96.5m	Further explorations of this 'side pipe working' are needed at its back and in the area above the entry point to assess their extent and whether they give access to the 'main pipe workings' or indeed whether they are part of this. A level here may link with the long level documented by Meads in 1858 at -99m.
PS16	*c.* -95.5m to -99.0m	Entry of this 'side pipe working' would establish the nature of this passage and may give access to the 'main pipe workings' at depth.
PS18	-115.0m to -117.5m	Entry of this level or 'side pipe working' would establish the nature

		of this passage and may give access to the 'main pipe workings' at depth.
PS19	-121.0m to -123.0m	Entry of this level or 'side pipe working' would establish the nature of this passage and may give access to the 'main pipe workings' at depth and also the winding shaft below the blockage here.
WS11	*c.* -95.0m to -97.5m	Entry of this level or 'side pipe working' at the back of WS11 would establish the nature of this passage and may give access to the 'main pipe working' at depth.
WS12	*c.* -100.5m	Entry of this level or '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 and perhaps the long level documented by Meads in 1858 at -99m.
WS13	-109m to -110.5m	Entry of this level or 'side pipe working' at the back of WS13 would establish the nature of this passage and may give access to the 'main pipe workings' at depth.
PW11	-58.0m to -???	While this spacious 'main pipe working' passage may have a 'horizontal' floor it needs exploring thoroughly to see if there are also ways down to depth.
Also see Features PS8 and PS10 below.		

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

Feature	*Depth*	*Observations*
PS8	*c.* -57.0m to -59.0m	Entry of the level at the back of this 'side pipe working' would establish the nature of this passage and may give access to these important features and also give alternate entry points to the 'main pipe workings' at depth.
PS10	-62.5m to -65.0m	Entry of this passage would establish its nature and may give access to these important features and/or give access to the 'main pipe workings' at depth. Even if it were decided that the entry point is too low, a good view from the shaft to behind the wall would be very useful in establishing the interpretation of this important feature.

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.
PW3	-0.0m to -22.0m	Entry of this complex and important area of passages, currently for the most part left unexplored, would document their character and extent and thus expand our knowledge of the 'main pipe workings' where they have not been enlarged to single large chambers.
PW4/6	*c.* -22.0m to -58.0m	Explorations of the various 'alcoves' and small passages going off the chamber side at various depths and thus give a better picture of the complexity of the 'pipe workings' here.

From this table it can be seen that there are ten leads in Sections A and B that may give access to the extensive lower workings that have not yet been entered and thus greatly expand our knowledge of Deep Ecton Mine; in two cases they may also give access to the historically and archaeologically important canal level at -62m. For the most part these explorations, from all three dive sites, will only be possible once the submersible is used in autonomous mode. In addition, re-entering all three dive sites will address current uncertainties with the orientation of features at depth caused by 'drift' in the navigation measurements.

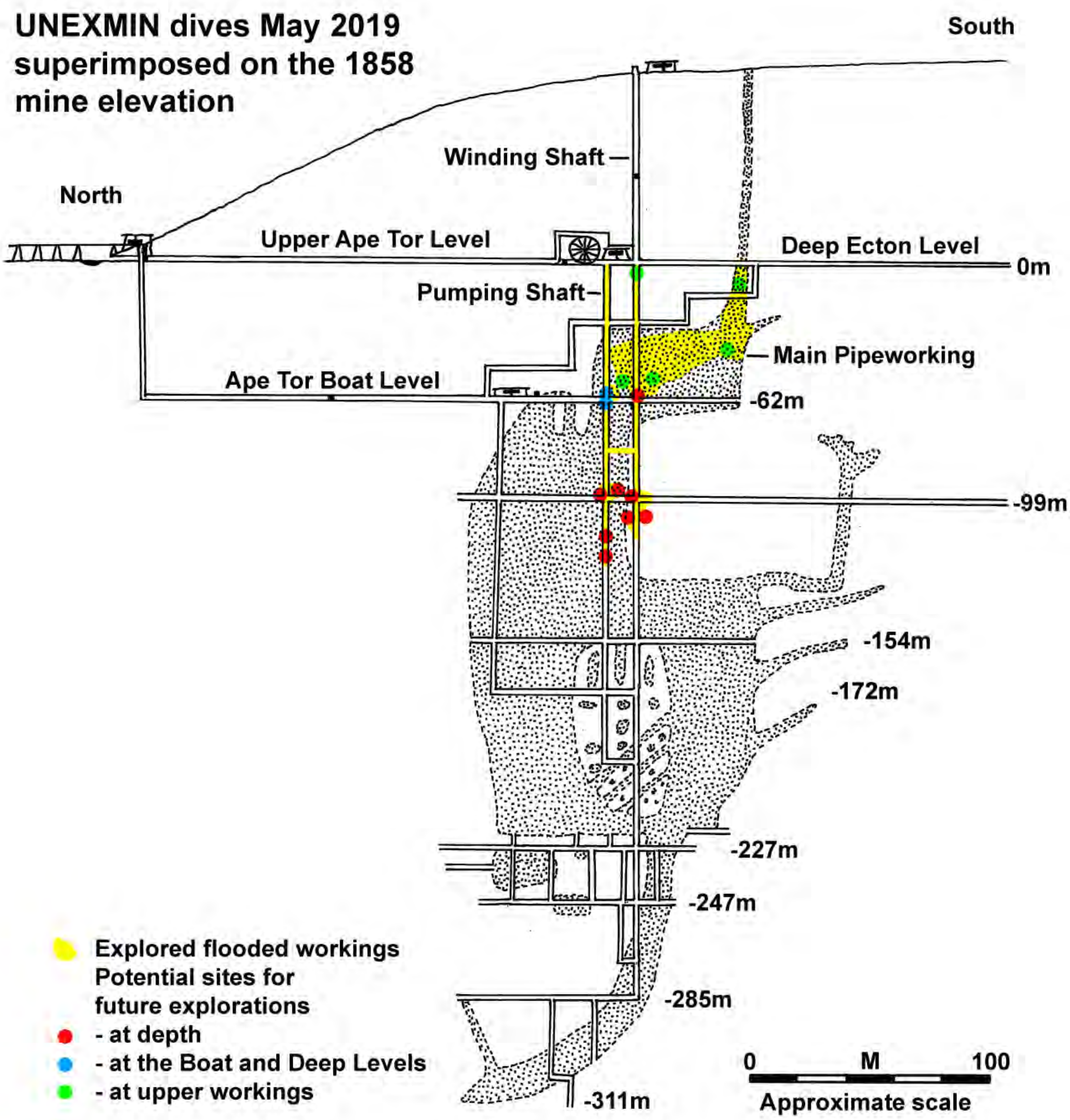


Fig. 7.69: The location of potential leads for future exploration, as listed in Table 7.8, imposed on the Meads 1848 elevation. A distinction is drawn between those that may lead to the 'main pipe workings at depth, those that may give entry to the documented canal at -62m and others where there are further explorations to be made higher in the workings.

7.8 Appendix 1: The 1780s Pumping Shaft - Archaeological Details

This Appendix describes the archaeological features and artefacts in, and viewed from, the pumping shaft observed on the seven dives here (17th, 18th, 20th, 24th, 25th, 26th, 28th May); all are given in the table below.

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 with a blockage at -124m to *c.* -126m (see PS21 below), which prevented explorations below this point. As the shaft is descended its sides are relatively irregular but with the rectangular shape retained with ends that are narrower than the longer sides. Gunpowder shot hole scars were frequently observed, often facing downwards and sometimes found at regularly spaced intervals that reflect its sinking, with the shaft bottom taken down by about 0.5m each the depth was lowered.

There are several cross-cuts and levels, some certainly interpreted others less so, going off the shaft (see PS 3, 5, 7, 9, 12-13, 18-19), as well as large timbers and sites of timbers across the shaft near its ends that retained platforms and/or supported equipment and timber partitions (see PS1-4, 6, 9-11, 14, 17, 20), and 'side pipe workings' that are intersected (see PS8, 12, 15-16, 18-19), two with associated levels or possible levels leading from them (see PS8, 16). Artefacts such as displaced timberwork, tramway rails and small diameter pipes are found in various places (see PS5, 13, 15).

In the table below it should be noted that depth given should be treated as having a +/-0.5m uncertainly because of the varying pitch of the submersible and minor differences in the point at which the -0.0m was set on different dives. The compass directions given here (as opposed to the YAWs recorded by the submersibles, which can vary significantly for a variety of reasons) are correct to about -90m but below this there is significant uncertainly due the problems of 'drift' with the navigation logging. In the lower parts of the shaft the visibility of features on the videos was often poor, particularly for features PS15-PS19. The workings at PS15 and PS16 were particularly hard to understand and aspects of their descriptions given below may be in error.

Table 7.9: The Recorded Archaeological Data in the Pumping Shaft (the given 0 point for depth is that set on the launch target placed in the shaft, which was set *c.* 0.8m below the top of the shaft).

Depth below 0m	*Feature Number*	*Description*
0.0-1.9m	PS1	**Substantial Timber Beam**, with rectangular cross section, to north-west end of shaft, which is *c.* 0.3m high and *c.* 0.2m wide, set horizontally between the two shaft sides, where it is set in notches in the walls, to define a narrow shaft compartment to this end (Fig. 7.30). Directly above this there are **Notches for Another Beam,** one in each shaft side for a second timber of smaller size. To the south-west side of the shaft the notch is a carefully made rectangular slot that is *c.* 0.20m wide and *c.* 0.12m high, cut into the lowermost course of the ashlar wall that defines the shaft side here. To the north-east 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 from the base of the upper one to the top of the still *in-situ* one below. There are further timbers at the other end of the shaft at PS2. There are comparable timbers/platforms and notches for these at the north-west end of the shaft at PS3, PS4, PS10, and PS14 and probably at PS17 and PS20, with other timbers at the south-east end of the shaft at PS2, PS6 and PS11.
1.6-2.8m	PS2	**Notches and Rock-Cut Eyes for Four Timbers**, in both shaft sides to the south-east end of the shaft (Fig. 7.34). There are two pairs of these, one above the other, set *c.* 0.3m horizontally apart, with those nearest the shaft end being for somewhat smaller timbers than the other pair. On the

		north-east side of the shaft at the upper set there are two roughly circular eyes for the timbers rather than notches. Each of the six notches has its base and two sides defined. The two timbers 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 south-west shaft side has an iron fastening pin near its top. The timber beams would have had bases that were *c.* 0.5m vertically apart. Presumably these timbers were for supporting two platforms, one above the other, in the narrow shaft compartment here, with the larger timber defining the edge of this and the narrower ones beneath the platforms; the upper one matches the PS1 horizon at the other end of the shaft. Why there were two platforms so close together is not known; perhaps one replaced the other. There are comparable timbers/platforms and notches for these at the south-east end of the shaft at PS6 and PS11, with other timbers at the north-west end of the shaft at PS1, PS3, PS4, PS10, PS14 and probably at PS17 and PS20.
8.0-8.9m	PS3	**Choked Level** and **Substantial Timber Beam or Possible Platform** at the north-west end of the shaft in the north-east half of this (Fig. 7.26). The extant timber, with 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 north-east and south-west sides of the shaft. To the north-east end of the timber there is an iron pin in the shaft wall that helped keep the timber 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* timber, so that its base aligned roughly with the top of that still present at the shaft end. At its entrance, the level is *c.* 1.0m wide, *c.* 1.6m high above the timber and has a rounded top. The rubble fill within the level is to the roof, with a visible slope which lessens in steepness as it comes down, such that the lowermost stones lie flat and are adjacent to or overlay the outermost timber. The destination of this level, which heads north-westwards, is not known. There are other levels leading off the shaft, including one that cross-cuts to the winding shaft at PS13 and another possibly at PS5, and others, like that at PS3, that go elsewhere at PS8, PS9, PS12 and probably/possibly PS17-19. There are comparable timbers/platforms and notches for these at the north-west end of the shaft at PS1, PS4, PS10, PS14 and probably at PS17 and PS20, with other timbers at the south-east end of the shaft at PS2, PS6 and PS11.
11.2-11.8m	PS4	**Two Substantial Timber Beams**, each *c.* 0.30m high and *c.* 0.20m wide, that form platform supports at the north-west end of the shaft (Fig. 7.32). The timbers, with 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. There is no sign of notches in the timbers' sides that would have held iron pumping pipes. There is a heap of stones, and three displaced small timbers, resting on top 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, PS10, and PS14 and probably at PS17 and PS20, with other timbers at the south-east end of the shaft at PS2, PS6 and PS11.

25.8-27.2m	PS5	**Small Open Cross-Cut**, in the north-west end of the shaft to the south-west side of this (Fig. 7.25). At its entrance this is *c.* 1.4m high and only *c.* 0.8m wide with a flat roof at the shaft side but arched inside. On the shaft side a short distance to the right of the level at its floor level there is a straight iron pin pointing diagonally upwards. The floor is flat and silt covered, with a few stones and three small displaced timbers near the rock lip to the shaft. Inside, the level is as broad as it is high. This cross-cut may well be heading to WS2 in the winding shaft, but PS5 lies to the north-west end of the pumping shaft so there can be no straight-line link. There is another level leading off the shaft that certainly cross-cuts to the winding shaft at PS13, and others at PS3, PS7, PS8, PS9, PS12 and probably/possibly PS17-19 that go elsewhere.
50.1-50.6m	PS6	**Four Timber Notches** at south-east end of shaft for substantial timbers. All are rectangular with base and sides defined. The outer ones were set in the north-east and south-west walls of the shaft about 0.5m from the shaft end, as were the other two but with these against the shaft end. Each would have held timbers that were *c.* 0.3m high and *c.* 0.2m wide. They would presumably have held a platform made of boards. There are comparable timbers/platforms and notches for these at the south-east end of the shaft at PS2 and PS11, with other timbers at the north-west end of the shaft at PS1, PS3, PS4, PS10, PS14 and probably at PS17 and PS20.
52.9-55.0m	PS7	**Small Level**, in the south-west side of the shaft at its south-east end. The upper open part is *c.* 1.3m high and *c.* 1.0m wide, but may have been partially backfilled as, from the shaft side the floor slopes up steeply to –53.6m depth, and it is unclear, because of silts here, whether this is bedrock or waste stone; the latter seems most likely from what can be seen. The cross-cut is irregularly shaped and has a sloping side to the left, which also forms the roof, and an irregular side to the right, perhaps suggesting it was driven for air when the pumping shaft was being sunk rather than for access. At the left cross-cut side 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 side, there is a horizontally-placed iron hook with right-angled bend and outer half rising vertically, with a widened end. There are levels leading off the shaft that cross-cut to the winding shaft at PS13 and possibly PS5, and others at PS3, PS8, PS9, PS12 and probably/possibly PS17-19 that go elsewhere.
53.0-59.3m	PS8	**Tall 'Side Pipe working' (with a Level at its End)** that lies in the north-east side wall of the shaft and covers all of its length (Figs. 7.20, 7.23, 7.65). At the shaft it has an arched top, near-vertical irregular sides and is *c.* 4.0m wide; the left side has a prominent bulge part way down at *c.* -55.5m down. To the south-east end there is a second low hole just above the backfill which is described under PS9. The flat bottom of the main working, at *c.* -59.3m depth and a little over 6m below the working top, has a lip of rock at the shaft side but inside the passage there are piles of rubble on the floor, up to *c.* -58.5m on the right side. At the right side of the open 'pipe working', 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 open 'pipe working', 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, set so that its base rises diagonally. A short distance above this there is an iron pin with looped end set approximately horizontally. The 'pipe working' goes north-east for *c.* 4.0m with a low side passage to the right near the bottom. Near the roof there is a horizontal timber and the inner end of the working drops vertically. A **Level** with an arched roof goes off horizontally at floor level but was not explored; its destination is unknown, but it may be associated with the Ape Tor '*34 Fathom Boat Level*' that was about at -62m depth (also see PS9). There are other levels leading off the shaft, including those that may be associated with the boat level at PS9 and PS 12, others that cross-cut to the winding shaft at PS13 and possibly PS5, and others at PS3. PS7 and probably/possibly PS17-19 that go elsewhere.
58.0-61.5m	PS9	**Level or 'Side Pipe working' with Substantial Platform and Timber Beams at its Base**. In the south-east end of the shaft, to the south-east side of PS8, there is a low hole just above the backfill of this, which appears not to link with the PS8 passage (Fig. 7.21); to the right side of this there is a horizontal iron pin in the wall at *c.* -58.3m. The passage has been largely filled with rubble, from *c.* -58.5m down, is crudely walled across next to the shaft and has a base at *c* -61m depth. The passage heads roughly east and its destination is unknown, but it may be associated with the Ape Tor '*34 Fathom Boat Level*' that was about at -62m depth (also see PS8). There are other levels leading off the shaft, including those that may be associated with the boat level at PS8 and PS 12, others that cross-cut to the winding shaft at PS13 and possibly PS5, and others at PS3, PS7 and probably/possibly PS17-19 that go elsewhere. At *c.* 58.5m depth there is an iron hook in the shaft side, with horizontal base and upper arm at right-angles, placed at about the same horizon as the top of the crude drystone wall at the right side of the opening and at a similar horizon to the pin within this opening. At the base of the opening, below a crude retaining wall in from of the blocked part of the opening, there is a substantial timber support for a platform (Figs. 7.8, 7.28, 7.33). This comprises a bottom timber set away from the shaft end with its base at *c.* -61.50m depth, which is rectangular in cross section and *c.* 0.3m high and *c.* 0.2m wide, with another similar timber behind at the shaft wall, both horizontally placed between the two shaft sides and set into notches in the walls. To the right side, just below the wall-side timber there is a vertical iron pin holding back a stone just above the rock base of the opening here. Above the timber platform there are two shorter timbers set end to end, laid on the outer main timber platform beam. The left one has a bolt with washer through it near its bottom close to the left end. Rising from the top of the left upper timber, near the centre of the passage, going up to close to the top of the retaining wall above, there is a vertically-set iron pin. This has a square cross plate three-quarters of the way to the top and a circular washer near the top. To the north-east side of the timbers there is a gap between the middle upper timber and the wall, but with a third timber here set at a slightly higher level. Above the left end of the central timber there is a smaller timber rising upwards, incorporated into the rubble of the wall, with the end of another timber next to it protruding from the blocking wall with a bolt and square washer at its end. To the south-west side of the passage, set against the wall and again above the two rows of timbers, there is a

		vertically placed set of four short narrow planks laid horizontally one above the other that rise to close to the top of the wall. The second and fourth ones up have bolts and washers protruding. The set of planks has straight edges to left and right sides, with three rotted nails or bolts going through the planks near the right side.
60.1-60.3m	PS10	**Substantial Timber Beam,** which is of square cross-section and *c.* 0.2m high and *c.* 0.2m wide, placed to north-west end of shaft, at about *c.* 0.8m below the flat base of PS8 (Fig. 7.31). It is set horizontally between the two shaft sides, where it is set in notches in the walls, to define a narrow shaft compartment. This has the top end of a timber of 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, PS14 and probably at PS17 and PS20, with other timbers at the south-east end of the shaft at PS2, PS6 and PS11.
62.1-62.3m	PS11	**Platform with Two Substantial Timber Beams** set horizontally to the south-east end of shaft about 1.8m below the base of the timber beam at PS10, with a vertical timber, set between the two beams, rising above that has fallen north-westwards and now rests diagonally on PS10 near its top (Fig. 7.29); this timber is more rotted than the other two and may be a different type of wood. The two horizontal timbers are each *c.* 0.2m high and *c.* 0.2m wide, forming platform supports at the south-east end of the shaft. They are set in notches in the two side walls of the shaft and are placed a gap between them of similar width to the timbers, and a second much wider gap between them and the shaft wall. The timber nearest the shaft end may well have been reused from elsewhere as it has two cut rectangular notches on one side. The displaced vertical timber is set between the two platform timbers, with an iron pin holding it in place to one side. It may perhaps be a vestige of a timber '*lacing*' (vertical timber partition) between the side and main shaft compartments rising to the level of the timber beams of PS9. There are several stones resting along the top of the two horizontal timbers that have presumably fallen from above. At the platform timbers south-western end there is a short length of rope looped around the bottom of one of these rocks. There are comparable timbers/platforms and notches for these at the south-east end of the shaft at PS2 and PS6, with other timbers at the north-west end of the shaft at PS1, PS3, PS4, PS10, PS14 and probably at PS17 and PS20.
62.5-65.0m	PS12	**Walled-off Level** to the north-east side of the shaft, with an uneven rounded cross-section but flat rock base; other than the top *c.* 1.0m this is walled up (Fig. 7.27). The overall height of the level is 2.5m and its width is *c.* 2.0m; the wall, the top of which is at *c.* -63.5m, is 1.5m high. The wall is carefully built of limestone slabs and blocks laid horizontally with about 11-14 courses and the interstices are mortared or sealed with clay (also see PS13). The material in the interstices is red in colour near the base but above it shades to orange. Inside the level, as viewed from the shaft, to the left there is a flat floor, comprising a limonite-type deposit that has flowed over the top of the wall, probably associated with water running here. To the right half, beyond the wall, there is a visible heap of rubble that extends up to close to the roof at the passage side; the passage may go upwards here but this is out of sight. This level could be interpreted as associated with the documented '*34 Fathom Boat Level*' and its southwards continuation as '*Deep Level*', with

		the wall originally built as a dam, but with its base at -65m it is below the stated depth in historical records of -62m. Therefore it is more likely that the walled off passage was either a cistern for a lift of pump pipes, with the passage behind being an old '**Side Pipe working**' that was modified to be 'level-like' at the shaft side for the dam, or that it is a passage that later had the dam built to contain a spring of water that was breached in the 'pipe workings' nearby; from here the water could be removed in a controlled way via the shaft. There are other levels leading off the shaft, including those that may be associated with the boat level at PS8 and PS9, others that cross-cut to the winding shaft at PS13 and possibly PS5, and others at PS3, PS7 and probably/possibly PS17-19 that go elsewhere.
79.7-82.0m	PS13	**Cross-Cut to Winding Shaft**, in the south-west side and north-east end of the shaft, filling much of these except the south-east corner of the side (Figs. 7.24, 7.35). This is sub-rectangular in section, with flat roof and floor, and originally it was a little over *c.* 2.0m high and *c.* 5.0m wide. It has sediments and rubble on the floor, and a large displaced timber, with a *c.* 0.6m high heap of stones to the shaft side on the left that has what may be red-orange clay in the interstices (see PS12). To the left side of the level, near the roof at -80.5m depth, there is an iron 'eye' with an upturned looped end. The level was entered in 2019 and at first runs south-west for about 4m, to a point where there is a blind end orientated WSW. Just before this end the level continues as a branch passage with an arched roof running to the SSE to enter the side of the winding shaft. This is the same feature as Cross-Cut WS8 in the winding shaft. There is one other level leading off the shaft that possibly cross-cuts to the winding shaft at PS5, and others at PS3, PS7, PS8, PS9, PS12 and probably/possibly PS17-19 that go elsewhere.
84.3-84.5m	PS14	**Substantial Timber Beam** to the north-west end of shaft, which is *c.* 0.2m high and *c.* 0.2m wide, and placed horizontally between the two shaft sides to define a narrow shaft compartment (Fig. 7.66). Here it is set in notches in the walls. Part way along the beam top there is a large dished hollow that reduces the beam depth by half. On the shaft wall, at a point roughly half way along the beam base, there is an iron 'eye' with the looped end to the side. There are comparable timbers/platforms and notches for these at the north-west end of the shaft at PS1, PS3, PS4, and PS10, and probably at PS17 and PS20, with other timbers at the south-east end of the shaft at PS2, PS6 and PS11.
90.3-96.5m (and rising above 90.3 inside)	PS15	**'Side Pipe working'** in the north-east side of the shaft. 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, at the horizon entered in the top half, runs north-east for about 5-6m and becomes significantly wider to the north-west side, with only a narrow wall of rock between here and the shaft, giving a total passage width of something like 10m. In this upper area, rubble rises steeply upwards to the south-east side to *c.* -92m (Fig. 7.22), with a displaced timber beam at *c.* -94.0m. The rubble also rises at the back to *c.* -91m and may well also be present to the north-west. To the left side of the entrance, at greater depth, there is a walled pack going into the working 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 **Level** with flat roof going back north-eastwards, with its entrance within a rubble slope here. Right of here, the bottom part of the main working is narrower with a rock slope to the right side and part of the back rising at about 45 degrees to the rubble noted above where the passage is wider. Parts of the back to the left, and the left-side, were not clearly visible. The main PS15 passage extends to an unknown height above the horizon of the opening to the shaft. As parts of the passage to the back and above were not visible on the dive videos it is not known if it goes from here to other workings; the possibility that PS15 was part of the 'main pipe workings' should not be discounted. It may be that the level at about -95.0m to -96.5m is linked with a level running roughly north/south that is shown on Meads 1858 elevation through the mine at 54 fathoms (-99m) depth, which is shown extending significant distances beyond the 'main pipe workings' in both directions.
c. 95.5-99.0m	PS16	**'Side Pipe working',** set back at the north-western end of the shaft, with a relatively flat roof at *c.* -95.5m and sloping sides, with a visible bottom at *c.* -97.0m, but with rubble and a displaced timber on the floor in the passage in front between here and the shaft, resting on a bedrock base at *c.* -99.0m at the shaft edge. The overall height of this passage suggests this working was a 'side pipe working' rather than a part-backfilled level.
108.0- 111.6m	PS17	**Platform with Two Substantial Timber Beams,** set horizontally into the two walls of the shaft near its north-west end. These are each *c.* 0.3m high and *c.* 0.2m wide, with a gap of similar width between them, located at about -111.2m to -111.6m. Above there is what appears to be a wall of ashlar blocks laid horizontally in two courses built below the right side of an opening going off roughly westwards, possibly a '**Level**'. There is rubble on the floor of the platform and the passage going off at *c.* -110m and a displaced length of small diameter metal pipe or rail running along the passage. The top of this opening was not clearly seen on the videos. 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 probably at PS20, with other timbers at the south-east end of the shaft at PS2, PS6 and PS11. There are other levels leading off the shaft, including those that cross-cut to the winding shaft at PS13 and possibly PS5, and others, as at PS17, at PS7, PS8, PS9, PS12 and probably/possibly PS18-19, that go elsewhere.
115.0-117.5m	PS18	**Level or 'Side Pipe working'** with a flat roof to a wide opening and a flat rock floor (Fig. 7.23). This lies in the south-eastern half of the shaft and possibly extends towards the winding shaft. There are other levels leading off the shaft, including those that cross-cut to the winding shaft at PS13 and possibly PS5, and others, as at PS18, at PS7, PS8, PS9, PS12 and probably/possibly PS17 and PS19, that go elsewhere.
121.0-123.0m	PS19	**Level or 'Side Pipe working'** with sloping flat roof and horizontal rock floor with stones on it, *c.* 1.0m above the highest part of the blockage at PS21. This lies in the south-eastern half of the shaft and possibly extends towards the winding shaft (Fig. 7.23). At floor level, in the shaft side to

		the right there is a horizontal iron pin. Above it, at *c.* -122m, there is another iron pin with end upturned at right-angles. There are other levels leading off the shaft, including those that cross-cut to the winding shaft at PS13 and possibly PS5, and others, as at PS19, at PS7, PS8, PS9, PS12 and probably/possibly PS17-18, that go elsewhere.
123.5-123.8m	PS20	**Substantial Timber Beam**, of *c.* 0.3m height and *c.* 0.2m width, set horizontally across the shaft in notches nears its north-west end, at about the same level as the base of PS19. There are comparable timbers/platforms and notches for these at the north-west end of the shaft at PS1, PS3, PS4, PS10, PS14 and probably at PS17, with other timbers at the south-east end of the shaft at PS2, PS6 and PS11.
124.0-*c.* 126m	PS21	**Blockage** in the shaft, comprising a pile of rocks across the 'floor' at one side *c.* 1.0m below the base of PS19; elsewhere there is a central heap and to one side the fill is at a greater depth than elsewhere. The side of this hole is near-vertical and may be walled. What lies beneath this blockage, which has caused its formation here, is not known; it is perhaps over a platform and the shaft may be open below.

7.9 Appendix 2: The 1760s-70s Winding Shaft - Archaeological Details

This Appendix describes the archaeological features and artefacts in and viewed from the winding shaft observed on the one dive here (29th May); all are given in the table below.

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 285m, but now with a blockage at -112.5m to -113.5m that prevented explorations below this point (see WS14 below). As the shaft is descended its sides are somewhat uneven but the rectangular shape with rounded corners is usually retained, with a more oval plan only occasionally observed. Gunpowder shot hole scars often face downwards and sometimes are found at regularly spaced intervals that reflect its' sinking, with the shaft bottom taken down in stages by about 0.5m each the depth was lowered.

There are several cross-cuts and levels going off the shaft (see WS1, 2, 5, 7-8), a timber beam across the shaft and possible sites of removed timber beams (see WS2-4, 10), and 'side pipe workings' that are intersected (see WS6, 11-13), three with associated possible levels leading from them (see WS11-13). Artefacts such as displaced timberwork, tramway rails and small diameter pipes are found in various places (see WS1, 5-6, 8-10, 12-14).

In the table below it should be noted that depth given should be treated as having a +/-0.5m uncertainly because of the varying pitch of the submersible and minor differences in the point at which the -0.0m was set in the winding and pumping shafts (the latter linked at WS8). The compass directions given here (as opposed to the YAWs recorded by the submersibles, which can vary significantly for a variety of reasons) are correct down to about -85m but below this there is significant uncertainly due the problems of 'drift' with the navigation logging. In the lower parts of the shaft the visibility of features on the videos was often poor, particularly for features WS11-WS13.

Table 7.10: The Recorded Archaeological Data in the Winding Shaft (the given 0 point for depth is that set on the launch target placed in the shaft, which was set *c.* 0.9m below the top of the shaft).

Depth below 0m	*Feature Number*	*Description*
5.00-6.70m	WS1	**Small Level** at the north end of the shaft in the half towards its north-east corner (Fig. 7.43). The passage is round topped at the shaft and has a flat floor; it is *c.* 1.8m high and *c.* 1.0m wide. The destination of this level, which heads northwards, is not known; there is no matching entrance in the pumping shaft. Other levels from the pumping shaft are found at WS2, WS5, WS7, WS8 and possibly WS11-13. In the shaft, to the right side of the passage, there is an iron pin with looped end set on a rock ledge. The level floor is of rock with *c.* 1.2m of rubble fill above, with a small-diameter, presumably displaced, metal pipe protruding to the right-hand side. Within the passage there is what appears to be a substantial displaced timber (or possibly a rock) lying at a near-horizontal angle and set a short distance in, together with a displaced sediment-covered timber or rail. There is a garland (cut drainage channel) above the level, cut into both sides and north end of the shaft, with an apex at the north-west shaft corner at *c.* -3.2m down the shaft, with both arms descending diagonally to the top of the level.
26.2-27.2m	WS2	**Small Cross-Cut,** at the north end of the shaft (Fig. 7.41). The passage only occupies the left half of the shaft-end and here it is sub-rectangular in shape and is *c.* 1.0m high and *c.* 0.7m wide. Beyond a corner, about *c.* 1.0m into the passage, it gets larger to the left-hand side. This cross-cut may well be heading to PS5 in the pumping shaft, but PS5 lies to the north-west end of this shaft so there can be no straight-line link. The floor is sediment covered with a few rocks. 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. At the 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. 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 and possibly WS11-13.
c. 29m	WS3	**Two Possible Timber Notches,** both circular in shape, in the western shaft side near the north corner. That to the left is set slightly further down the shaft compared to the other. Both may be fortuitous shaft-sinking scars.
33.0m	WS4	**One or Possibly Two Timber Notches,** 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. 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 here is not known.
51.9-53.9m	WS5	**Opening**, on the east side of the shaft, which is *c.* 2.0m high and *c.* 3.0m wide. 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 two displaced short sections of iron tramway rails of flat-bottomed type and a small wooden beam. While 'level-like', the opening at WS5 may well have started life as an accidental breach in the shaft wall made when it was being sunk, where it broke into an 'alcove' in the 'main pipe workings', which soon afterwards was enlarged and tidied to prevent stones dropping down the shaft.
56.5-57.5m	WS6	**'Side Pipe working',** to west side of shaft, opposite WS7 but with a rock floor at *c.* 1.0m higher up the shaft (Figs. 7.9, 7.37, 7.38, 7.45). At its entrance the side passage is *c.* 1.0m high and *c.* 2.0m wide, with an irregular diamond-shaped cross-section matching the sloping bedding. The passage appears to get larger inside and is certainly higher; here the floor comprises a rubble heap that slopes down northwards. 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, which is irregular in shape, with a narrow cleft behind and a little rubble on the floor. In the entrance to the main passage at *c.* -57.0m down there is a sturdy horizontal timber with rectangular cross-section extending to both passage sides. In the central area it has a small beam resting diagonally on it with the upper end towards the shaft. North of here there are short parts of two small timbers at different angles behind and to the underside of the main timber. To the south side of the passage there are two sturdy beams of moderately-sized cross-section, with a gap between, both fastened to the main beam at right-angles to it. They slope nearly-vertically upwards into the passage and 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 sturdy timbers with rectangular cross-sections fastened to each other to form an L-shaped structure; these have clearly collapsed from elsewhere. It may well be, as suggested by the jumbled nature of the timberwork, that all these timbers have fallen from above and wedged here, coming from within the working; originally they formed a complex framework of uncertain interpretation. Hooked over the diagonal plank at the centre of the passage 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.
57.5-59.0m	WS7	**Cross-Cut to the 'Main Pipe working'.** This is located to the east side of rectangular shaft and is *c.* 1.5m high and *c.* 1.5m wide, with a sub-rectangular profile at its entrance with a slightly arched roof (Fig. 7.37). Just within the entrance near the roof there are straight iron pins, one to either side, each pointing diagonally upwards. What lies within the cross-cut on its floor is described under PW10. 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. There are comparable cross-cuts to the pumping shaft and 'main pipe workings' at WS8 and possibly WS2, with other levels to unknown destinations at WS1 and possibly WS11-13.
79.0-81.4m	WS8	**Cross-Cut to the Pumping Shaft** at the shaft side to the west (Figs. 7.42, 7.46). This level is now *c.* 2.0m high and 3.0m wide and has a curved top; the interior of which is described under PS13. To either side of the level, part way up the sides on the corners between shaft and level, at -80.0m depth, there are iron 'eyes', one per side and each with an upturned looped end. On the floor of the level to its SW side, next to the shaft, there is a long iron bar with short attached curved end-bars at right-angles; this may be a displaced tie rod. The lower part of the level has been backfilled and has been retained by a crude drystone wall, using limestone slabs, blocks and rounded pieces; the original flat rock base of the level is at – 81.4m depth. This is the same feature as Cross-Cut PS13 in the pumping shaft and was entered from here in 2019. 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 and possibly WS11-13.
80.5-85.0m	WS9	**Artefacts** extend down from the west side of the shaft at WS8 to WS10, wedged at a variety of angles. These 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 this at the top of the rubble heap. The lower end of the pipe is set on a small ledge away from WS10, just above the horizon of the rubble heap here. There is a diver's line tangled around the two rails and this extends to the bottom of the open shaft (WS14). At one place it is tangled with a short piece of rectangular cross-sectioned wood and immediately below this tangled with a short length of flat-bottomed type tramway rail. A little lower down it is tangled with another short bent piece of flat-bottomed type tramway rail.
86.0m	WS10	**Substantial Timber Beam,** one end set horizontally into southern end wall of the shaft close to the east side, and at the other end into the south-western corner of the shaft (Fig. 7.44). Above this there is a heap of fallen

		material extending to the end wall of the shaft. Here there are three large displaced timber beams at near-horizontal angles, together with at least seven small timbers in the pile of rubble resting on the fixed beam and the lowermost displaced beam. There may be a shallow, small, **Alcove** above and behind the beam and rubble heap.
95.3-99.5m	WS11	**Large 'Side Pipe working'** on the east side and the north end of the shaft, with an entrance that has a rounded top, near-vertical walls and rounded base to the right and centre, but with a narrow downward continuation to WS12 to the left-hand side (Figs. 7.37, 7.39). Above this, the main open passage at the shaft side is *c.* 3.0m high and approximately 4m wide. Within, to the right-hand side, at the south-east corner of the 'pipe working', there is a sturdy horizontal timber set into the passage walls 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 extends downwards to -98.5m, where there is bedrock that slopes forward to the shaft edge. Within, to the left-hand side, beyond a protruding rock buttress, at a similar level to the right-hand platform, there are two sturdy horizontal timbers at -97.5m, set in the walls of a narrow but deep passage at the end of the shaft. These form another 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 passage's left wall above the platform there is an iron 'eye' with looped end. Below the platform, a vertical wall of waste stone extends down at the back of the platform and there is another horizontal timber at *c.* -98.0m set in front of the wall. In front of this on the right wall, diagonally downwards 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 timber's base and two sides. To the top left there is a second iron pin protruding diagonally upwards from the wall that was placed to help secure the same timber in place. Below this horizon the wall continues downwards to the top right side of WS12 at *c.* -99.5m. Above the top timber platform to the left, behind this at the back of the working, there is a round-topped **Level or 'Side Pipe working',** with rubble on the floor, which goes back in a northerly direction; the end could not be seen. There are comparable probable/possible levels within 'side pipe workings' at WS12 and WS13. To the right the back of the 'pipe working' was barely visible in the gloom but appears to be backfilled with waste stone. There is a timber beam secured by two iron pins supporting part of the roof running into the backfilled workings, with its near end attached to what appears to be a second beam set vertically and running down to the floor on the rock buttress. 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.
c. 99.0-103m+	WS12	**Large 'Side Pipe working'** on the eastern side and northern end of the shaft, located at a lower horizon than WS11 and effectively a continuation of this (Figs. 7.37, 7.40, 7.67). The passage has a large oval shaped entry at the shaft, with arched top, which at the side of the shaft is *c.* 3.0m high and about 5m wide. Inside, to the right-hand side there is as steeply sloping drystone wall of waste stone coming down from WS11, with a slope of rubble dropping to *c.* -

		100.5m to its left into the 'main pipe working' of WS12. On the rubble there is a small circular object that may possibly be a wheel from a tramway tub. Immediately left of the wall there is an opening, part filled with rubble, running away from the shaft, and possibly choked at the end. On the left 'pipe working' wall here, outside this opening, above the right side of the descending 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 curving linear heap of rubble, coming from the opening next to the wall noted above. This rubble heap is set on top of a ridge of rock between the shaft and a large 'side pipe working' going downwards beyond here. 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 ridge, in the 'pipe working' going down, the stone heap to the right again descends as a steeply sloping crudely built 'wall' before resting on rock. Here the 'side pipe working' goes down vertically. The present base 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 narrow 'vein-like' working. To the right there are two or possibly three horizontally-set substantial timbers across the passage; presumably vestiges of a working floor, and the base of the 'pipe working' below could not be seen. At the back of the WS12 'pipe working', at the horizon of the base of the opening to the shaft, there are three openings running away from the shaft, the bases of which in two cases were not seen. To the right, well below wall top level and below the base of the 'wall' the first is an irregular opening, only the top of which was seen at *c.* -102m, which is *c.* 1.5m wide. To the centre, at around wall-top level, the second opening has a flat top and rubble on the floor. This opening is about 1.5m high and *c.* 1.0m wide; it may be a **Level** and there are comparable probable/possible levels within 'side pipe workings' at WS11 and WS13. To the left-hand side of the 'side pipe working' the third opening is an irregular, tall, narrow working that in its upper part, which rises above wall-top level, slopes steeply to the right, while below it is more vertical with the base not visible. At the back of this, near the top, an oval hole goes on and there may be another below.
107.9-110.6m	WS13	**'Side Pipe working'** on the northern end and western side of the shaft, there is a large but shallow opening with irregular top, which at the shaft is *c.* 2.8m high and about 3m wide (Fig. 7.37); inside, the rock floor slopes up at about 45 degrees to the right and the 'pipe working' may well go upwards and out of sight here. There is rubble on the floor of the passage, including much on the right-hand slope where it 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 the shallow 'side pipe working' to the left-hand side a regularly shaped **Probable Level,** with rounded top at -109.0m, goes back away from the shaft in a westerly direction; it is *c.* 1.5m high and *c.* 1.0m wide. There are comparable possible levels within 'side pipe workings' at WS11 and WS12. Adjacent to WS13, from about the horizon of the roof of the level, there is a displaced metal pipe just outside the entrance going downwards nearly vertically to WS14.
112.5-113.5m	WS14	**Blockage** in the shaft, comprising a pile of large rocks and smaller

		material with at least three part-buried pieces of small-diameter metal pipe within the fill (Fig. 7.68). There are also five longer sections of small-diameter metal pipes rising from here at a variety of angles and resting on the shaft sides; one is longer than the others and extends up to WS15, another has a flanged end. What has caused the blockage here is not known; the shaft may be open below.

7.10 Appendix 3: The 'Main Pipe workings' - Archaeological Details

This Appendix describes the archaeological features and artefacts in the 'main pipe working' observed on the two dives here (27th, 28th May); all are given in the table below.

The 'main pipe working' was explored down to *c.* -58.5m, with a possible downward continuation left unexplored (see PW11 below). The workings (Figs. 7.10, 7.11, 7.60, 7.61) assessed comprise a chamber at -0.0m to -11.5m (see PW1), with a second one below starting at about –22m (see PW 4, 6). The second chamber becomes massive in size from –35m and extends northwards, but this cavity has been partially backfilled from the southern end with a heap of waste stone, which here may be 25-30m deep; from the northern end the rubble slopes steeply downwards and there are retaining walls that hold it back (see PW8-9). Between the two chambers and to the side of the upper chamber there is a complex series of smaller but sometimes still spacious passages (see PW3), most of which were left unexplored. The lower chamber also has openings to its sides that were not explored. At about -58m there is a short cross-cut to the winding shaft (see PW10). There are artefacts scattered on floors and ledges (see PW 2, 5-6, 9-10), including displaced timberwork, but also with other items, many of which may be relatively modern in date, reaching their present positions after having been dropped from above the water level.

Exploration in the 'main pipe workings' was carried out not only by the submersible but also simultaneously on two occasions by human divers, to a depth of about 25 metres: their main role was to record the robot on video, but they were also able to report some supplementary information on what they saw on a reconnoitre in places nearby for which the submersible gave no data.

In the table below it should be noted that depth given should be treated as having a +/-0.5m uncertainly because of the varying pitch of the submersible and minor differences in the point at which the -0.0m was set on different dives. The compass directions given here (as opposed to the YAWs recorded by the submersibles, which can vary significantly for a variety of reasons) are uncertain because of the lack of cross-reference data, except at PW10 at the bottom of the explored workings, but there is no reason to think they are significantly in error. In parts of the workings the visibility of features on the videos was sometimes poor, because of the distance from the submersible in larger workings and disturbed sediments in the water, and this was problematic for features PW3-4 and PW6-7.

Table 7.11: The Recorded Archaeological Data in the 'Main Pipe workings' (the given 0 point for depth is that set on the launch target placed in the shaft, which was set *c.* 1.0m below the floor level of the broad horizontal ledge above water that links various passages going off at this horizon).

Depth below 0m	*Feature Number*	*Description*
0.0m to –11.5m	PW1	**Top 'Main Pipe working' Chamber**, comprising a large irregular cavity, the lower part of which is below water; at the water surface it measures *c.* 5m north/south and *c.* 9m east/west. To the west the rubble-covered floor is a relatively shallow broad rock ledge below the water, which slopes down eastwards for up to *c.* 3m in plan to where the chamber end goes vertical. To the east end and both sides of the chamber, the walls go down vertically from the water level. At the east end, the floor it is up to *c.* 11.5m down at the lip of the main way down in PW3. Above this hole there are several windows cut into the rock to the complex area of passages at PW3 (Fig. 7.59). These include three above the main way down at *c.* –1.0m depth, *c.* -1.5m depth and *c.* –2.5-4.5m depth. The upper two are below the opening above water in the chamber wall, with a waterfall, to the north-east corner of the chamber. Below water, the lowermost opening lies to the ENE and is the largest of the three, while above it and to the left the other two are only small windows. This lowermost one is oval and is in the left side of a large prominent alcove, with another oval hole in its right hand side to the south-east, with its top at *c.* –2.5m depth and base at approximately -5.0m. There is a horizontal iron pin in the chamber wall to the east, a short distance above the centre of the alcove. Below the left hole in the alcove there us another opening with an angular top at *c.* -5.5m to the ENE corner of the PW1 chamber and slightly right of

		the hole above; this is the main entry point into PW3. At a short distance into the hole there is a rock bridge with its top at *c.* -7.5m, and another at *c.* –9.5m. Below the upper 'bridge' the passage becomes wider as an alcove to the right, within which a second hole beyond a 'pillar' goes off here to the SE. Further to the left of the openings already described, on the north side of the chamber, there is a large but relatively narrow but high passage, parts of which extend back a short way, butt with possible holes going off the back to the top and bottom; there is a horizontal timber across the passage part way down at *c.* -5.0m. This passage has a top at just below the water level and a bottom somewhere below *c.* –10.5m to the right of the top oriented NNE. To the south-west side of the chamber, at *c.* -4.5m to *c.* -6.0m down, there is a further hole, with arched top and rubble on the floor. This is probably a **Cross-Cut** to the small shaft in a '*striking house*' (ore unloading chamber) a short distance from the 'main pipe working' just above water level. This passage is *c.* 1.5m high and *c.* 1.0m wide and may be that entered by the divers (but who said that it was to the north side of the chamber), who reported that a short distance inside it met a passage going both ways that was not explored. Here there were iron 'hooks' on the walls. Most of these holes were not explored, except one that is described under PW3. Artefacts in the chamber are described under PW2.
6.0m-11.5m	PW2	**Artefacts** on the floor of the First Chamber included a pile of items to the east end at about -9.5 to -10.0m depth. Here there is a metal grill, with three bars in a metal frame, with other badly bent parts above and below, including bars, and a modern rectangular wooden (plywood) board resting on the top; all the metal parts are hard to interpret but again they may all be modern. While one dive was in progress, it was thought that we saw two cast-iron tub wheels next to a metal frame, virtually below the grill, etc., but these cannot be found on the dive videos. On the same side of the chamber, but further east on a large stone slab wedged across the passage with rubble beneath, by the lip of the main hole into PW3 at about -11.5m down, 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) (Fig. 7.64). Below the south side of the chamber there is a metal bar or pipe (possibly a scaffold pole) resting on the wall and two displaced timbers on the floor of a broad ledge at approximately 7.0-7.5m down, with another pipe or bar to the left resting horizontally at the side of an opening going down. On a rubble covered ledge part way down towards the western end of the chamber, at approximately -6.5m down, there is a small metal two-compartment frame; this again may be modern.
0.0m to –22.0m	PW3	**Main Way Down and Unexplored Adjacent Passages** to the east end of the First Chamber, and continuing down to about -22m. It has a complex series of passage entrances going in all directions but predominantly running to the east of the chamber, in a proverbial Swiss cheese, which were mostly not entered (Figs. 7.52, 7.63). These include holes of various sizes, rock bridges and pillars between them. One large void has an iron pin at its left top at *c.* -11.5m, with a timber across it well below. At the same horizon as the pin, there is a thin slab wedged across a passage to the right with artefacts resting on it that are described under PW2; this was the main way down, with the slab to the north of the main

		hole where it was entered from the eastern end of the entrance chamber, while the pin lay to the south. One passage was entered by the divers; it was steeply inclined, going up and south from the main way down. This links with the two windows noted under PW1; at its top, beyond where there are three horizontal timbers spanning the passage that can be seen from above, it breaks the water surface at a known cavity that can be entered via cross-cut above water. The top of this passage entered by the divers lies a short distance east of the Entrance Chamber in its north-eastern corner. The timbers comprise two set horizontally across the passage and a plank resting on them at right angles. The divers also reported that they found a passage they did not enter going upwards where pieces of 'calcite raft' were present and thus they thought this must breach the water surface; it is not clear where this was located. The main way down comprises an irregular passage, which drops near-vertically downwards from -11.5m depth to -22m depth, where it enter the large chamber at PW4 that lies east of the Entrance Chamber (PW1); the descending PW3 passage is rectangular in plan and measures about 7m north/south by 10m east/west.
c. 22.0m-39.5m	PW4	**Large 'Main Pipe working' Chamber**, which descends vertically from the main way down at PW3 and gets larger towards the bottom (Figs. 7.51, 7.53). In its upper parts is roughly oval in plan and very irregular in shape, with a large extension lying roughly to the east that is not as wide as the rest. In its upper parts it measures roughly 10-15m by 20-25m. Below, the chamber becomes larger in size from *c.* -35m down to 39.5m and it is roughly 20m across east/west, with a long extension running roughly northwards, the long axis in this direction measuring roughly 45m. Alcoves or passages of various sizes in the side walls of the PW4 chamber, that were not explored, were seen on the sonar point-cloud images (Fig. 7.53). The floor of the passage 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, a large hollow appears to be blind. In contrast, a second hollow at the north end of the chamber continues down as passage PW6. Comparing what was found with the Meads 1958 mine cross section, this suggests that the backfill in the chamber is considerable and could be *c.* 25-30m deep. Artefacts on its floor are given under PW5.
36.0m-39.5m	PW5	**Artefacts** on the floor of the PW4 chamber include; a bent iron grill; a displaced tramway rail of flat bottomed type; various displaced timbers; a small-diameter iron pipe or scaffold pole; possible silt-covered iron pipes, bars or rails; a small iron ring; and a small square iron frame. Some of these may be modern.
39.5m-58.5m	PW6	**Spacious Sloping 'Main Pipe working' Passage**, the floor of which runs steeply downwards from the southern side of the PW4 chamber, running roughly northwards above the backfill of waste stone down to -58.5m (Fig. 7.51). On the sloping floor there are several timber planks and beams, small diameter metal pipes (possibly scaffold poles), a metal frame in 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). As with the upper part of the PW4 chamber the PW6 walls and roof are irregular. The roof to the south end is at about -35m, continuing roughly

		horizontally from here northwards, dropping by less than 10m by the time the far end of PW6 is reached. The passage has an approximate width of 15m, with a height at the southern end of about 12m, but with this increasing to about 25m at the northern end by PW10. Near the base of the explored working, there is a large hole in the floor that is described under PW8. Cross-Cut PW10 leads off at the bottom of PW6/8 at -58.5m. Two small irregularly-shaped side-passages were seen to the south side of the main passage at between *c.* -51.0m and *c.* -54.0m, a short distance above the top of PW8 (Fig. 7.56). The one to the right is 'level-like' but very soon enters the winding shaft (see WS5); it may well 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 displaced tramway rail of flat-bottomed type and a large timber with round cross-section. The other opening, to the left side, was not entered and appears to be an irregular 'side pipe working'. Much of the floor of Passage PW6, except for parts of the lower slope (see PW7), comprises mine waste including much rubble and this may well be of significant depth (see PW4). Whether the current base, which coincides with Cross-Cut PW10, is the original depth of this working is not known; Meads 1858 drawing may suggest it extends down to about -65 to-70m. 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.
51.5m-*c.* 53.0m	PW7	**Retaining Wall,** built of roughly-coursed limestone slabs and blocks, part-way down Passage PW6, with its *c.*1.0m wide flat top crossing the whole passage at -51.5m (Fig. 7.54). On the upslope 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 may be a protrusion of bedrock with a steeply sloping face that runs down to PW8. The wall was presumably built to prevent rubble running further down and blocking Cross-Cut PW10.
55.0m-58.5m	PW8	**Retaining Walls** at the bottom of Passage PW6, which keep clear a relatively small flat sub-rectangular area (Figs. 7.55, 7.58). They are at the current base of the working outside Cross-Cut PW10, and within a deep hole in the debris floor of the 'main pipe working'. The bottom wall stands to approximately the same height as the level at PW10 on both sides, and is well-built with limestone slabs and blocks to the two sides of the cross-cut entrance, but in the central area between it is less regularly built and of variable height, with a low section towards PW11. The area defined measures about 7m in the direction of PW10 by 4m at right angles to this. Behind and above the lower wall just described there is a near-vertical crude wall of blocks that is about 2-3m high, which holds back the rubble slope. Both, with a total height of about 5m or more, were presumably built to prevent rubble blocking the cross-cut.
58.5m	PW9	**Displaced Timberwork** on the floor of the deep hole in Passage PW6 defined by PW8, immediately in front of the entrance to Cross-Cut PW10 on the flat area here. They comprise a sturdy timber with remaining short fragments of two smaller timbers fastened to this at right-angles. They are probably part of a vertical timber wall or horizontal working platform.
57.3m-58.5m	PW10	**Cross-Cut to the Winding Shaft** running roughly westwards, cut into a steep slope of rock in PW6 (Figs. 7.55, 7.57). This has an entrance with 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, part-way along, 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, just beyond the rubble heap, the passage enters the main winding shaft. The cross-cut was perhaps designed to transport ore from PW4 and PW6 to the winding shaft for haulage towards surface, but as there is no loading chamber here it may never have been used in earnest in this way and its real purpose may well have been for access to 'side pipe workings' beyond the winding shaft at WS7. The winding shaft here and workings beyond to the west are described under the Winding Shaft in Appendix 2
58.0m-???	PW11	**Spacious 'Main Pipe working' Passage** continuing horizontally and perhaps downwards but not explored (Fig. 7.58). This lies to the north of PW8 and PW10, to the east side of PW6. It is about 5m wide and was plotted running roughly northwards for at least 15m.

7.11 Appendix 4: Historical Accounts of the Deep Ecton Workings

This appendix gives all the identified first hand historical accounts that make reference to the character of the flooded workings at Deep Ecton Mine, given in chronological order.

Sir Joseph Banks 1767
In his 1767 journal (Cambridge University Library: Ad Mss 6294.) Banks wrote that:

'*Went to see a Coppermine belonging to the duke of Devonshire probably the richest in the Island, this year it will clear about 11 thousand pounds besides doing the whole years work at a navigable drift which is worked in dead stone without a spark of oar, Every circumstance of this mine & the hill it is in are so wonderful that they merit a very particular description.*'

He goes on to describe the geology, mineralogy and fungi on the mine timbers, noting the miners are '*working upon seems to be a pipe which instead of going horizontal is set upon its head and going directly perpendicular it is of immense size and very irregular figure so that the chambers of the mine are so magnificent as scarcely to be equalled by the finest buildings*' and '*The depth of the mine is 160 fathom from the crown of the hill from which place it has been brought down by shafts began about King Williams time but never very rich till within these ten years*' [In error, as William IV came to the throne in 1830].

'*The workmanship of this mine is as wonderful for its boldness and cleverness as any other part of it particularly a navigable drift much under Level by which ore is convey'd with scarce any trouble from the Farfield to a convenient shaft where it is drawn up with horses to the day.*'

'*Its profits have been an increasing fund solely belonging to the Duke of Devonshire. In less than ten years they have increased from 3 thousand a year to last year's receiving which made ten. This year's account, the director Mr Shore tells me, will be nearer twelve*'.

William Efford 1769
Efford in his published account describes the mine in detail (Efford 1769). After describing Ecton Hill and the history of the mine before taken over in-house by the Fourth and Fifth Dukes, he wrote:

'*To take a view of this stupendous Copper-Mine, you must enter an Adit at the base of the hill by the river Dove* [In error – River Manifold], *and proceed about 400 yards, almost in a direct line. At your entrance, about sixty yards, tis four feet and a half high, walled up on each side with good stone masonry; but afterwards it varies in height, and rises in some places to six feet. When you arrive at the centre, there is a spacious lodgement of timber, for landing and receiving the Ore from below, which is drawn up by a man at a winch, who generally works naked, and is put into four-wheeled wagons that will hold about a ton and a half each. These wagons have cast brass wheels, and are run in grooves thro' the Adit, by boys from 12 to 14 years of age, with great facility.*'

'*When on the lodgement, you behold a large hollow over your head, at least 250 yards high, by the sides of which there is a passage to the summit, but dangerous to attempt, as the timberworks seem in a decayed state.*'

'*Thus far into the mountain, with the aid of light, tis easy enough of access. The late Duke of Devonshire ventured to this platform, took a cursory view of the works, gave the miners ten guineas to drink, but returned immediately, not choosing to descend below. Indeed, such a horrid gloom, men boring of rocks under your feet, such explosions in blasting, and such a dreadful gulph to descend, present a scene of terror, that few people, who are not versed in mining, care to pass through.*'

'*From the platform the descent is about 160 yards, through different lodgements, by ladders, lobs (steps), and cross-pieces of timber let into the rock, to the place of action, where a new scene, ten thousand times more astonishing than that above, presents itself; a place as horrible to view, as imagination can conceive – On the passage down, the constant blasting of the rocks, ten times louder than the loudest thunder, seems to roll and shake the whole body of the mountain. When at the bottom, strangers are obliged to take shelter in a nitch cut in the rocks, to avoid the effects* *of blasting the rocks, as the miners generally give a salute of half a dozen blasts, in quick succession, by way of welcome to those diabolical mansions.*'

'*At the bottom of this amazing work, the monstrous cavern or vacuum above, the glimmering light of candles, and nasty suffocating smell of sulphur and gunpowder, all conspire to increase your surprise, and heighten your apprehensions.*' He then noted the Ecton ore deposit '*runs not in regular veins, or courses, but sinks perpendicular down, widening and swelling out at the bottom, in the form of a bell.*'

'*suppose yourself now upwards of 200 fathoms deep in the bowels of a large mountain, in a great hollow of immense diameter, then suppose around you an impenetrable wall of lime-stone rock, interspersed with small veins of Copper-ore, yellow, black and some brown, intermixt with Spar, Marcasite, Mundic, and other sulphureous compositions, of all colours, and at the same time figure to yourself the sooty complexions of the miners, their labour and miserable way of living in those subterraneous regions, and you will then be apt to fancy yourself in another world. Yet these inhabitants, being trained up in darkness and slavery, are not perhaps less happy, or less contented, than those who possess the most flattering enjoyments of light and liberty.*'

'*There is no timber made use of, except for lodgements, or platforms, ladders, or steps set into the rocks, for ascending and descending into the mine; neither is there any quantity of water to retard the works, notwithstanding it is at least 150 yards below the bed of the river: four horses, six hours each at a common Wem or Engine, are sufficient to keep the mine clear.*'

'*The timber-works about the Mine are very ill contrived and worse executed. In descending from the principle lodgement you pass thirty ladders, some half broken, others not half staved; in some places by half cut notches, or steps in the rock; in others you must almost slide on your breech, and often in imminent danger of tumbling topsy-turvy into the Mine; nor are the shores which support the lodgement below in better condition.*'

'*Notwithstanding the great depth of this Mine, (which is the deepest in Britain) a little expense, judiciously applied, would render the approaches to the lowermost part, easy to the miners; but however troublesome the descent may be, above sixty stout, well-made fellows, work here night and day, six hours at a time, for one shilling each man; and altho' the major part work naked, (a pair of coarse canvas drawers excepted) they are as merry and jovial a set of mortals, as ever inhabited such infernal abodes – So much for the internal parts; we now come to methods of dressing, cleaning and fitting the Ore for sale.*'

'*The ore as before observed, when conveyed out by the boys, is thrown together in a heap, and two men with large hammers, or sledges, are employed to break it into small pieces. This done, it is carried in small hand barrows, by little boys, to a place under a shed, erected on purpose, to be picked and sorted, and it is then laid out by in different parcels, best, second, and worst; this operation is performed by little girls from eight to twelve years of age, who are surprisingly quick at the work, separating the various kinds with astonishing dexterity. From this place, the Ore is carried to another large and convenient shed, where about fifty women sit back to back, on benches, to buck or beat it with flat hammers, still keeping every particular sort separate from each other. The Ore, now reduced to a small sand, is again removed to the Buddles, for washing, where an old experienced Cornish man has the superintendency of it, as a great deal of the finest ore would be lost, if this operation is not properly perform'd. Here then it is curiously washed and cleansed, and afterwards exposed for sale in the open air, in various heaps; ticketed according to the different qualities and quantities. When all is ready, notice is given to the Smelting-houses, whose proprietors, or managers attend, and each bids what price he thinks proper, (generally from £7 to £16 per ton) the highest bidder being the buyer: it is then fetched away at the buyer's expence. The refuse part of the Ore, which is not fit for sale, is beat down small, and carried to the smelting-house on the premises, erected by his Grace, and there run into a Regulus, in large pigs or bars, and is then sold from £70 to £90 per ton, Upon the whole, nothing is lost.*'

'*The great advantage to the country round, arises from the number of hands employed, and the circulation of between three and four thousand pounds in cash annually, in a place poor and thinly inhabited before this Mine was discovered, but now quite improved, and more than 300* *men, women, and children employed winter and summer, who have proper overseers for every department, where everything goes on with utmost harmony and cheerfulness.'*

'The Miners, as before hinted, work at two pence per hour, six hours at a time: women by task, earn from four-pence to eight-pence a day, and are paid by measure according to the quantity of Ore they can buck; girls and boys from two-pence to four-pence a day, some more: thus there is a constant employment for both sexes, and all ages, from five to sixty years old. The Carpenter's shop, the Smiths forge; the Cooperage, with the neat dwelling houses of the superintendents, little kitchen gardens and out-houses annexed, are all singular in their kind, and happily adapted to make life agreeable in that solitary place, which lies between two monstrous hills, separated at least two miles from any other inhabitants.'

'This Copper Mine, in the state above described, clears annually between 8 and £10,000 and if worked with that spirit which usually accompanies large returns, double that sum might be made of it; but his Grace, it seems, is content that it employs all the labouring poor who present themselves for work, from the neighbouring parishes.'

'on the opposite side of Ecton Hill is a Lead Mine, which is likely to turn out to great advantage; the veins of Lead approaching very near to the Copper; and they are driving in an Adit; parallel to the other.'

John Harper *c.* 1769-70

The unpublished account by Harper was written sometime in the period 1767-70, probably in around 1769-70 as it is near the back of a notebook that spans these dates (Derbyshire Record Office: 2375M/63/55). It is a handwritten draft with additions made (given here in parenthesis); unreadable words and other comments by me are put in square brackets. An accompanying sketch plan confirms it is Deep Ecton Mine that is being described, but that Harper wrongly orientated himself and thus states directions incorrectly; corrected below in square brackets.

'Went in ye mouth of the sough (which is ab^{t} 20 feet above Surface of ye Manifold). N^{o} ab^{t} 60 yards – boarded about 160 yards water carr: straight line southwards [north-east].
Then ab^{t} 70 yards further on (a) boarded passage winding first to ye east [north-west] *– then south* [north-east] *again.'*

'Then come to a large (circular) opening (or vault or chamber) ab^{t} 30y wide, ye sides (and roof) of it all stone and spar with holes or places in it from whence ore taken away pretty (much) alike, from all parts of ye circular vault.
The floor of this opening or chamber is rock at ye southern [north-east] *end (there is) an opening (or trap door) down (into) another opening, vault (or chamber ab^{t} 80 yards below ye first).'*

'(Ye descent) down to this and other chambers (is by ladders at side it was near rocks and there) are a kind of landing places called by ye miners bundings and this (2nd) in a circular form below ye 1st.
[?.....] *ye roof of this second chamber appears to be near 30 yards high over head.*
In ye walls or sides of this vault in some parts more (in some fewer) holes or places dug into ye rock than others. Most holes appear to be on ye south of sth east side.'

In the margin is written: *'(some holes a yard or two high and sev^{l} yards obliquely as ye ore is dug in one part ye miners go with* [?.....] *part of ye circular vault. These holes are some of them near as big as a room of ten or 12 feet some smaller like cupboards.)'*

'In all (there are) 7 of these vaults or chambers including ye first and an eighth now sinking ab^{t} 20 yds deep and (which had a good) deal of water in (being Sunday when seen and pumps not working, for ye miners can work only as ye water pumped out (from some of these vaults) from time to time – but some of ye vaults are quite dry – in others springs break in.'

'The 3rd like ye second, but some (of ye seven vaults) are cut more oval and one or two nearly triangular. This 3rd one of ye largest (note some of these vaults are 30, 20 – and (ye lower ones) not above 15 yards high). Some appear to be a^{bt} 30 yards wide across – and some much larger near 60 – the 3rd appears to be one of the largest).'

'*To all appearance ye vaults ly^e^ partly nearly one under another – and no great of appearance of varying – or hading to any point of ye compass any way equals to one or two hundred feet but of keeping a kind of circular farm.*'

Late [Fourth] *Duke went down to part of ye 4th chamber.*' [The Fourth Duke died in 1764, confirming mining was taking place below the Ape Tor 34 fathom level by that date].

Harper then noted the Ape Tor 34 fathom level, stating: '*From ye 3rd floor a sough or water carr for boats, which goes eastwards* [north-west] *to ye place where ye Engine (horse engine) is worked - which is abt 50 fathoms high (abt 300ft) it is cutted abt one hundred yards - from ye sough up to ye engine.*'

He also noted '*Water in ye carriages abt 2:3 and in some places where boats pass near 4 feet –* [?.....] *pumps and winlasses with 2 handles – which draw up water into troughs*'

The depth of this level is overstated in his final draft – in the first draft he states about 270ft (82m), which is somewhat nearer to the mark, the engine being above river level at about 240ft (73m), but this was crossed out and increased.

Robert Shore 1770
At the end of 1770 Robert Shore, the mine agent for Deep Ecton Mine and thus a reliable source of information, wrote a brief unpublished report on the state of the Ecton Copper Mine (Chatsworth Manuscripts - Devonshire Collections – Ecton Vouchers Box 1760-74).

'*The Copper Vein at Ecton goes down pritty near in a Perpendicular direction at this time, is now sunk from the Sough or Levil which is taken from the River Manifold, upwards of 70 fatms and all the conveniancys completed to the depth and now ready for sinking afreash. The work upon the sd Bothams is not so large a Compass as they have been nor able to raise such large quantitys as they have hear to fore, but the quality much better.*'

Eric Geisler 1772
In 1772 Geisler wrote the following account of Ecton Mine (Althin 1971):

'*Belonging to the Duke of Devonshire, was with several other works under the inspection of Mr. Shore'.......'At the foot of the mountain, at a depth of 60-70 fathoms, an adit has been made, where water has been led in, and transport into the open is arranged in long and narrow boats, but also in carts with 4 small iron wheels with grooves, guided between sleepers made of 5 inch squared logs. After going with a gosse* [boy] *on the water into the adit, which was done quickly and comfortably for 150 fathoms, one would then walk into a wide room, created by ore being removed from there as well as higher up and still* [in work] *80 fathoms under the adit. Where stocken is now mined 15 fathoms in one diameter, east to west, and 10 fathoms in the other, all equally good, only mixed more or less with quartz and lime.......For easier raising, a perpendicular shaft has been driven down from the highest point of the mountain. Through this shaft a steam engine will convey the ore from the depths up to the adit.*

James Watt (Junior) 1790
This account is included in a letter to his father written in June 1790 describing a tour of the region from Manchester where he was an apprentice (Boulton & Watt Collection, Birmingham: MS3219/4/12/42.). He noted of Ecton Mine that: '*This is the most singular vein I ever saw, the bending and positions of the strata is curious in the extreme, and I must confess appear to me not explicable by any of our Geological theories. The vein frequently bulges out into large bellies of 50 to 100 fathoms breadth then again becomes contracted to 2 or 3 feet and the waving of the strata seems to me to be somewhat in the manner I have represented here* [with a small sketch showing three cavities surrounded by beds at different angles]. *The lines coming from the sides show imperfectly the manner in which the strata appear on both sides of the Vein, but I was so struck with the uncommon appearance of which I could comprehend nothing, that I made no accurate observations. They are now working at the depth of 150 fathoms and are got into one of the constrictions of the Vein, which having lasted longer than they expected, they have turned off half their men, not being able to find employment for them; but there appears little doubt to me that the mine will recover, as it frequently has done already. The engine was extremely dirty and the Engineman not found, but I spoke to Mr Wild one of the directors, to tell him*

what I had said respecting his negligence. Mr Flint does not attend the mine and it is reported that he has fallen out with Mr Heaton the Duke's Steward.'

John Mawe 1802

Mawe gave a brief published account of Ecton (Mawe 1802). He described the copper ores and noted galena, blende and other minerals, as well as the character of the mineralisation. He mentioned that: '*This mine was probably worked at a very early period; it is one of the deepest in Europe, and it is now worked to the depth of 220 fathoms or 1320 feet*' and that '*the profits were immense*'. '*The mine was extremely productive, and at one time employed more than 1000 people; the rich ore was in amazing large heaps, being in some places 70 yards broad, in others not above ten.*'

John Farey 1811

In the first volume of his review of Derbyshire, which commonly included mines in adjacent counties (Farey 1811), Farey made several short references to the mine:

- '*Ecton Pipe…. Copper and Lead, Slickensides, Shaft 440 yards deep!! A railway tunnel into the hill, and water Sough through it.*' (p. 258).
- *The body of Copper Ore seems now nearly or quite exhausted in Ecton Mine, and numerous scrins and small Veins, or strings, branching therefrom, which miners neglected to follow when the Copper Ore was in such plenty, still produce considerable quantities of Lead Ore, which is smelted at Ecton, and about Ore enough to produce a Ton of Copper weekly at Whiston; where about 1781, 12 Tons of refined copper were produced weekly from this Mine.*' (pp. 353-54).

Anon 1839

An anonymous description of Ecton Hill (Anon 1839), states:

'*At the base of this hill…. is the entrance to the deepest mine in Great Britain*' It reviews the 17th and 18th century history, noting '*since the mine has ceased to yield the enormous amount of mineral riches for which in past days it was so famous, public curiosity has died away*'. The author observed that '*the operations of the few remaining adventurers being conducted on a limited scale*' and '*the descent is a task of difficulty, not unattended with danger*' because of state of the ladders.

'*In the autumn of the present year (1838) we (the writer and a friend) determined upon exploring it*' They wore '*coarse miners' frocks*' and entered the adit '*accompanied by two or three of the most experienced miners. The passage for some distance is floored with boards. Placed across sleepers, beneath which flows a current of water, a few inches deep. Proceeding along this level for about three hundred yards, we arrived at the point of descent, which is accomplished by the ladders before mentioned. Their sides are formed of wood, and the staves chiefly of iron, some of which are loose, and others so worn away by the repeated treading of the miners, as to convey a fearful sense of insecurity to those who were unaccustomed daily to make trial of their strength. We now found out the utility of the miners' substitute for a candlestick, (a lump of moist adhesive clay into which a candle is thrust;) this could be placed securely against the side of the shaft, while the hand that held it was at liberty firmly to grasp the iron hooks and stays, which in the most hazardous situations have been driven into the rocks to assist descent. After descending what appeared to us an almost interminable number of ladders, and after groping our way through several cavernous passages, hewn out of solid rock, and scarcely high enough in some places, to admit of our standing erect, we landed within forty yards of the bottom of the mine, in a gloomy excavation of great extent, and very considerable height. In the dense and overwhelming obscurity which reigned around us, scarcely broken by the feeble glimmer of our lights, we were unable to for any probable estimate of its proportions; if we state its altitude to be in some parts not less than fifty or sixty feet, it is certainly not overrated.*' What the author meant by the bottom of the mine is not made clear, but presumably he meant the bottom workings that were actively being mined rather that the lowest workings ever made.

He went on, talking of the depth and remoteness of the lower workings that '*the situation itself is one of appalling loneliness, and even in the company of the miners, who from the force of habit, beheld the scene with careless indifference, it is hardly possible to shake off the apprehensions which it is so well calculated to inspire.*' '*Just before our arrival the miners had effected a blast. The shock of which loosened some pieces of rock, suspended and almost detached from the rock. Some of these now fell within a few feet of the spot in which we were resting.*'

'*The rich bed of ore, in excavating which this vast chasm has been formed, is now exhausted; and thin leafy veins are all that remain for the miners to work upon; as one of them remarked to us (rather expressively) 'the trunk and the branches were exhausted, - they were then at work on the twigs'…….'Our guides next led us through a narrow passage on one side of the cavern, to the mouth of a shaft leading to the bottom of the mine; but being told that the passage was insecure, we did not risk a further descent. Proceeding a short distance, we arrived at the great perpendicular shaft; on looking upwards the sky at the summit of the mountain was distinctly visible.*'

They then ascended until '*On reaching the upper level, we heard the sound of running water, and turning off to one side were suddenly conducted to an immense water-wheel, of extraordinary power; its diameter being thirty-two feet, and its width across the staves about six. By a singular exercise of ingenuity, this wheel is put in motion by the water collected in the upper part of the mine, while its power is employed in drawing water off that which would otherwise accumulate in the lower. Nothing we had hitherto beheld surpassed, for startling effect, the scene now before us. The revolution of this enormous wheel, and the action of its appendant machinery over a dark and apparently unfathomable abyss, added to the deafening roar of waters, increasing in a ten-fold degree by the echo of the cavern, might serve for the reality of some one of those scenes deemed to exist only in the imagination of the poet……Near the wheel there is a capstan, with rope equal in strength to a ship's cable, used for raising heavy weights. To preserve the rope from the effects of damp, fires are sometimes kept burning, often for months together*.' They emerged out of the level after being one hour and half underground, a time suggesting their descent down the 'pipe workings' had not reached anything like the bottom. The author went on to say that '*the depth of Ecton Mine is stated to be 1,650 feet*', saying it was still the deepest mine in Britain, with one at Monkwearmouth Colliery in Sunderland being 1,600 ft. He also noted that the miners had a lease from the Sixth Duke of Devonshire and pay him a tribute of 1/10 of the ore produced. Two companies, 'The Burgoyne' and 'The North Staffordshire', were also at work. This last company is stated in error for they were working at the Bincliffe Mines south of Wetton rather than at Ecton. That the waterwheel was described as elsewhere from the ladderway is interesting for it shows that there was no serviceable ladderway in the '*Great Shaft*' next to the waterwheel, and that descent into the 'pipe workings' was via the old working from river level downwards.

Robert Garner 1844

This description of the Ecton Mine by Garner was presumably written at least a year or two before it was published (Garner 1844). It states:

'*Ecton copper mine is remarkable for its great depth – upwards of 1500 feet, as well as for the extent to which its excavations have been made*'. It notes the mineralised pipe deposit and then goes on '*The drainage of this mine is effected by a water-wheel, upwards of thirty feet in diameter and six broad, worked by a stream, which is conveyed into the mine*' from the north. Garner also mentions '*An ancient steam engine, having a copper boiler, is a conspicuous object on the high hill at the mouth of the shaft*' and that '*there are several adits or levels from the side and foot of the hill in the direction of the vein. At the upper level the ore is landed, being drawn up in iron tubs, one ascending as the other descends. The shaft is not bricked, but has the rugged and bare rock at its sides; and, consequently, is not often used for the miners to go down by. At present ropes of iron wire are used in this shaft: though the buckets move at a rapid rate they are four or five minutes in reaching the bottom. At the end of the second adit, which opens into the valley, a little above the bed of the river, and about a hundred yards below the shaft mouth, is the water wheel working the pumps; and here, too, may be seen the drawing shaft, through a lateral opening or chasm. There is also a great capstan here for lifting heavy weights; and by another level, one of the chambers formed by the extraction of the ore, may be entered from this spot. The water from the pumps makes its way from the mine through the adit above described, under the boards of the flooring. The summit of the shaft by which the workman descend may also be seen near the pump; this is done by ladders. But few will make this descent, and we confess we did not wish the fatigue of going further*.'

Garner then goes on to quote Efford's 1769 account of the mine below river level and to note 17th century gunpowder working. '*Of late little has been done: but recently a company has been formed and the mine having been pumped of its water, good specimens of ore have again been raised from its bottom. Lead ore is also found, and much suphret of zinc, combined frequently with copper, a union, however, considered to be no desideratum, as the two cannot be easily separated by washing.*'

Anon 1850

An anonymous author speculated that further riches were to be found in Deep Ecton Mine (Mining Journal, Vol. 20, No. 786, 14th Sept. 1850, p. 433). *'The mine is entered by an adit level, which for some fathoms is arched where it passes through some loose ground but once it enters the limestone no further support is required. This adit is about 150 fathoms in length to the drainage shaft, at which point there is working a waterwheel at 50 fathoms from the surface, which keeps the mine drained. This wheel was erected about 24 years ago, its diameter is 33 feet and breast 6 feet. The excavation at this spot is very large, as there is a capstan and room for stalling for horses, which were formally employed here. In the 30 fathom level, which is reached by convenient ladders, the mine was very productive and the excavations are of immense scale. From this to the 50 fathom level the workings are larger; but still lower from this to the 80 fathoms level the workings are truly extraordinary. A light being placed in one of the upper openings (the 30 fathom level), and one lower down at the 50, produced a striking effect. Here there is probably a clear opening of upwards of 350 feet in height, by an average width of 150 feet, some parts being wider, the whole of which has been worked out, readily accounting for the immense heaps of refuse outside. The mine is still deeper, but becoming at length unproductive, is now idle – the only work in hand being that of keeping the mines drained by the water wheel.*'

John Dickinson Brunton 1858

A description of the old workings below river level at Deep Ecton was given as they were flooding (Mining Journal Vol. 28, 13 March 1858 p. 167): '*Yesterday I went through the old workings down to the 30 fathom level below adit. From the small extent of the workings on the pipe vein at this part it is evident that the great ore deposit of Ecton was not above the 30. At about this depth an intersection took place of a cross load with the pipe greatly increasing the productiveness; but it was not until the 50, at which another cross load came in, that the immense gulf of ore commenced which has never yet been equalled. From the 50 down to the 80 is now a cavern of 300 yds long, 100 yds wide at bottom and 20 yds wide at top, showing how the pipe increased as it went down: this enormous cavity was once a mass of lead and copper ore. Between 80 and 90 the pipe narrowed but opened out again and thence down to 200 continued to yield ore in immense quantities. The copper ore averaged from 15 to 20 per cent of copper. Ecton yielded ore to the value of 2,500,000 sterling.*'

George Attwood 1883

Writing in the Mining Journal in November 1883 (*Lead Mining in Derbyshire*. Mining Journal 53, 24 Nov. 1883, p. 1335.), Attwood wrote of the old Ecton Mine:

'*We were the last but who worked the old mine; and I was at the last bottom workings, which as I left it was at 457 yards*' and '*we took the lease of Ecton for working lead and blende*'. '*The reason we gave up Ecton Mine was the duke's agents* [John Taylor and Co] *would not allow us to let the water into the bottoms. The wheel underground had not the power to fork the water, our intention was to have let the water up to Ape Torr level, the second cavity. That would have lightened the weight, and the wheel would have then managed the water. We should have taken down the dam we erected at the Dutchman, and driven east on the vein, the only chance of any working to profit in the duke's royalty*'. This account refers to work in Deep Ecton Mine in the 1850s at latest.

William Ninnes 1883

Also writing in 1883 (*Ecton Copper Mines*. Mining Journal Vol. 53, 15 Dec. 1883, pp. 1362), Ninnes wrote of '*the Great Opening, where if a good stone thrower was to stand in its centre it would be impossible for him to hit the sides or roof of this artificial cavern with a stone, the distance being too great*'.

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For the archaeological assessment presented here, Norbert Zajzon and Carlos Almeida are thanked for seeking and taking my advice on where to explore while the dives were in progress. Data, in the form of dive videos compiled from the still images taken by the five submersible cameras, and sonar survey plans and elevations, were provided by Hilco van Moerkerk, James Tweedie, Steve Henley and Mike Mcloughlin; without these the archaeological assessment could not have been completed. Richard Shaw gave advice on how archaeological features observed during the dives could be interpreted, while he, together with Norbert Zajzon, Carlos Almeida, Steve Henley and Mike Mcloughlin, passed on information on what was observed during the dives that I had to miss because of family commitments. The two divers in the Hungarian film crew also passed on observations on what they observed during their dives. Prior to the 2019 dives Jim Plant gave important information on the depths at which there were blockages in the two main shafts, which he plumbed with a weighted line several decades ago.

Figs 7.17, 7.18, 7.49, and 7.50 were taken by the late Paul Deakin. Fig. 7.20 was compiled by Steve Henley.

Steve Henley also kindly proof read a draft text of this report and did a large amount of work trying to understand the complex features of PS15 and PS16, which on superficial watching were downright misleading. He also was the first to realise that a side passage in PW6 breached the winding shaft at WS5. Richard Shaw also did additional proof reading.

Richard Shaw and myself as assistant took the lead in installing the infrastructure needed for the dives, with help from Peter Kennett, Rob Mace, Peter Neville and Ian Smith. Mark Hudson is thanked for doing preliminary relatively shallow dives in 2018 in the two shafts and 'main pipe workings', using his own ROV, which highlighted the problems and opportunities when exploring these flooded features.

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8 ANNEX 2: Geological Observations and Notes from Ecton Pilot Mission

Interpretations and notes by geologists from different participants in the UNEXMIN consortium are presented in this Annex. These are compiled from observations and interpretations by S, Henley (RCI), Luis Lopes (LPRC), Alberto Sanchez (EFG), Gorazd Žibret (GeoZS), Emil Pučko (GeoZS), and other geologists in the UNEXMIN consortium.

Annex 3 presents a synthesis by Richard Shaw of EMET, of the extent to which this update geological knowledge of the mine.

8.1 Notes and Observations on data from Ecton Mine

These are notes on observations made from the videos and still images recorded by the robots in dives from all three launch locations. It is not the intention here to offer a detailed interpretation of the geology of the mine, which will be included in Annex 3.

8.1.1 Lithology and stratigraphy

The Ecton Mine is hosted by a thick Lower Carboniferous sedimentary sequence, consisting of deep water facies thick-bedded limestones and thin-bedded limestone/shale sequences, described in detail by Ford (2000). There are some thin clay wayboards consisting of decomposed fine-grained volcanic ash. The UNEXMIN dives showed that down to depths of around 60 metres the thick bedded limestones are predominant, while deeper parts of the two shafts explored were sunk through generally thinner-bedded limestones and shales, interspersed with a few thicker limestone beds.

Figure 8.1.1: Depth 36.5m (front camera). Near-vertical stratification as seen in the south wall of the shaft. Small cross veins of calcite with millimetre to centimetre in size are seen. These veins are crossing the stratifications with an acute angle, the most important on the right side of the picture.

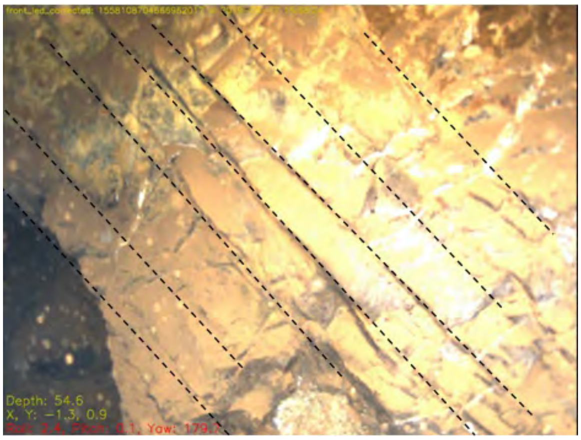


Figure 8.1.2: Depth 54.6m (front camera). Stratification seen in mine wall. Apparent dip of 50º to W. This is seen in the south wall of the shaft.

Figure 8.1.3: Depth 55.0m (right camera): Stratification as seen in the wall of the shaft. This structure dips towards W

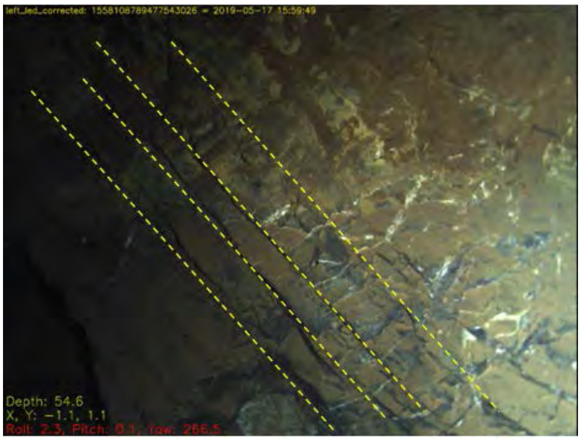


Figure 8.1.4: Depth 54.6m (left camera). Thick bedded limestone with apparent dip to W about 50º

From water level down to about 50 metres depth, the dominant lithology is thick bedded limestone, with vertical dip, representing the eastern side of the asymmetric large-scale Ecton anticline. From 50 metres onwards, the dip levels out (Figures 8.1.1 to 8.1.4), and the lithology is more varied, with interbedded thin limestones and shales between thicker limestone layers.

8.1.2 Structure - folding and faulting

The sedimentary rocks of the Ecton area responded to stresses during the late Carboniferous by intense folding as well as some faulting. The fold styles developed by the different lithologies are very different, largely as a result of the differing mechanical properties of thick bedded limestone, thin bedded limestone/shale sequences or sequence of alternating thick and thin beds. Some examples of the different styles are presented in Figures 8.1.5 to 8.1.15. Thicker limestone beds tend to form large amplitude anticlines and synclines. Thinner beds form smaller scale folds, and where there are thinly bedded limestones and shale sequences between thicker beds, these tend to form small scale crumples and shear zones accommodating the larger scale folds that are formed by the ticker beds. There is some evidence of multiple fold phases, with re-folding as well as semi-brittle kink-band deformation, not previously recorded in this area. However, because of alternation of the thicker and thinner layers, the resulting fold geometry can be complex and in places could well appear to be multi-phase. This is especially the case if some of the apparent folding in thinner beds is actually a result of sedimentary slumping.

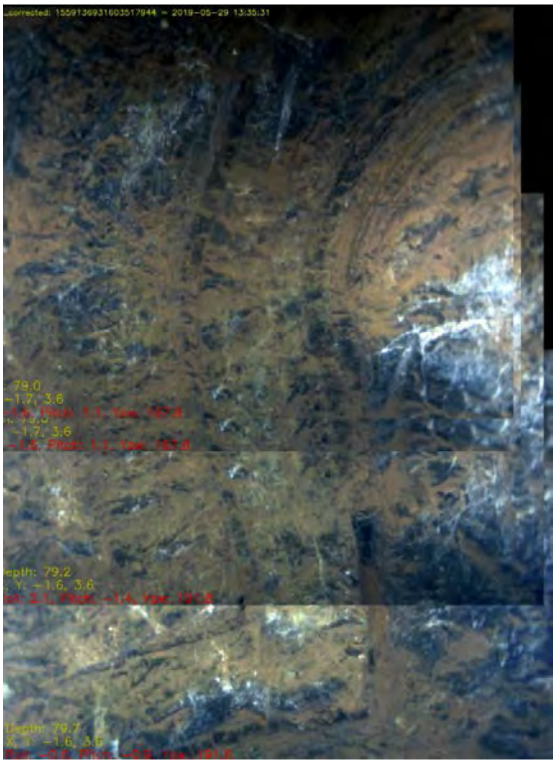


Figure 8.1.5 Folding in thick-bedded limestone. Composite image. Winding shaft -79m.

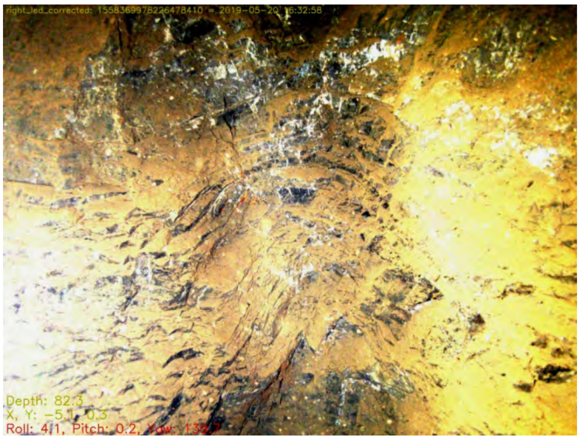


Figure 8.1.6 Anticline, rounded in thick bed (above), more angular in crumpled thin beds (below). Pumping shaft -82m.

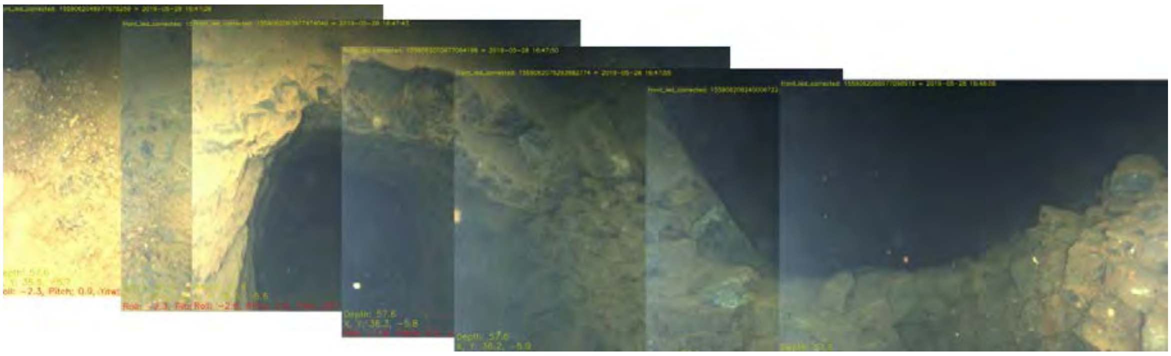


Figure 8.1.7. Crosscut from pipe workings to winding shaft, viewed from bottom of upper pipe workings, -58m. Composite image. Miners took advantage of a large-scale north-west plunging anticline in thick-bedded limestone to drive this short tunnel.

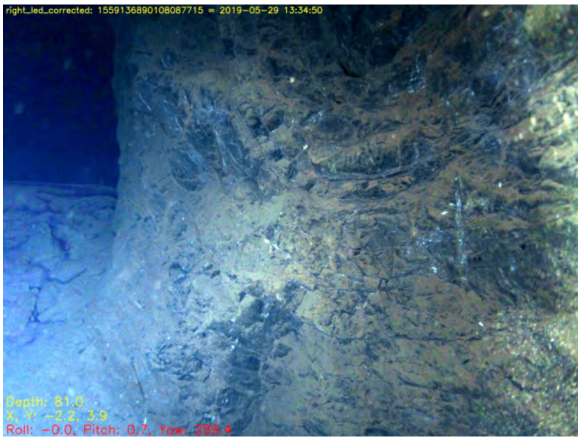


Figure 8.1.8 Rounded syncline in thick-bedded limestone. Cross-cut to pumping shaft on left. Winding shaft, -81m.

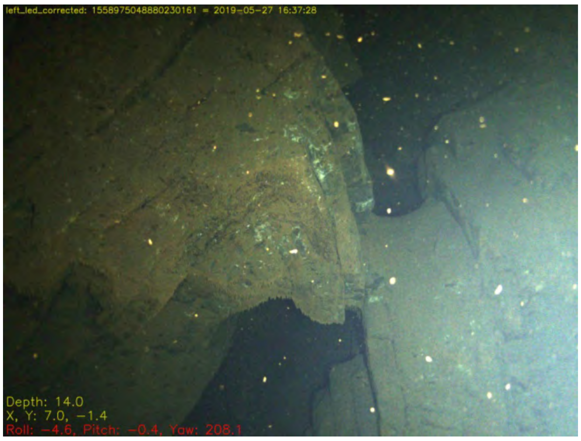


Figure 8.1.9 Rounded anticline in thick-bedded limestone. Pipe workings, -14m.

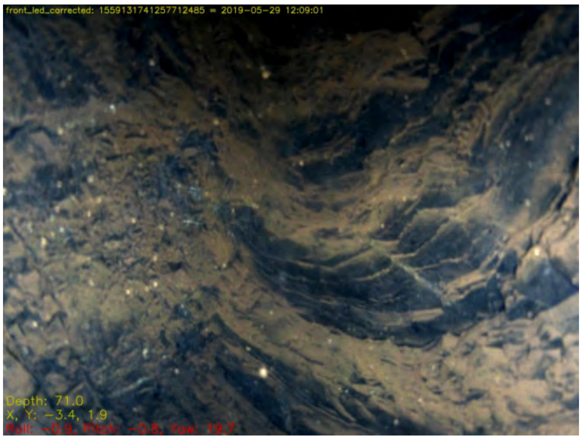


Figure 8.1.10 Syncline in thinly bedded limestone/shale sequence. Winding shaft -71m.

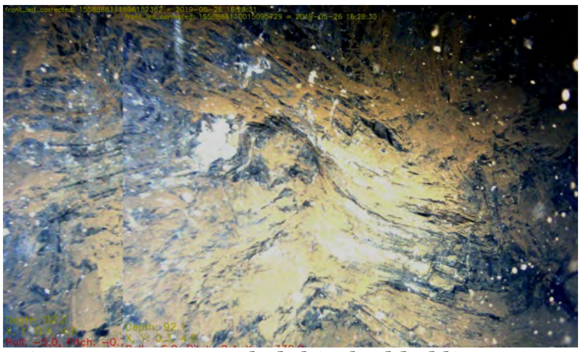


Figure 8.1.11 Crumpled thin-bedded limestone and shale. Pumping shaft -92m.

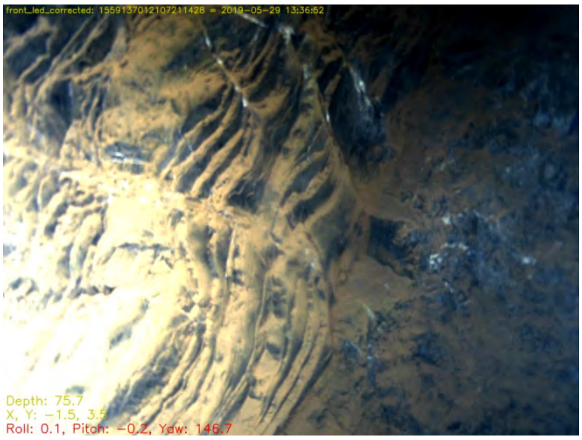


Figure 8.1.12 Thin bedded limestone/shale sequence crossed by shear zones and kink-bands. Winding shaft -75m.

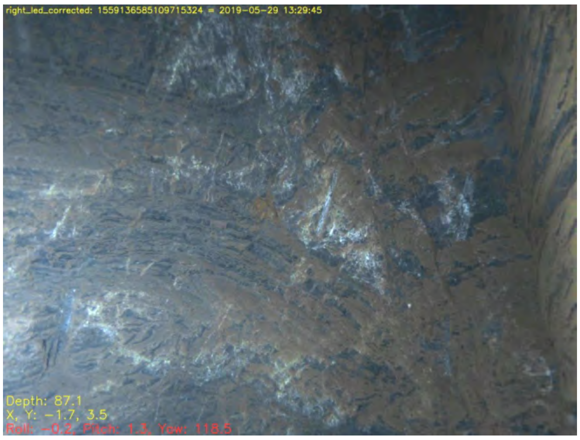


Figure 8.1.13 Asymmetric syncline with flattening of left-hand limb, possibly a reult of re-folding. Winding shaft -87m.

Figure 8.1.14 Sharp anticline in limestone sequence similar to surface exposure at Ape Tor. Pipe workings, -19m.

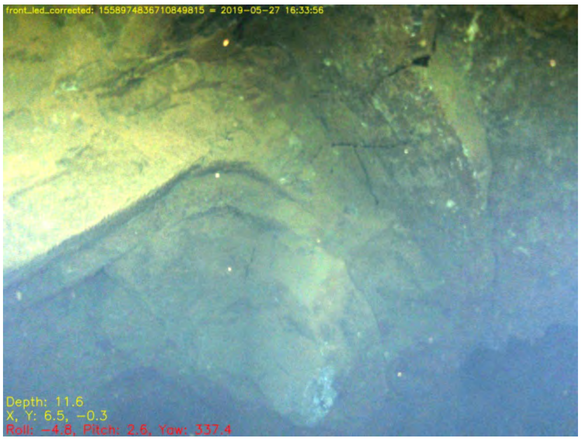


Figure 8.1.15 Rounded anticline in thick-bedded limestone. Pipe workings, -11m.

The work of Watson (1860) as reported by Porter (2004) and Ford (2000) suggests that the richest ores in the Ecton pipe were associated with "double saddles", interpreted as intersecting folds. Ford points out that it is unlikely that there would be fold axes with different orientations in the tectonic setting of Ecton, adjacent to the north-south margin of the Derbyshire limestone massif. Folding in the area has predominantly north-south axes.

However, there is an alternative interpretation of the "double saddle". It could well be the result of a second phase of folding with the same axial direction as the first. This is one interpretation of folding seen in the wall of the winding shaft at 46-50 metre depths, as seen in Figure 8.1.16. A tight asymmetric syncline (in places with axial planar fracturing) is intersected at the bottom of this interval by another synclinal fold which bends the 'nose' upwards to give a 'y' appearance.

Such re-folding at the crest of an anticline would be very likely to enhance the fluid trap effect of the anticline. We have no accurate description of the "double saddle" but this explanation may fit the observations. Furthermore, it was also reported that often the limbs ("wings") of folds would flatten out. Such an effect could also be caused by a second phase of less intense folding, on the same axes.

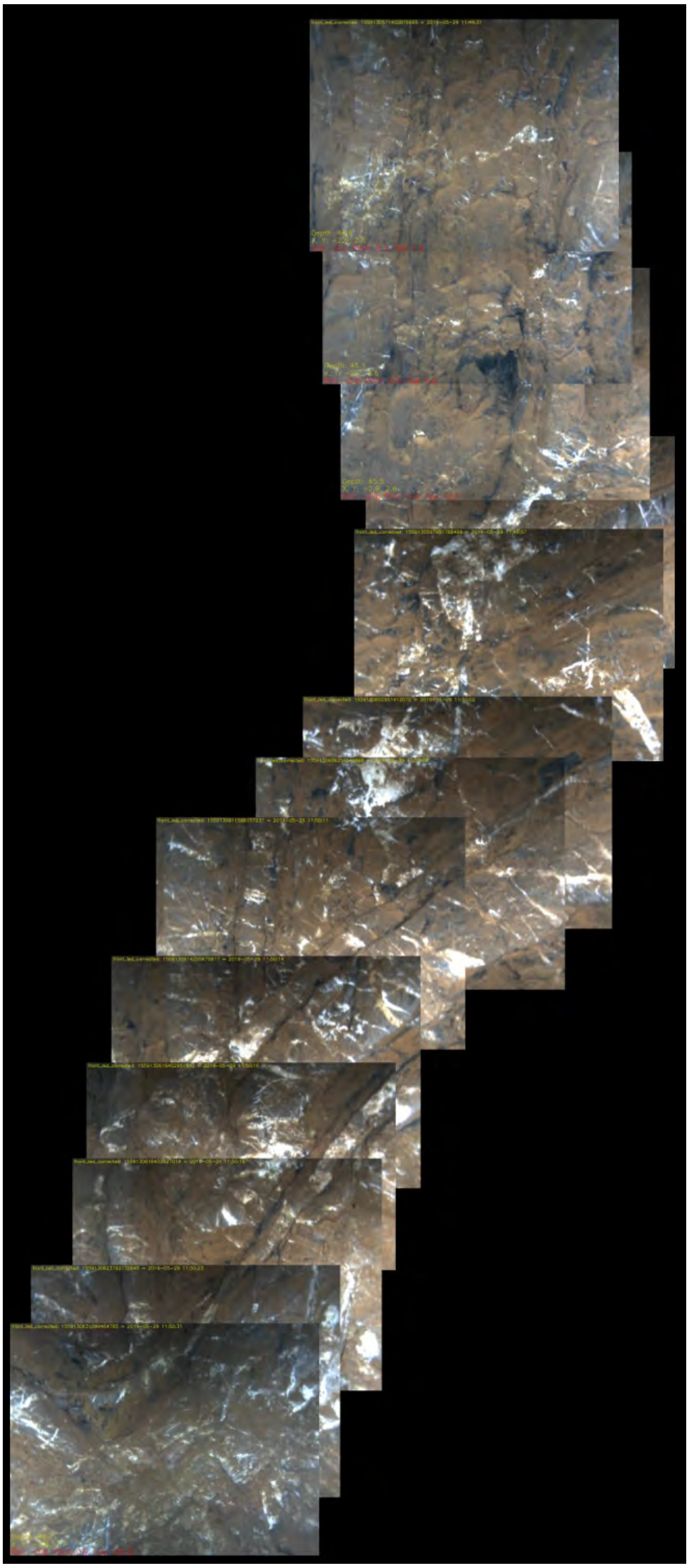
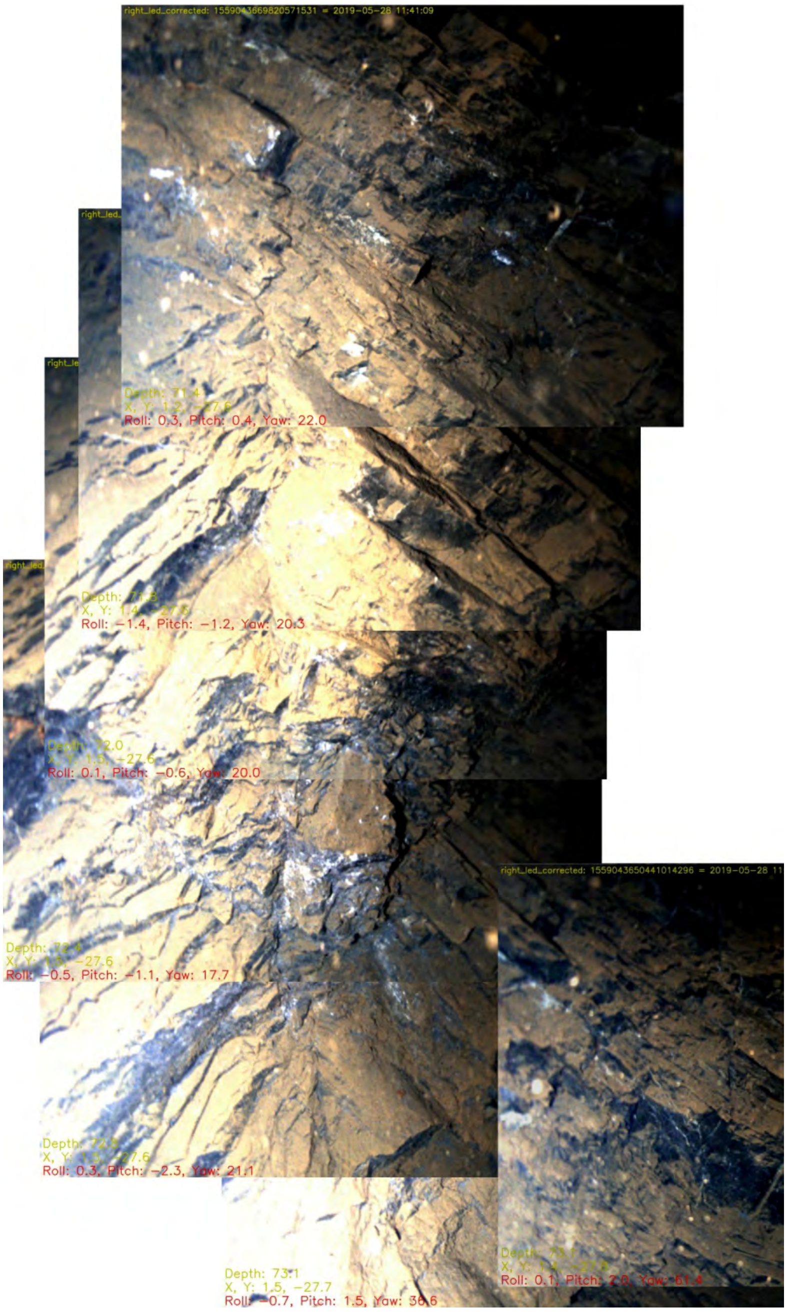


Figure 8.1.16 Syncline in winding shaft, with refolding of the trough at depth -50m.

Figure 8.1.17 Anticline with axial planar fracture. Composite image: Pumping shaft, -73m



The intensity of the folding in places leads to fracturing along or close to the axial planes. This has been documented (Porter, 2004, quoting Watson, 1860) as one of the tectonic features controlling the mineralisation. An excellent example of this is seen at 73m depth in the pumping shaft. In the composite image shown in Figure 8.1.17 the crest of the anticline can be seen near the bottom of the image, with axis plunging towards the camera, and limbs dipping away to the right and towards the camera on the left. The anticline crest is clearly broken, passing upwards into a fracture. In this example there is no obvious mineralisation.

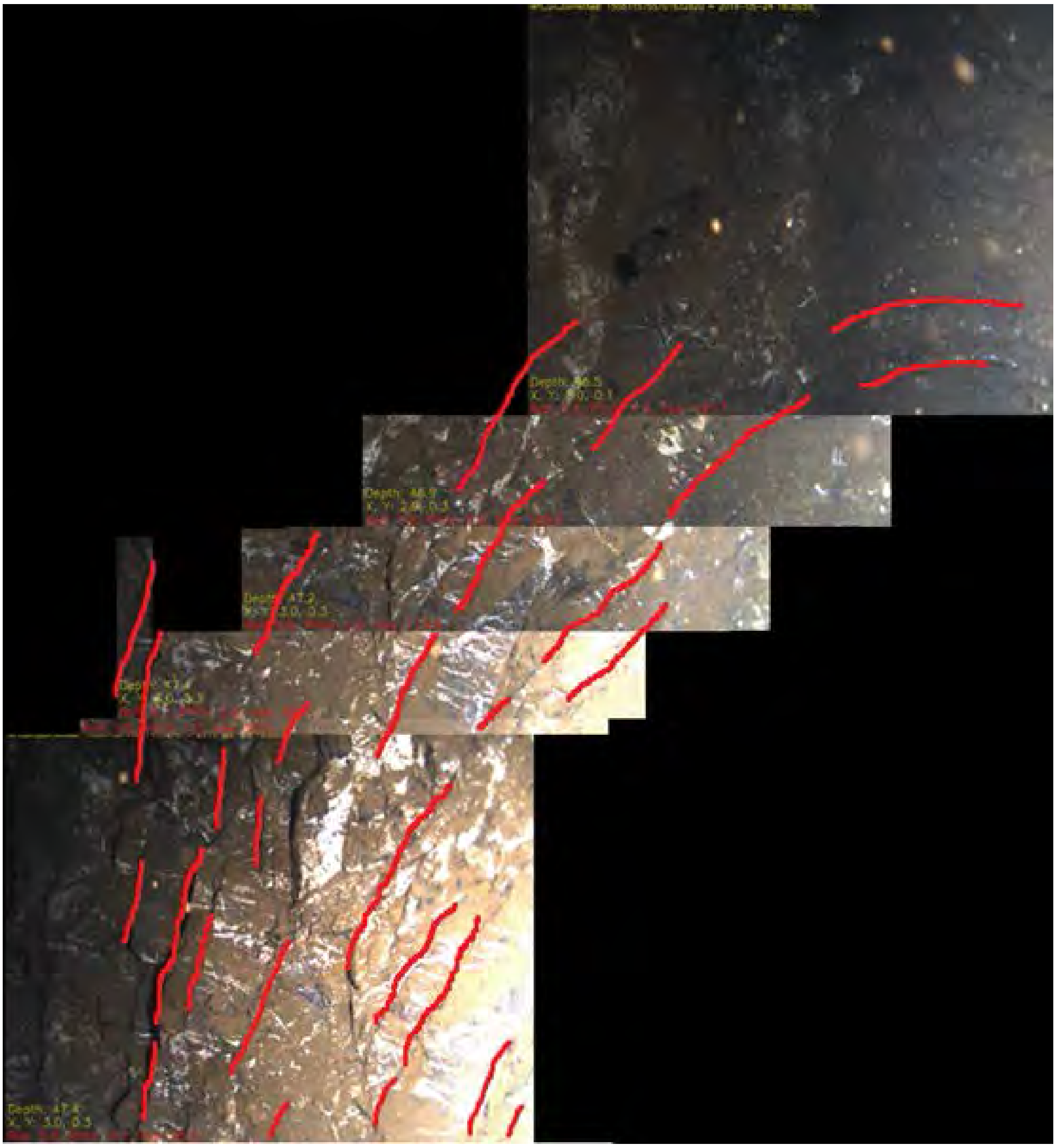


Figure 8.1.18: An open, rounded anticline in depth interval 46.5-47.4m (left camera).

Finally, it is noticeable that towards the main pipe mineralisation at depth there is increasing disruption, in the form of more intense folding, faulting, and ultimately brecciation in which the thicker and more competent limestone beds are broken up and the space is filled by deformation of the thinner beds. This can be seen in Figures 8.1.19 to 8.1.22.

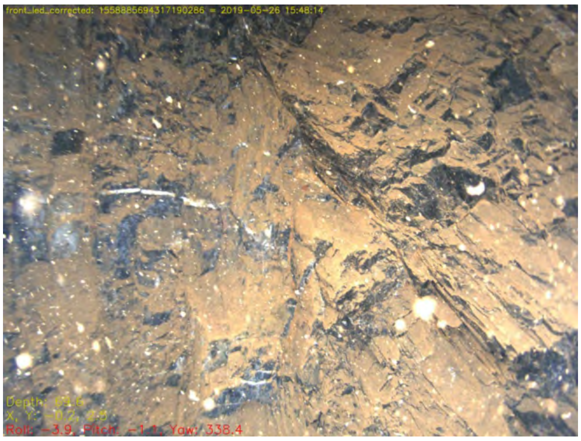


Figure 8.1.19 Tight sharp anticline with axial planar fracture. Pumping shaft, -60m.

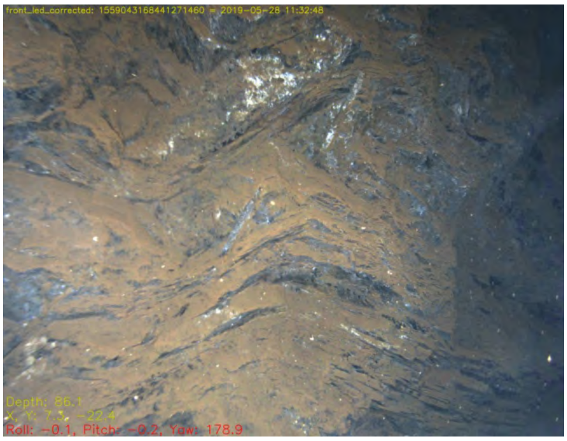


Figure 8.1.20 Folding of thin bedded limestones around broken sections of thicker bedded limestone. Pumping shaft, 86m.

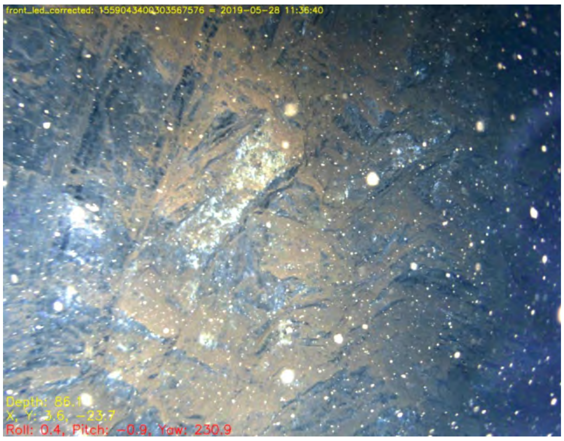


Figure 8.1.21 Fault parallel to bedding on left, cutting bedding on right at an acute angle. Possibly an axial planer fault in a syncline. Pumping shaft, -86m.

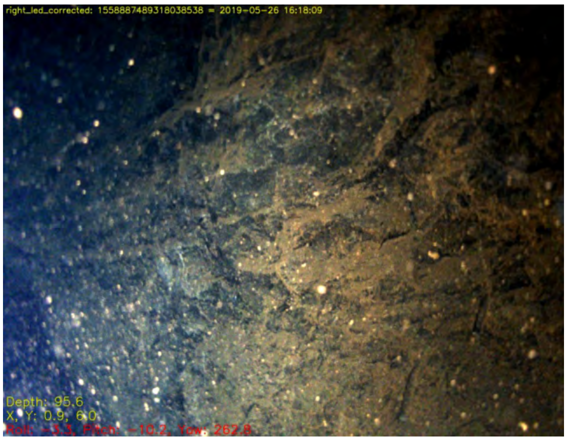


Figure 8.1.22 Thick limestone beds brecciated. Space infilled by material from softer thin bedded limestone. This is seen in the pipeworking at -95m depth.

The brecciation, seen in Figure 8.1.22 and elsewhere in the deeper parts of the pumping shaft and the pipe workings accessed from it, may be suggestive of the true nature of the pipe mineralisation. Ford (2000) quotes Sir Joseph Banks (1767) as describing large-scale polymict breccia within the pipe workings. Whether this was the natural form of the mineral, or a result of enthusiastic mining activity, is uncertain. However, such a breccia could be the result of multi-phase karstic dissolution of the limestone along convenient fractures, with replacement by sulphide minerals, and which could itself explain the irregular geometry of the deposit.

8.1.3 Mineralisation

The general form of the Ecton deposit is a 'pipe'. In the central and eastern part of the Peak District ore field, ore bodies referred to as pipes are generally sub-horizontal and tend to be karstic in origin (Ford, 2000). The pipes at Ecton and adjacent mines are different in that they are sub-vertical, and of irregular cylindrical form. They are not recorded as being either infilling of karstic cavities or replacement deposits, but with the mines closed and flooded since the 19th century little evidence has been accessible to help with interpretation.

Associated with the pipe deposits are also steeply dipping or vertical fissure veins, and reported rich deposits in 'saddles' (along the limbs of synclines and anticlines).

UNEXMIN dives in the two shafts and the upper pipe workings intersected a number of mineralisation features, though little trace of the copper/lead/zinc mineralisation is visible. It has been reported (Joseph Banks, 1767, as quoted by Ford, 2000) that the ore in the pipes consisted of breccias and networks of veins which break up the host rock. These are seen in places in the shafts close to the pipe workings (Figures 8.1.23, 8.1.24). The black patches seen in 8.1.24 could well be the "black stuff" mentioned by Ford (2000), perhaps shale impregnated with sulphides and/or bitumen as he suggests.

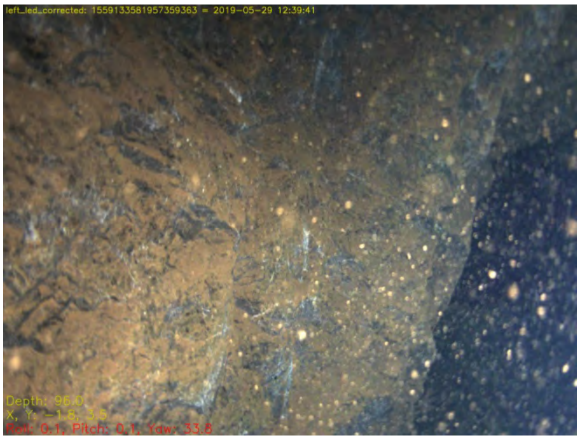


Figure 8.1.23 Mineralisation: ?calcite-cemented breccia. Winding shaft -96m.

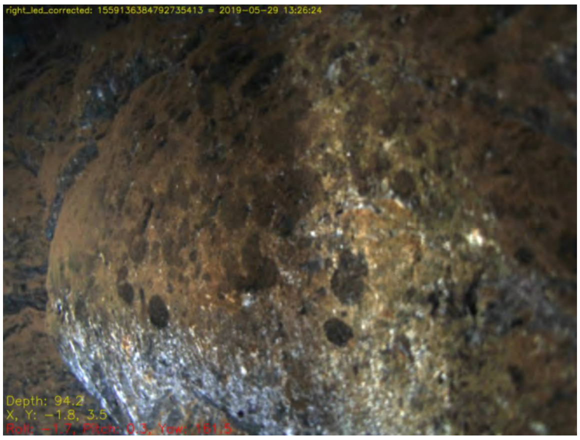


Figure 8.1.24 Mineralisation in cemented breccia. Dark patches may be chert or dark limestone. Winding shaft -94m.

Figure 8.1.25 Oxidised sulphide blobs in fracture plane. Winding shaft -61m.

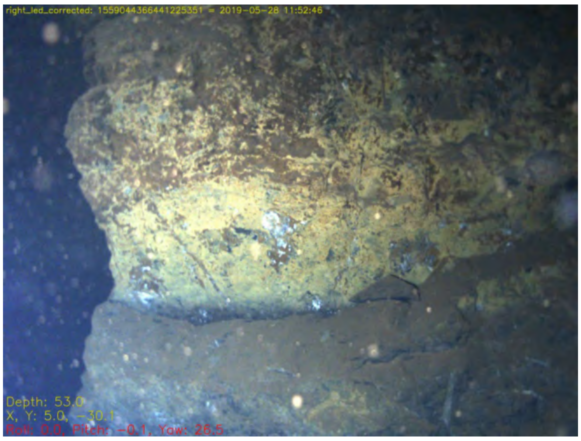


Figure 8.1.26 Possible replacement mineralisation in pumping shaft -53m. Barite? and calcite.

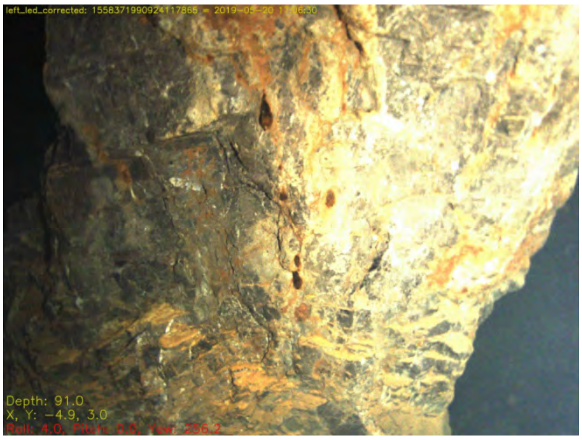


Figure 8.1.27 Sulphides (probably chalcopyrite, now oxidised) in intensely veined rock in a thin (*c.* 1m) rock wall adjacent to pipe workings (on left) and pumping shaft (on right), -91m.

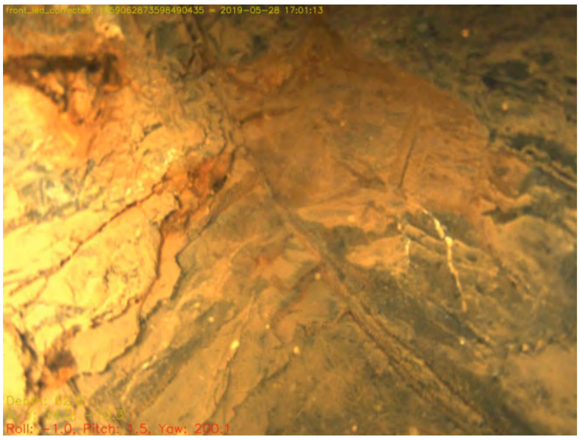


Figure 8.1.28 Oxidised sulphides in veinlets in winding shaft below crosscut to upper pipe workings; 62m.

The mineralisation history is complex, and clearly overlaps with tectonic movements, as shown in Figures 8.1.31 and 8.1.32 which show multiple phases of calcite vein formation, with minor fault movements and changes in stress orientation between infill events. Figures 8.1.33 and 8.1.34 show calcite veinlets infilling tension joints. This is seen commonly at Ecton; the tension joints are generally found on the limbs of folds, in the thicker and more competent beds.

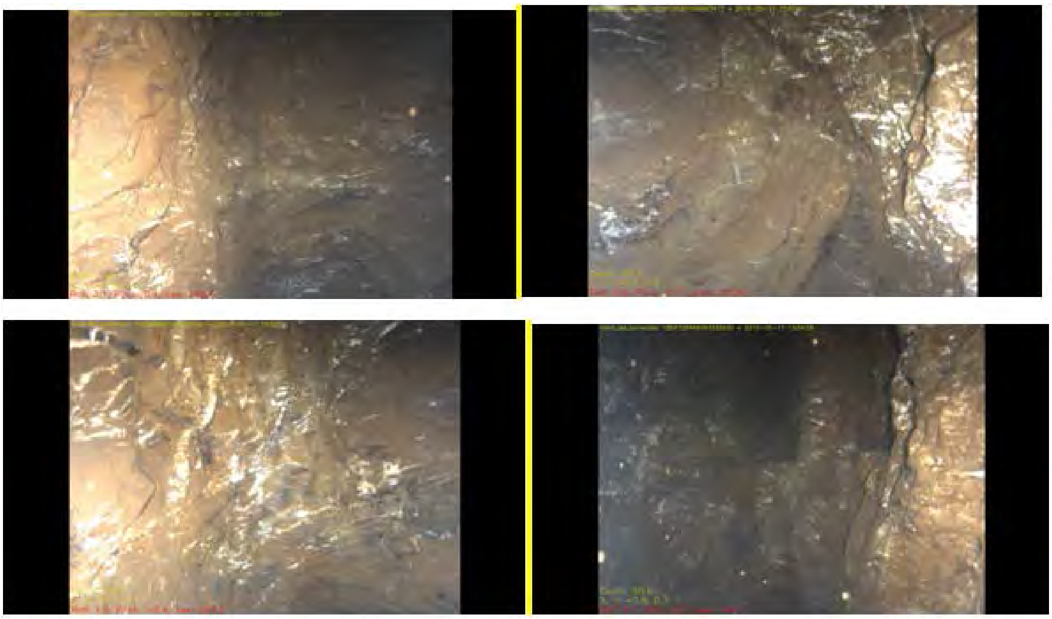


Figure 8.1.29: Depth interval 46-52m (front camera). In the space of 6m intense calcite veining is seen for over 6 metres, with several horizontal- oriented veins and also more massive areas with random spots of minerals. This is close to and a little higher than the side pipe working, and probably related to the metallic mineralisation.

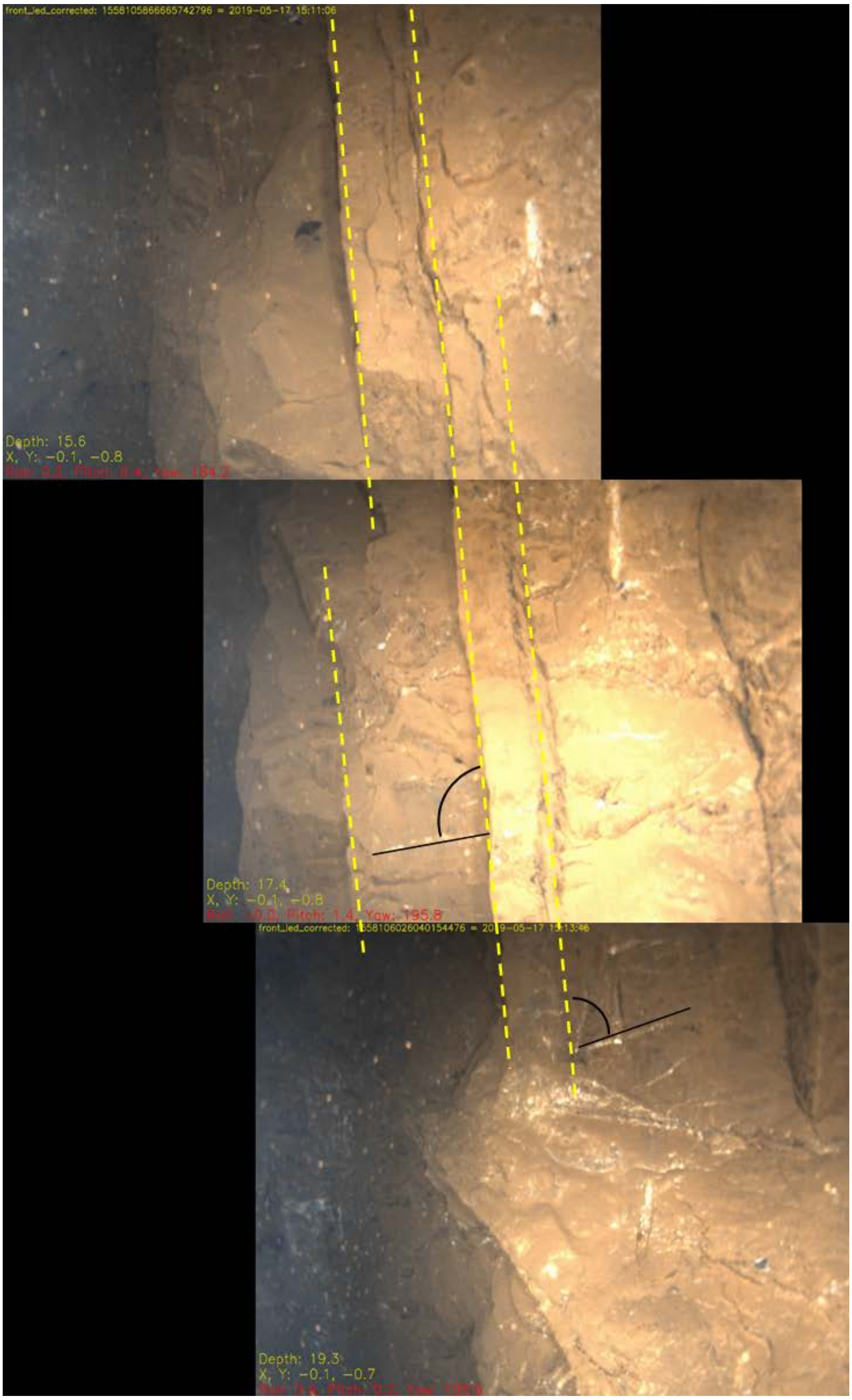


Figure 8.1.30: Depth interval 15.5 to 19.3m (front camera). Vertical stratification with localized calcite mineralization. “Randomly” oriented veins can be seen throughout the referred interval, but they are prevalent around 18m depth. Even though they appear in several directions they commonly cut the stratification at around 90º.

Figure 8.1.31 Multi-phase calcite veining with movement on fracture planes. White LED illumination. Winding shaft, -37m.

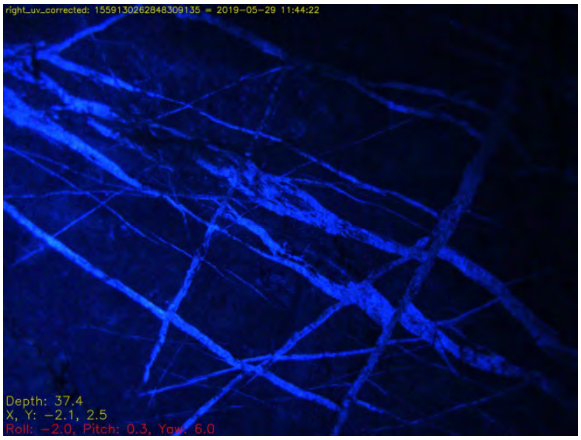


Figure 8.1.32 Multi-phase calcite veining. Same area as in Figure 8.1.20. Ultraviolet illumination. Winding shaft, -37m.

Figure 8.1.33 Calcite veinlets occupying en echelon tension joints showing syntectonic mineralisation. Winding shaft 37m.

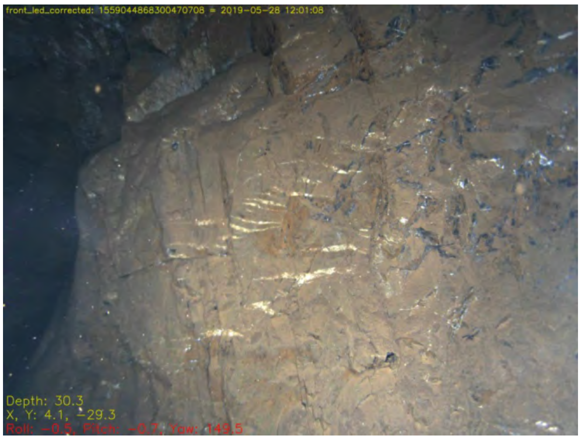


Figure 8.1.34 Sigmoidal en echelon calcite veinlets in thock-bedded limestone. Pumping shaft, 30m.

Figure 8.1.35: Depth 5.1 (Right camera). A system of fractures, mostly horizontal, filled with a black mineral (alteration?)

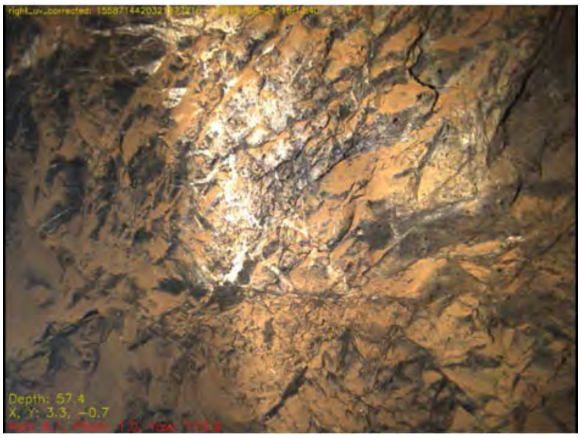


Figure 8.1.36: Depth 57.4 (right camera). A 'nest' of calcite veinlets near the side pipe working. Possibly related to the mineralisation.

Figure 8.1.37 A vertical vein containing oxidised sulphides (probably chalcopyrite) within the pumping shaft, but close to pipe workings. Pumping shaft, -111m.

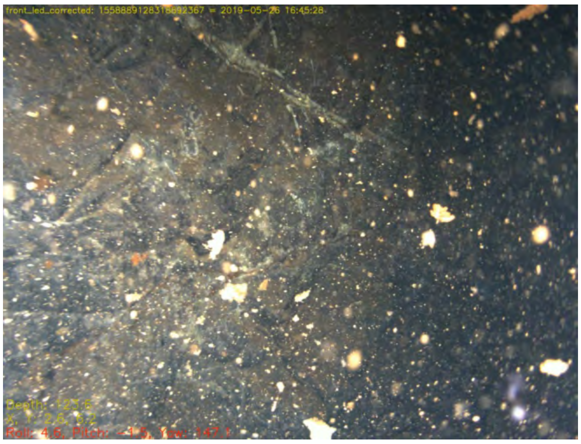


Figure 8.1.38 Vuggy calcite vein (top centre). Pumping shaft, -123m.

Finally, there is some visible evidence that the workings were kept clear of water for some considerable time during operation in the 18th and 19th centuries, in flowstone that has survived, including incipient stalactites: Figures 8.1.39 and 8.1.40. This would have formed during the many decades that the mine was operational. Flowstone formation stopped once the mine was flooded in the 1850s.

Figure 8.1.39 Flowstone: small stalactites on limestone. Pipe workings, -10m.

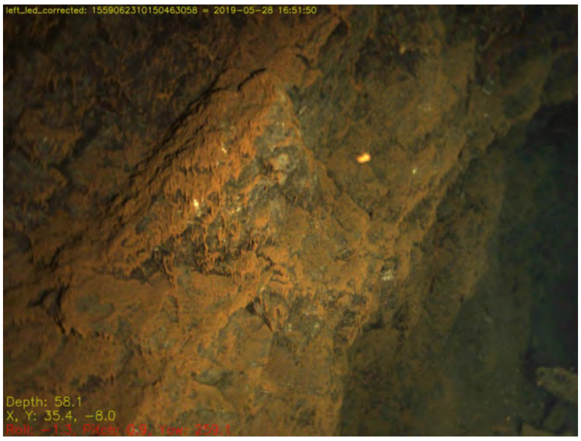


Figure 8.1.40 Flowstone: 'curtain' and stalactites in crosscut between pipe & winding shaft, -58m.

8.1.4 References

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Watson, J.J.W., 1860. Notes on the metalliferous saddles, or ore-bearing beds in the contorted strata of the Lower Carboniferous Rocks of certain parts of Derbyshire & North Staffordshire. The Geologist, Vo.3, p.357-369.

8.2 Geological profiles in pumping and winding shafts

Schematic geological profiles are shown, down the two shafts that were explored. These are illustrative only. Both shafts are known to be truly vertical to at least the depths that were explored by the UNEXMIN project.

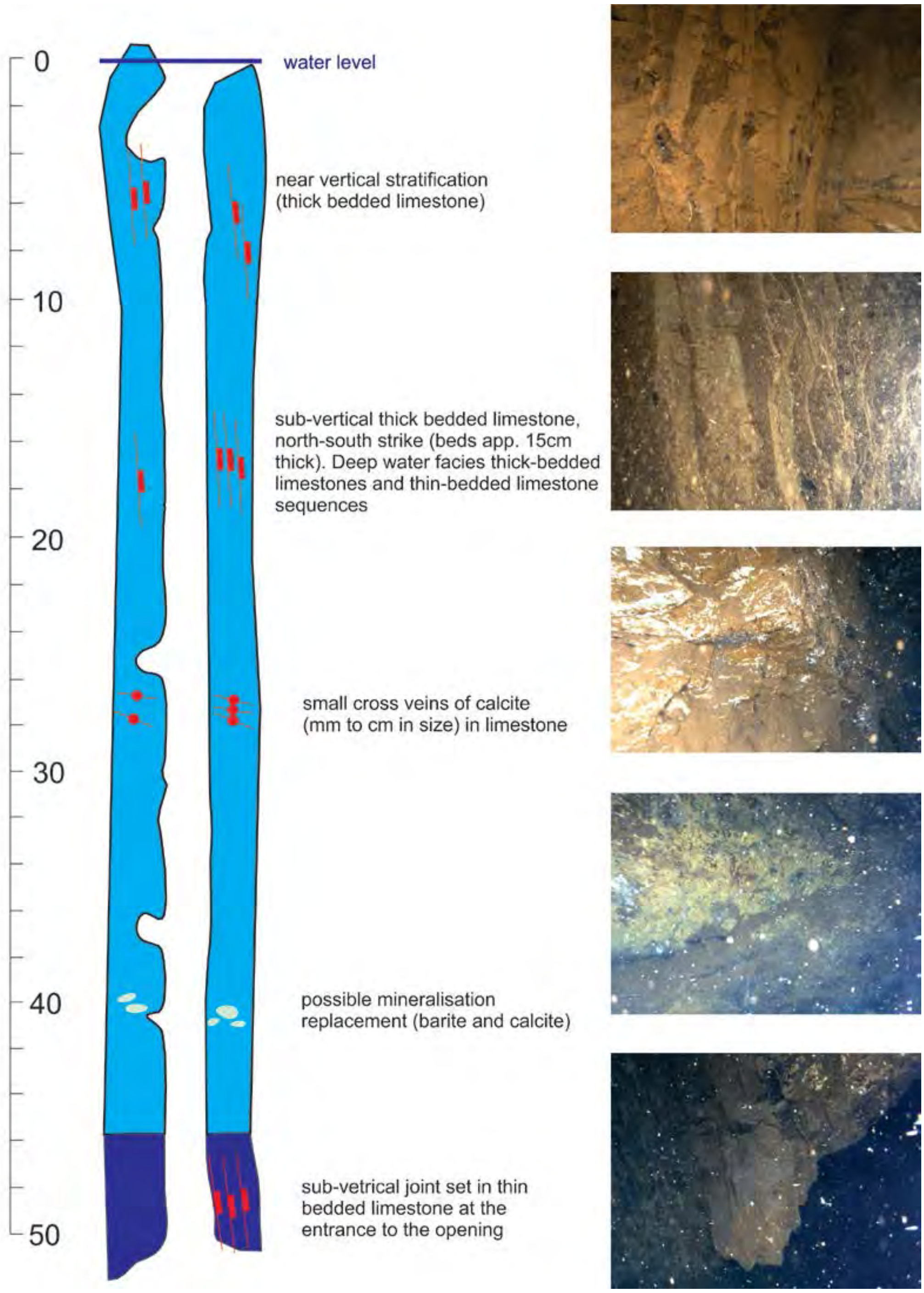

Figure 8.2.1 Some of the geological features in the uppermost 50m of the pumping shaft. (Key to symbols in Figure 8.2.3)

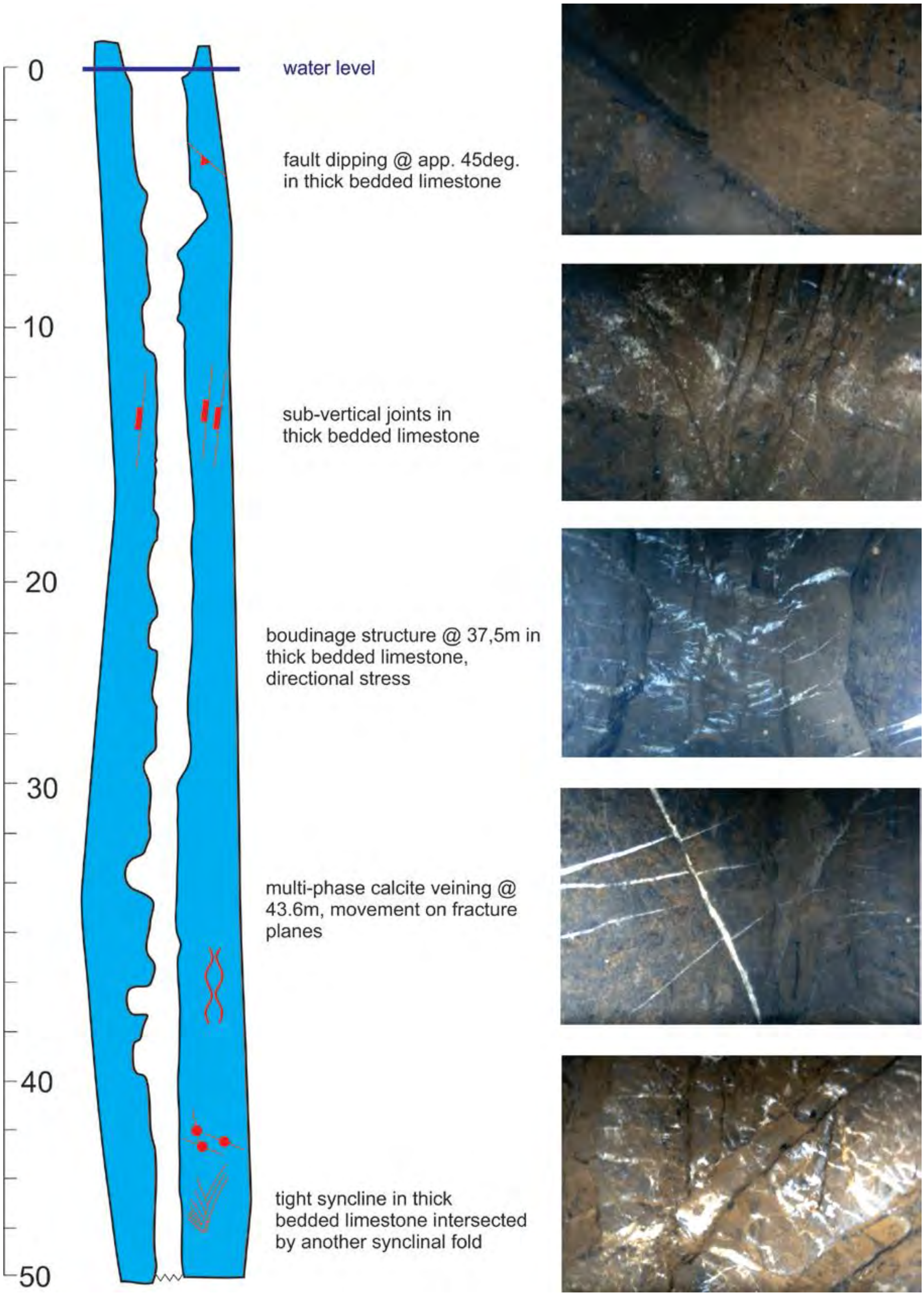

Figure 8.2.2 Some of the geological features in the uppermost 50m of the winding shaft. (Key to symbols in Figure 8.2.3)

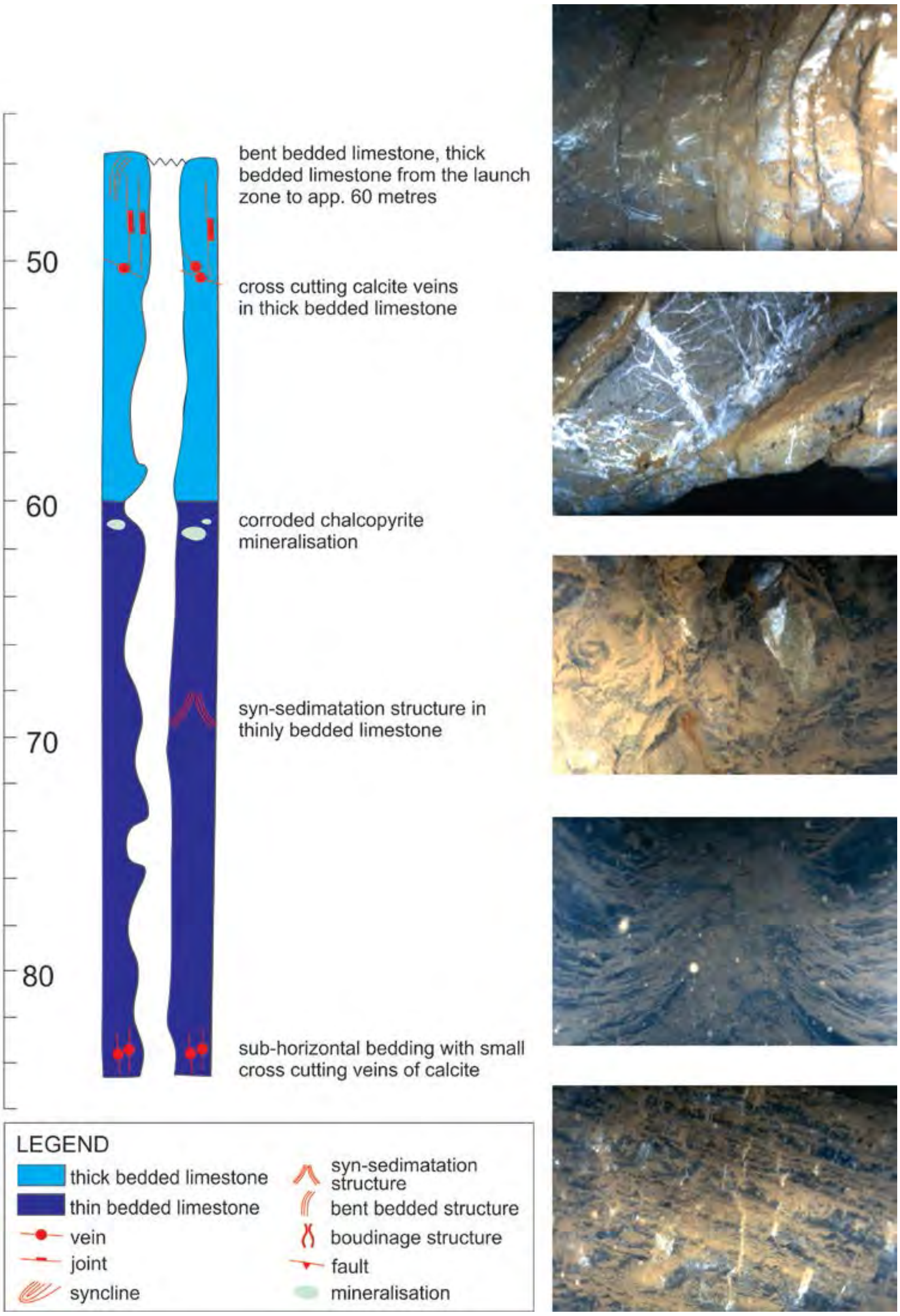

Figure 8.2.3 Some of the geological features from 50m to 85m depth in the winding shaft.

9 ANNEX 3: Detailed Geological Observations arising from the UNEXMIN Exploration Dives in Deep Ecton Mine by Richard Shaw (EMET)

Ten UNEXMIN explorer dives at the Deep Ecton Copper Mine have revealed a large amount of information on the geology of the mine workings that have been flooded since the 1850s. Observations include stratigraphy, structure and mineralization and they have helped to improve geological understanding of this once important ore body.

9.1 Introduction

This report describes the main geological findings of the ten exploration dives carried out by two of the UNEXMIN robots in the flooded workings of the Deep Ecton Mine during May 2019. The Deep Ecton Mine, within Ecton Hill in north-eastern Staffordshire, England, was mainly exploited for copper, and some lead and zinc [from the 1850s onwards], during the 18th and early 19th centuries.

Two shafts, one originally for winding ore and the other, the Great Shaft, for pumping, were dived to blockages at total depths of about -113m and -125m respectively. The two shafts were connected during one of the dives from the Great Shaft via a crosscut at a depth of about -81m. The flooded pipe workings were also dived to a depth of about -58.5m where a connection was made to the Winding Shaft. A considerable number of open pipe workings were not explored during the exploration programme.

This report is not intended to be a comprehensive review of the geology of the mine and local area nor is it a detailed inventory of the geological observations from the dives. Rather it is a summary of the main geological features observed and how these observations have enhanced our understanding of the mines' geology. Considerable amounts of information were collected by the robots during the UNEXMIN exploration dives which would merit a much more detailed evaluation in due course.

9.2 UNEXMIN

UNEXMIN is an EU-funded project that develops a novel robotic system, primarily for the autonomous exploration and mapping of Europe's flooded mines. The Robotic Explorer platform, made by three robots – UX-1a, UX-1b and UX-1c, uses non-invasive methods for the 3D mapping to gather valuable geological, mineralogical and spatial information.

9.3 Geological Context and Previous Work

It is beyond the scope of this report to provide a detailed description of the geology of the area around Deep Ecton Mine but it is appropriate to provide a summary of its' geological setting. Readers interested in more detailed geological information on the mines and surrounding areas are referred to Chisholm et al (1988), Critchley (1979) and Ford (2000) and the references therein.

Ecton lies close to the western edge of the Carboniferous Limestone outcrop of the Peak District, the UKs first national Park.

9.3.1 Stratigraphy

The Deep Ecton Mine is situated within Ecton Hill which comprises a sequence of mainly limestone strata of Dinantian (Lower Carboniferous) age.

In the Ecton area the Dinantian limestones are divided into four units (Aitkinhead et al; 1985):

- Mixon Limestones with Shales (Brigantian)
- Ecton Limestones (Asbian)
- Milldale Limestones (Chadian and Arundian)
- Rue Hill Dolomites and Red House Sandstones (Courceyan)

The oldest of these beds, the Rue Hill Dolomites/Red House Sandstones, are only exposed several kilometres to the south of Ecton but are probably present at depth beneath Ecton Hill. It is unlikely that they were reached by the Deep Ecton or Clayton Mine pipe workings both of which went for 300m below river level.

The Milldale Limestones are micritic limestones up to 700m thick and contain mud mound (reef) knolls. These rocks form the buried core of Ecton Hill and are probably the host rocks for the bulk of the mineralisation at Ecton.

The Ecton Limestones are at least 225m thick at Ecton and overlie the Milldale Limestones. They comprise generally more thickly bedded limestones with shaley partings and thin volcanic tuff layers, known as wayboards to the miners. Chert beds and nodules are common in these limestones. Mud mound (reef) knolls are also present comprising more thickly bedded limestones. These rocks form the bulk of the rocks exposed at surface on Ecton Hill where they occur on the flanks and summit and are well seen in both Salt's and Deep Ecton Levels.

The overlying Mixon Limestones with Shales has been eroded from Ecton Hill but occurs to the east, north and west of the hill.

All of the limestones at Ecton have variable bed thicknesses with zones where thinner (a few centimetres) or thicker (10s centimetres to about 1 metre) beds predominate. Chert is present in all of the limestones but is more frequent in the Ecton Limestones. Similarly shale beds and partings and thin volcanic tuffs occur throughout though more commonly in the Ecton Limestones.

9.3.2 Structure

In broad terms Ecton Hill is an asymmetric anticline that plunges to the north with a steep dipping eastern limb and a more gently dipping western limb.

Tight small scale folding is a feature of Ecton within the more thinly bedded beds, particularly around the anticlinal crest zone, and such folds are well exposed at Apes Tor at the north end of the hill. The miners referred to these small folds as 'huckle saddles' (anticlines) and 'trough saddles' (synclines) (Watson; 1860).

9.3.3 Ore Deposits

Ford (2000) describes three types of mineral deposit at Ecton. These are:

- Lodes – steeply dipping to near vertical fissure veins perhaps occupying faults;
- Saddles – Ores deposited in the limbs and joints of the smaller scale fold structures;
- Pipes – The main ore deposits at Ecton are more or less cylindrical features steeply inclined and cutting through the strata.

9.3.4 Minerals

The principal metallic minerals at Ecton are chalcopyrite, galena and sphalerite with some pyrite. The major gangue minerals are calcite, fluorite and barite. There are a large number of minor primary and secondary minerals present, including malachite and azurite. These are described by Ford (2000).

9.3.5 Mineralisation

All three ore deposit types noted above exhibit multi-phase mineralisation.

The lodes typically are fissure fill deposits mainly comprising calcite with smaller quantities of sulphides present together with some barite and fluorite.

The ore bearing saddles have not been observed at Ecton since the mine flooded in the 1850s but they appear to comprise both cavity fill (joint and bedding partings) and replacement deposits consisting predominantly of sulphide minerals.

The main pipes appear to have been formed by hydrothermal dissolution of previously fractured limestones associated with folding and minor faulting. They probably comprise cavity fill and replacement mineralisation consisting of the principal minerals (calcite, fluorite, barite, chalcopyrite, galena and sphalerite) with residual clays contained within a breccia of host limestone blocks. Contemporary records suggest that chalcopyrite values diminished with depth and that sphalerite values increased.

The development of hydrofractures within a broad zone around the pipes appears to have been the initial stage of mineralisation (Quirk; 1987) with deposition of at least 2 phases of massive white calcite in dilational, sometimes en echelon, fractures. These can be seen in both Deep Ecton and Salt's Levels.

9.4 Results from UNEXMIN dives

Note throughout this report all depths given are approximate and in metres below current water level. Because all three dive sites are hydraulically connected the standing water level is identical at all three dive locations.

UNEXMIN Dives at Ecton:
Great (Pumping) Shaft:

- 17th May 2019
- 18th May 2019
- 20th May 2019
- 24th May 2019
- 25th May 2019
- 26th May 2019
- 28th May 2019

Winding Shaft:

- 29th May 2019

Pipe:

- 27th May 2019
- 28th May 2019

9.4.1 Host Rocks

The accessible mine workings at Deep Ecton Mine are all within the Ecton Limestones. The Milldale Limestones in the core of the Ecton Anticline are exposed in Clayton Adit about 250m south of the Deep Ecton Pipe workings (Critchley; 1979) and are probably present a short distance below water level in Deep Ecton Mine.

UNEXMIN dives in both the Great Shaft and the winding shaft show that the strata in the top ca 50m of both shafts are mainly steeply dipping (>80° to vertical) (Figure 9.1) with an approximate north/south strike. This suggests that both shafts may have been sunk close to the axis of the Ecton Hill Anticline just within its steeply dipping eastern limb. The beds are moderately thickly bedded (mainly 10 to 20cm thick) and individual layers can be followed in the shaft walls over much of this distance. Below about -52m in the Great Shaft the dip shallows to about 60° or less and the beds are generally thicker, 20 to 60cm, (Figure 9.2) particularly around the pipe vein workings around -55m.

Figure 9.1: Near vertical bedding of thickly bedded Ecton Limestones (-40.6m in Great Shaft).

Figure 9.2: Shallow dipping bedding (-83.1m Great Shaft).

In both shafts below about -60m the limestones generally become more thinly bedded with variable dips, some tight folding and with contorted bedding in places (Figure 9.3 and Figure 9.4).

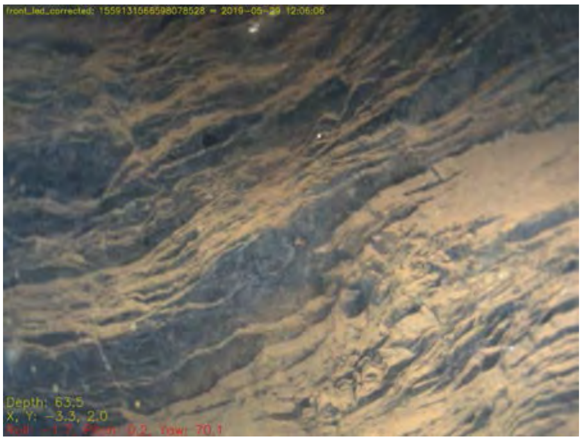

Figure 9.3: Thinly bedded shaly limestone (-63.5m Winding Shaft).

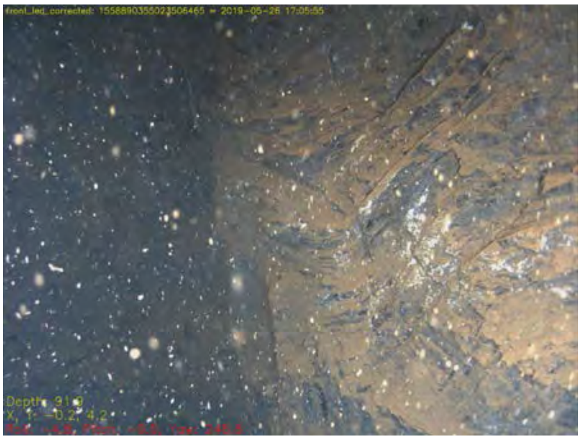

Figure 9.4: Contorted bedding (-91.9m Great Shaft).

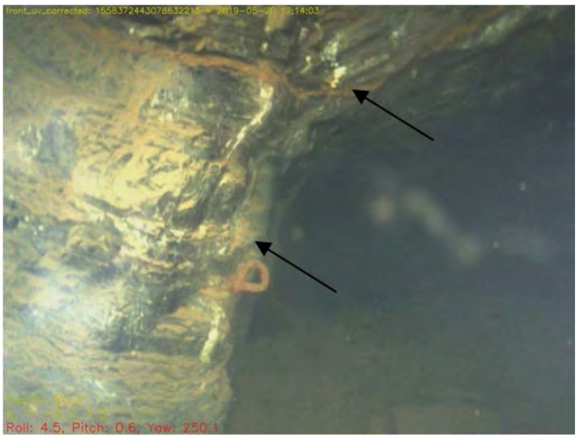

Figure 9.5: Thickly bedded limestones with ?copper staining (above miners eye) and bedding parallel ?vein of weathered chalcopyrite (both arrowed) (-80.3m Great Shaft).

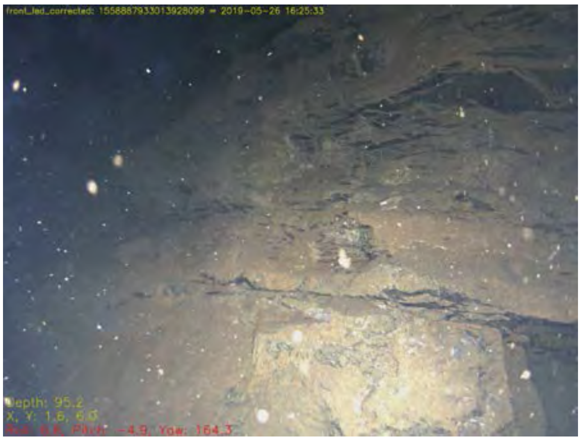

Figure 9.6: Near horizontal bedding in thickly bedded limestones (-95.2m Great Shaft).

Around the pipe vein workings encountered in both shafts between about -80 and -100m the limestones are generally more thickly bedded and may represent reef knoll facies (Figure 9.5) with more thinly bedded, perhaps more shaley, limestones between the pipe workings. Similar thickly bedded limestones appear to form the bulk of the walls of the pipe vein explored by UNEXMIN dives on 27th and 28th May 2019 (Figure 9.6, Figure 9.7 and Figure 9.8).

Figure 9.7: Thickly bedded near horizontally bedded limestones (-49.3m Pipe).

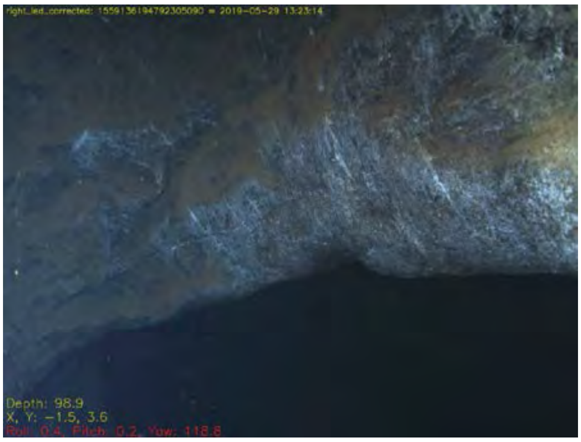

Figure 9.8: Thickly bedded limestone in pipe working pillar (-98.9m Winding Shaft).

It is often not possible from the imagery to identify with confidence specific rock types. The thicker bedded rocks are probably fine grained limestones and the more thinly bedded rocks are probably more shaley limestones (Figure 9.9). Beds and nodules of chert have mainly been noted in the upper 50m of both shafts and elsewhere (Figure 9.10 and Figure 9.11). A possible wayboard (volcanic tuff) was noted at -123.9m in the Great Shaft and crinoidal limestone (Figure 9.12) at the same location. The latter may be indicative of reef knoll facies limestones.

Figure 9.9: Near horizontal bedding with cross cutting calcite veining (-85.3m Great Shaft).

Figure 9.10: Chert beds in thickly bedded limestones (-79.8m Winding Shaft).

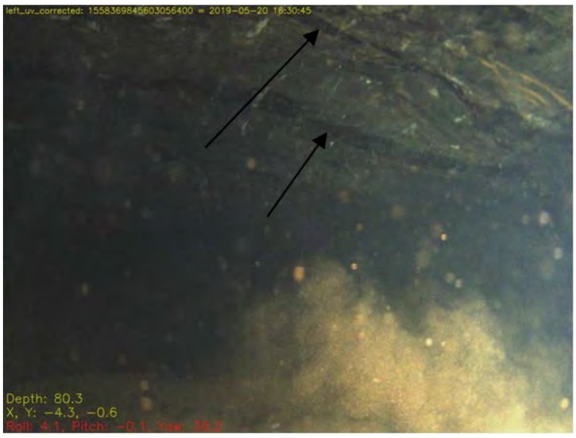

Figure 9.11: Chert beds (arrowed) in roof of cross cut between Great Shaft and Winding Shaft (-80.3m Great Shaft).

Figure 9.12: Crinoidal Limestone and ?thin volcanic tuff (both arrowed) (-123.9m Great Shaft).

No beds that are demonstrably shale, as opposed to shaley limestones, have been observed but it is likely, given what can be observed in the un-flooded workings above, that the majority of the bedding partings present have a thin (mm) shale layer present and some of those that are wider may represent shale beds a few centimetres thick.

While it is not possible to be definitive without a detailed palaeontological evaluation it is likely that the near vertical, more thickly bedded limestones through which both shafts have been sunk for the first ca 50m are within the lower part of the Ecton Limestones. The deeper rocks, of more variable character, with more thinly bedded zones and more thickly bedded zones are probably the upper part of the Milldale Limestones with the latter representing reef knolls.

9.4.2 Structure

Structurally Ecton Hill is complex. As well as its main anticlinal structure there are numerous smaller folds. These have been observed at a variety of scales during the UNEXMIN dives and in a variety of rock types. They include both acute and more gently rounded anticlines and synclines as well as zones of more or less contorted bedding and more sinuously folded strata (Figure 9.13, Figure 9.15, Figure 9.14,

Figure 9.16, Figure 9.17, Figure 9.18, Figure 9.19, Figure 9.20, Figure 9.21, Figure 9.22, Figure 9.23 and Figure 9.24). A detailed structural analysis is beyond the scope of this report but the large amount of data that could be extracted from the UNEXMIN information would permit a thorough examination of the structures present to be made. Such a study would form a good B.Sc. or M.Sc. project.

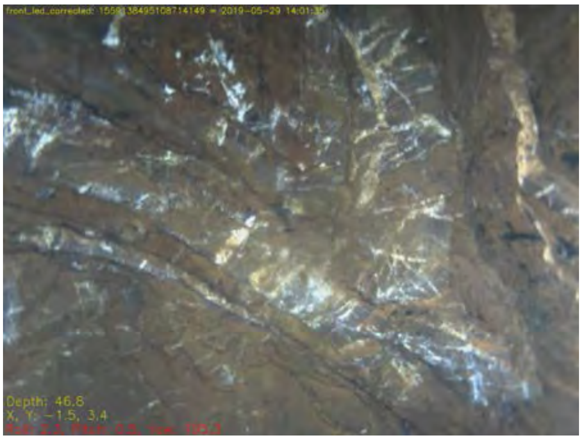

Figure 9.13: Syncline with calcite veining (-46.8m Winding Shaft).

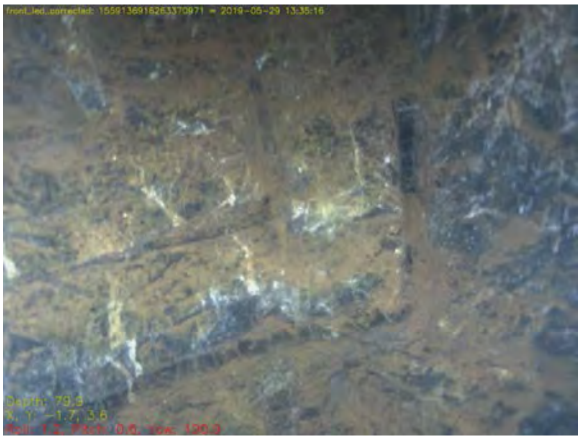

Figure 9.14: Syncline (-79.9m Winding Shaft).

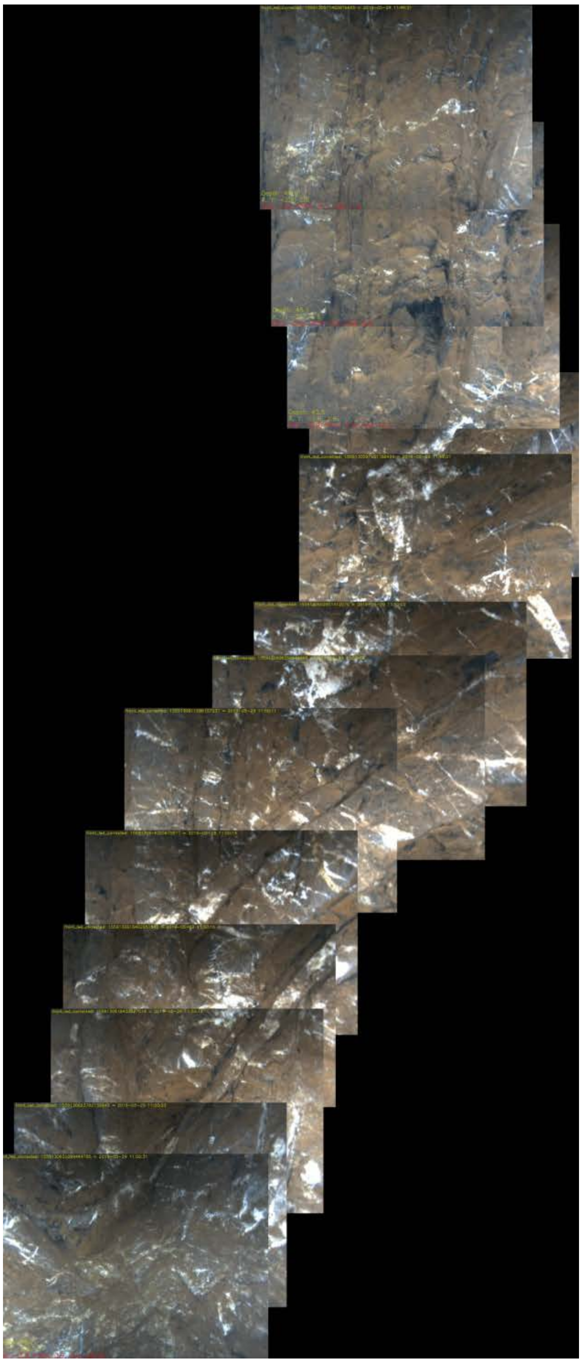

Figure 9.15: Composite image of a refolded Syncline (ca -44.5 to -49.0m Winding Shaft).

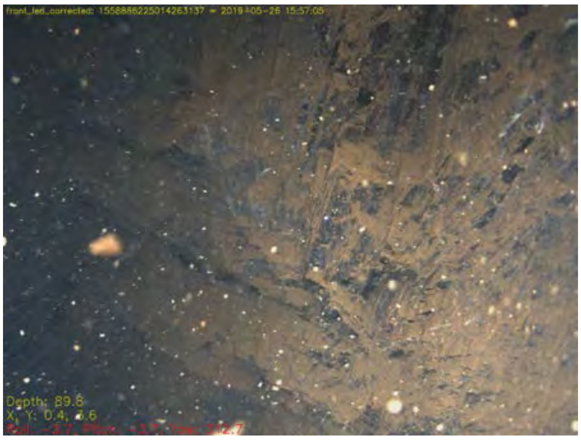

Figure 9.16: Syncline in thinly bedded limestones (-89.8m Great Shaft).

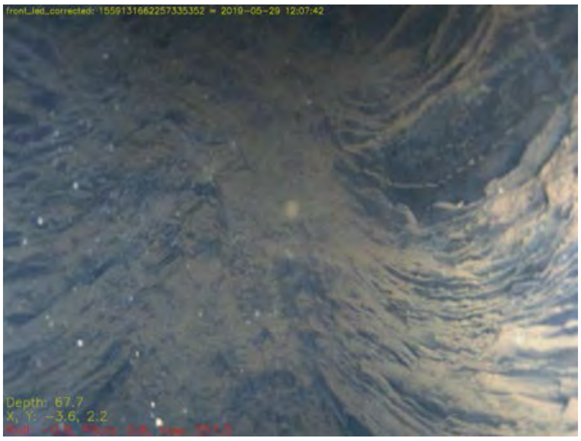

Figure 9.17: Anticline in thinly bedded limestones (-67.7m Winding Shaft).

Figure 9.18: Anticline and fault (-83.0m Winding Shaft).

Figure 9.19: 'S' fold in thinly bedded limestones (-91.7m Winding Shaft).

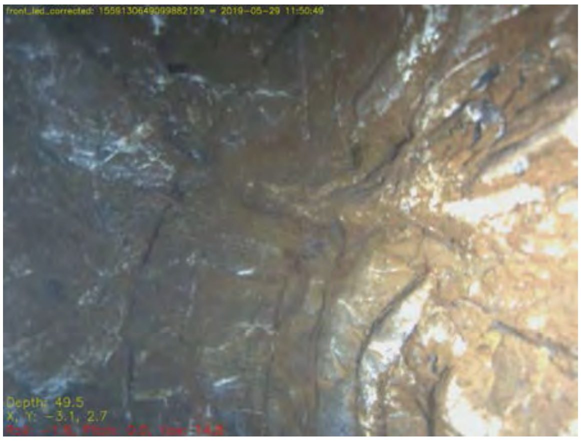

Figure 9.20: Contorted bedding (-49.5m Winding Shaft).

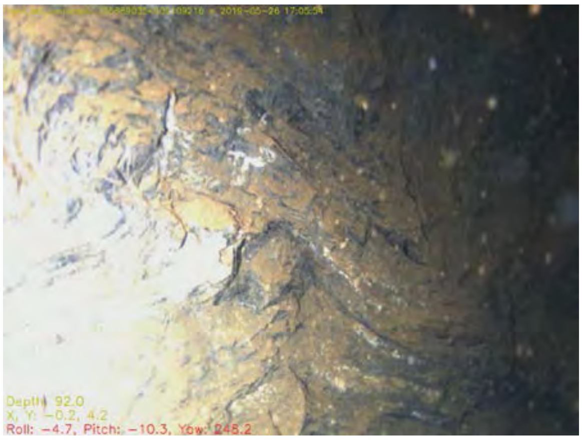

Figure 9.21: Contorted bedding (-92.0m Great Shaft).

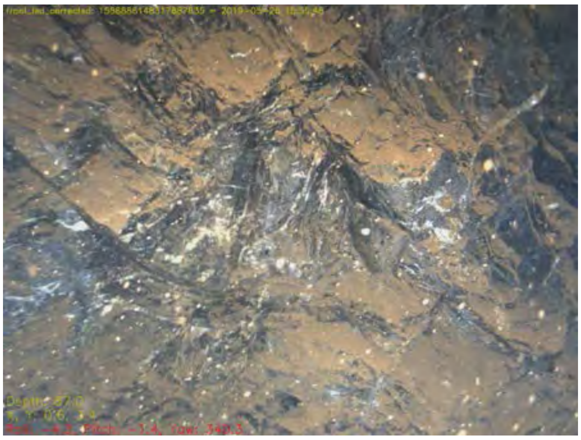

Figure 9.22: Contorted bedding (-87.0m Great Shaft).

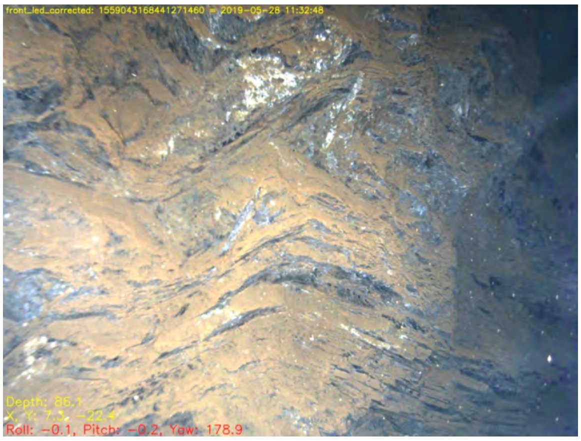

Figure 9.23: Syncline and anticline (-86.1m Great Shaft).

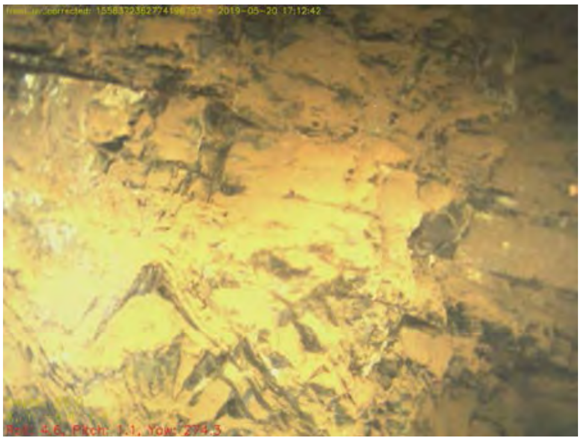

Figure 9.24: Contorted bedding (-85.5m Great Shaft).

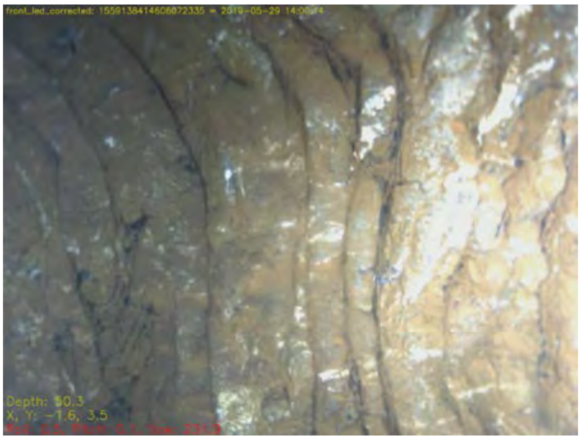

Figure 9.25: Bent bedding and ?bedding parallel faulting (left) (-50.3m Great Shaft).

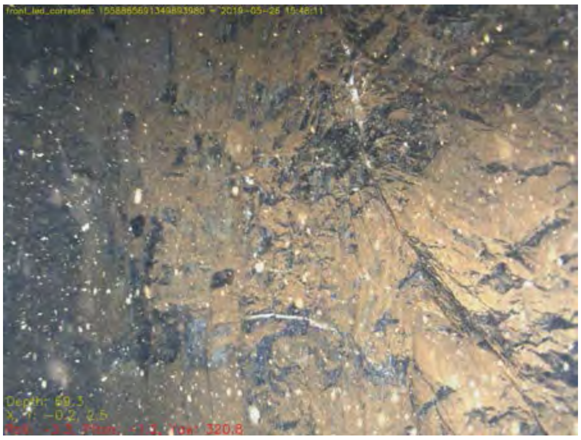

Figure 9.26: Fault or joint in anticline axis (-69.3m Great Shaft).

No major faults have been identified in the accessible un-flooded workings at Ecton though small faults are present and the lodes noted above show evidence of only limited movement. Similarly the UNEXMIN dives did not reveal any major fault structures though a number of small scale faults have been observed. These include bedding parallel features (Figure 9.25 and Figure 9.27) and small faults in the axes of minor folds (Figure 9.26). None of the faults seen showed major displacements, perhaps the largest being the off-setting of early stage calcite veining by the order of 0.5m (Figure 9.28).

Figure 9.27: Bedding parallel fault (centre) (-43.6m Winding Shaft).

Figure 9.28: Calcite veins offset by bedding parallel fault (-58.1m Great Shaft).

Jointing is ubiquitous with the thickly bedded limestones having the best developed joints. These are mainly perpendicular to bedding with the development of open joints in places (Figure 9.29).

Figure 9.29: Open joints (-57.3m Winding Shaft).

9.4.3 Mineralisation

Quirk (1987) noted the presence of an early phase of hydraulic fracturing filled by white calcite at Ecton. As noted above some zones of these calcite filled hydraulic fractures can be observed in both Deep Ecton and Salt's Levels in areas proximal to the pipe.

The UNEXMIN dives have demonstrated that this type of mineralisation is common at Ecton and that there is a spatial relationship between the pipe and the zones of calcite veining. It is highly likely that the miners would have been aware of this relationship and knew that the presence of the calcite veining was an indication that they were close to a pipe.

At least two, and possibly more than three, phases of hydraulic fracturing and calcite vein filling development can be identified from the UNEXMIN dives (e.g. Figure 9.30 and Figure 9.31). There are clear cross-cutting relationships sometimes with evidence of minor displacement of earlier fractures (Figure 9.33 and Figure 9.35). Development of en echelon zones within patches of calcite veining shows that the area was tectonically active at the time of their development (e.g. Figure 9.32 and Figure 9.34).

While not unequivocal it is apparent from the relationship between the worked out pipe veins and the early calcite veining (e.g. Figure 9.49) that the development of the ore bearing pipe is later than the veining.

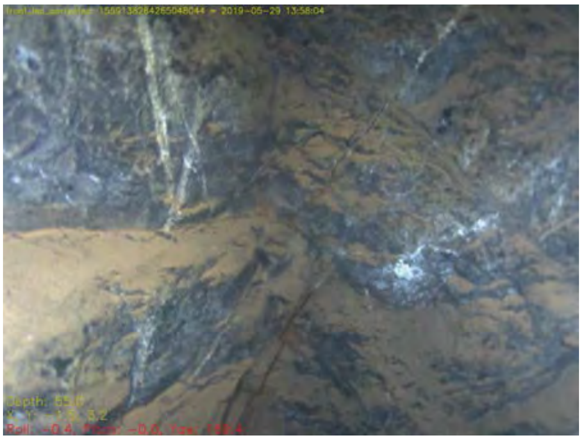

Figure 9.30: Two phase hydrofracturing with calcite infill (-55.0m Winding Shaft).

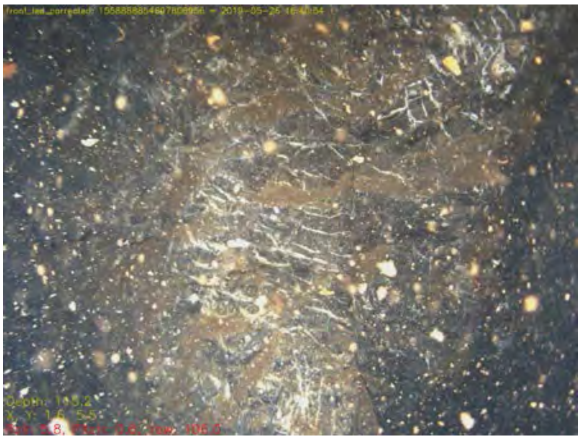

Figure 9.31: Hydraulic fracturing with calcite veining (-115.2m Great Shaft).

Figure 9.32: En echelon hydraulic fracturing with calcite fills (-37.6m Winding Shaft).

Figure 9.33: ?three phases of cross cutting calcite veins in hydraulic fractures. Note displacement of earlier veins by later ones (-37.4m Winding Shaft).

Figure 9.34: En echelon calcite filled cross cutting hydraulic fractures (-36.5m Winding Shaft).

Figure 9.35: Calcite filled cross cutting hydraulic fractures (-36.5m Winding Shaft).

No conclusive evidence of primary ore minerals was identified. Where seen during the UNEXMIN dives the pipe veins have been thoroughly stripped to the host rock walls by the 18th and 19th century miners who have left little evidence of the ore body in the pipe workings explored. Evidence of mineralisation was not common but in close proximity to pipe workings found in both the Great and Winding Shafts discrete 'rusty' patches were observed at a number of locations and in a number of forms. It is probably that these patches represent corroding chalcopyrite deposits similar to that which can be seen just above water level in the accessible Deep Ecton pipe workings, at the launch site here, opposite the base of the ladderway. In the flooded workings, exposure to air for around 100 years during operational mining and subsequently more than 150 years underwater since the deep workings were abandoned has promoted the corrosion. These deposits occur as isolated nodules (Figure 9.36, Figure 9.37 and Figure 9.38) and as bedding parallel to and cross-cutting veinlets (Figure 9.39 and Figure 9.40) and in some instances appear to have associated green secondary (post mining) copper mineralisation (Figure 9.40, Figure 9.41).

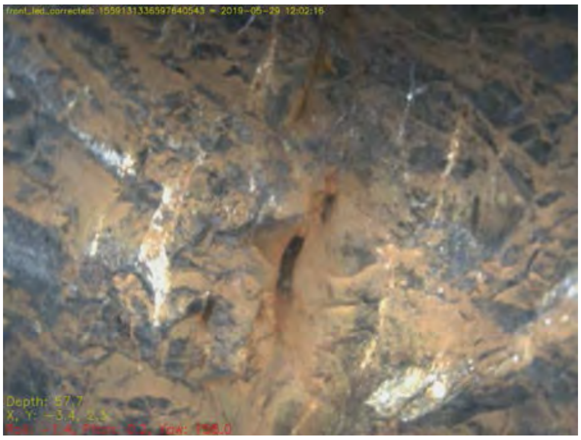

Figure 9.36: Corroding chalcopyrite in thickly bedded limestones (-57.7m Winding Shaft).

Figure 9.37: Corroding chalcopyrite mineralisation (-61.6m Winding Shaft).

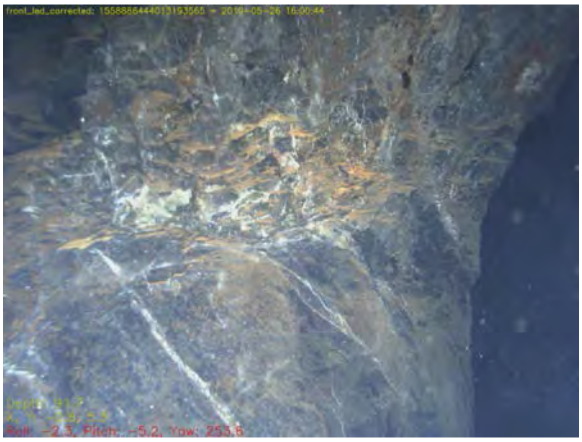

Figure 9.38: Chalcopyrite mineralisation (-91.7m Great Shaft).

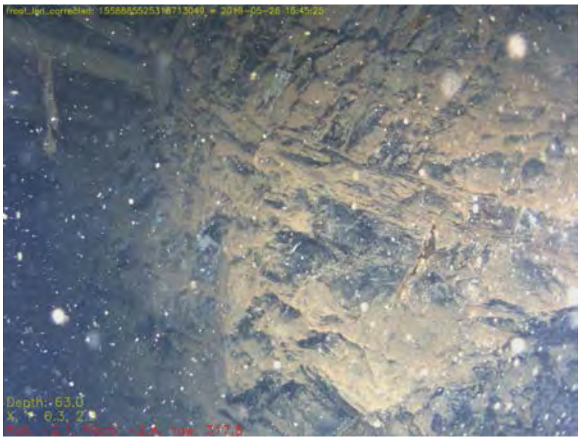

Figure 9.39: Chalcopyrite mineralisation in joint (-63.0m Great Shaft).

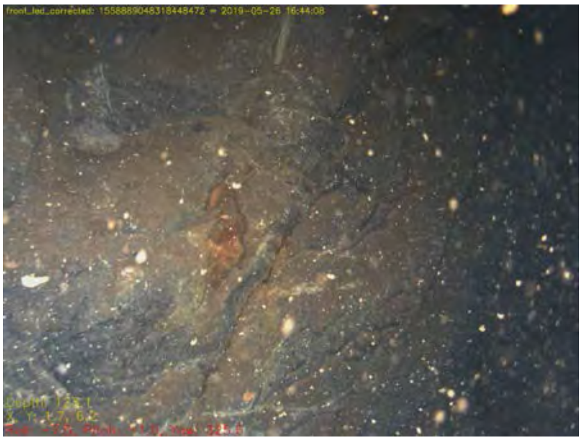

Figure 9.40: Chalcopyrite mineralisation with secondary copper (probably malachite) staining adjacent (-123.1m Great Shaft).

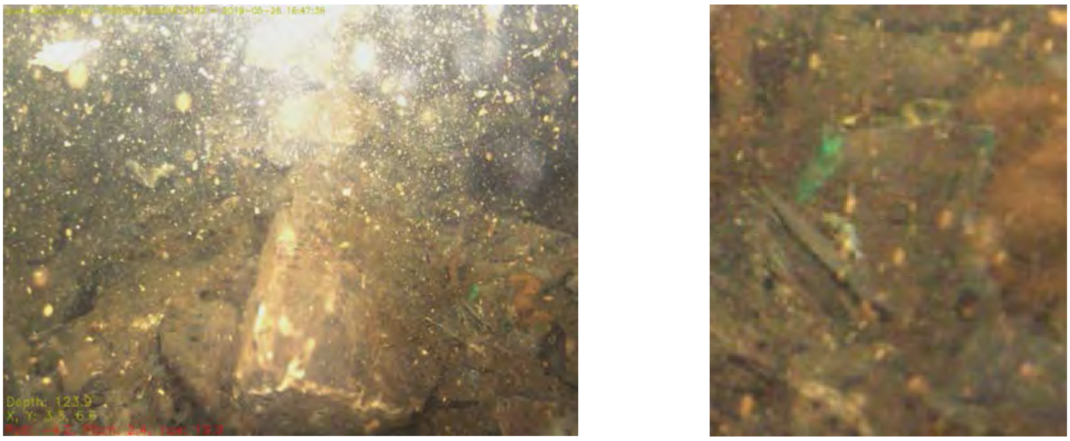

Figure 9.41: Secondary copper (malachite) staining on loose block in blockage (right-hand image is an enlargement of part of the main image) (123.9m Great Shaft).

Apart from the probable secondary malachite noted above one occurrence of malachite was noted on a block of limestone that forms part of the blockage at -123.9m in the Great Shaft. While this is likely to have originated from a higher level in the mine it is the only instance noted (Figure 9.41).

No other ore minerals have yet been certainly identified from the UNEXMIN data.

There are at least two occurrences of enigmatic black patches in the Winding Shaft at -94.2m (Figure 9.42) and -59.6m (Figure 9.43). While these are similar they do not appear to be identical. They both appear to be features within the rock though the -94.2m feature seems to be more of a superficial deposit. They are both hosted in light, calcite veined limestone and may be a more bituminous limestone that has resisted the mineralisation process or are perhaps a manganese or iron rich deposit of some kind though neither appears to be chert. Equally likely they may be the result of mining activity such as blobs of grease shed from mine equipment that have adhered to the walls.

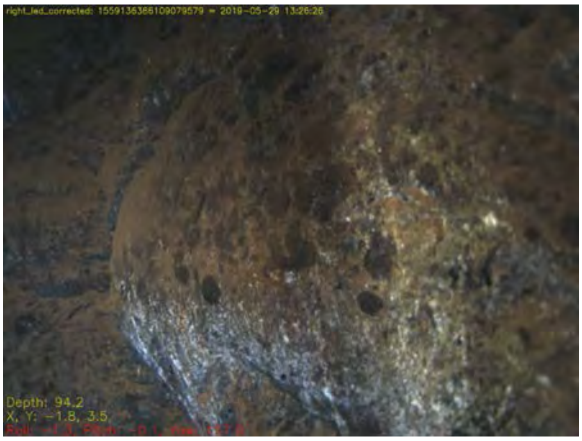

Figure 9.42: Enigmatic black patches (94.2m Winding Shaft).

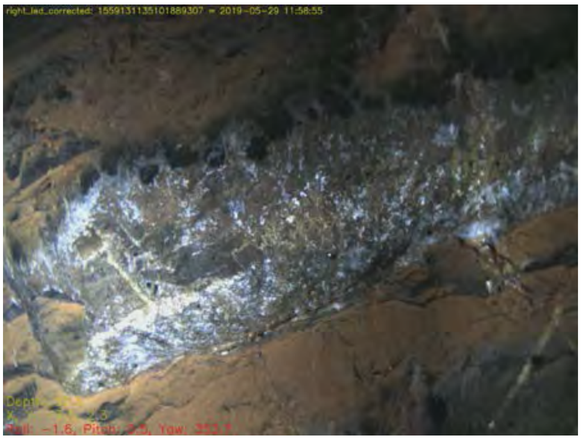

Figure 9.43: Enigmatic black patches (59.6m Winding Shaft).

9.4.4 Ore Deposits

The main Ecton pipe was dived from where it is intersected by Deep Ecton Level and below which it is flooded to a depth of around 55m. It was shown to be a large void, generally larger than the worked out pipe accessible above Deep Ecton Level, with irregular wall profiles and extensive stacked deads on its floor (Figure 9.44, Figure 9.45 and Figure 9.51). Several openings in both the Great and Winding Shafts between about 55m and their respective blockages at over 100m depth are where these shafts have intersected the pipe (Figure 9.46, Figure 9.47, Figure 9.48, Figure 9.49 and Figure 9.50). These were only explored by the UNEXMIN robots for a few metres from the shafts but some were shown to be large voids, again with extensive deposits of deads on the floor.

In all locations observed it is clear that the miners had stripped the pipe of mineralisation leaving only bare host rock limestone walls exposed. The pipe is of varying size though generally increasing in size with increasing depth where followed to about -55m close to the Winding Shaft. Glimpses into the deeper openings in both the Great and Winding Shafts suggest that the worked out pipe is very large. Where followed the upper part of the pipe meanders in direction and has variable inclination, varying from near horizontal to steep, perhaps around 70°, with an average of around 30° over the length explored.

The pipe appears to be hosted within more thickly bedded limestones that have variable dips as well as folds and not within the more thinly bedded facies limestones. It is likely that the host rocks are reef knoll facies limestones, and possibly also near reef knoll limestones, and that their more competent nature and perhaps higher purity are factors in controlling the pipes' formation with influence of structural controls (folding). The reef knolls may well have influenced folding in adjacent rocks.

Figure 9.44: 45° dip in thickly bedded limestones (-17.1m Pipe).

Figure 9.45: Steeply dipping thickly bedded limestones in pipe wall (-57.1m Pipe).

Figure 9.46: Pipe workings in thickly bedded limestones (-58.0m Great Shaft).

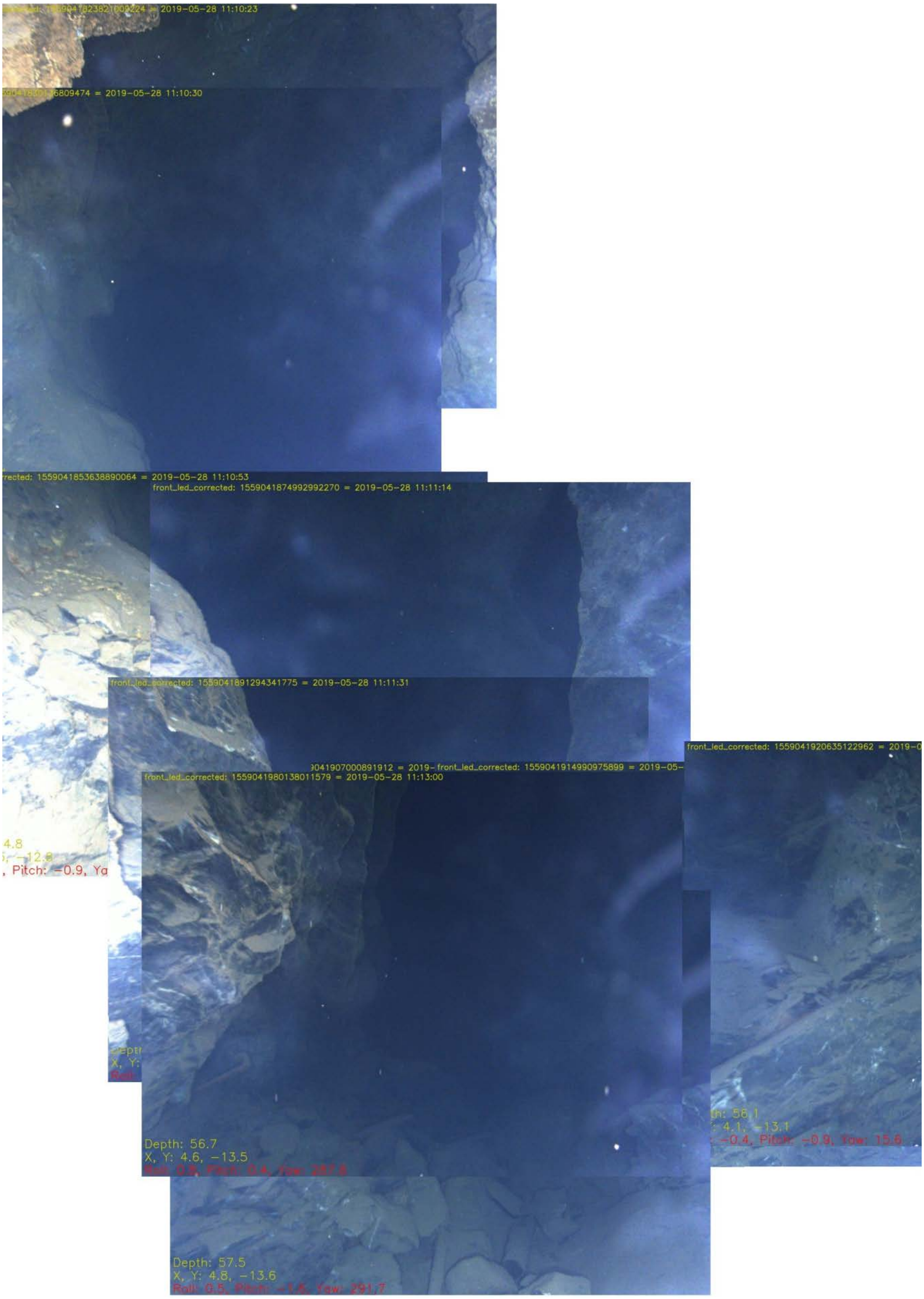

Figure 9.47: Composite image of one of the large pipe workings, over 5m high, encountered in the Great Shaft (-51 to -56m Great Shaft).

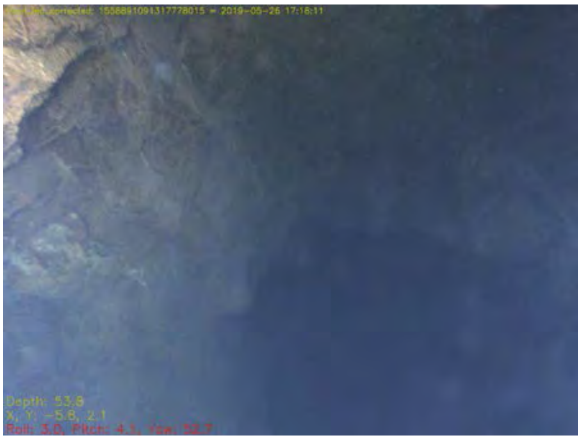

Figure 9.48: Pipe workings, (-53.8m Great Shaft).

Figure 9.49: Edge of worked out pipe. Note calcite veining and chalcopyrite in limestone wall rocks (-91.7m Great Shaft).

Figure 9.50: Large pipe workings (-91.6m Great Shaft).

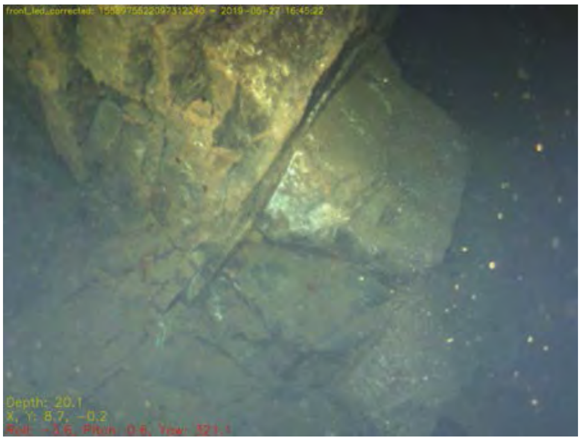

Figure 9.51: 60° in thickly bedded limestone (-20.1m Pipe).

At a depth of -13.8m in the pipe the miners have followed an anticlinal axis and limb into the wall away from the pipe (Figure 9.52). More information is required to enable this to be elucidated but it would appear that the miners were following ore from the pipe into peripheral deposits at this point.

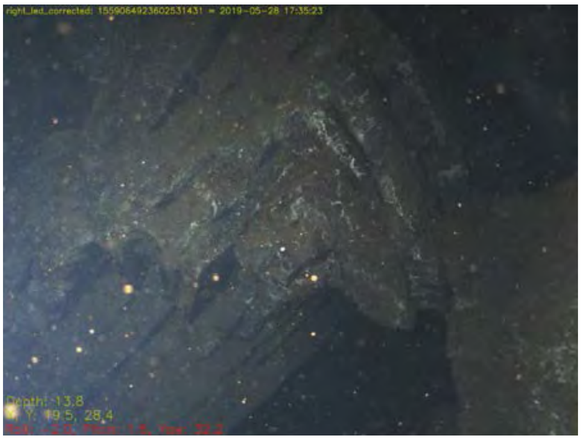

Figure 9.52: ‘Saddle’ workings in pipe wall - one of Watson’s ‘huckle saddles’? (-13.8m Pipe).

No lodes were identified in the parts of the pipe or shafts explored during the UNEXMIN dives.

9.4.5 New Understanding

The UNEXMIN dives at Ecton have added greatly to our knowledge of the Deep Ecton Pipe though much more remains to be elucidated.

Historic information, such as the cross section of the workings produced by Meads in 1858 (Meads, 1858) which is one of the few remaining original representations of the workings at Ecton, and the currently accessible workings in the pipe suggest that the pipe was near vertical over much of its length. The UNEXMIN dives have shown that the pipe is much less steep, at least for the first 50m or so below water surface, dipping at an average of about 30°. This is similar to that reported for the lead pipe vein at Dale Mine, about 1 km west of Deep Ecton. The dives have also shown that the pipe is a much more sinuous feature than previously understood.

The pipe greatly increases in size a short distance below current water level and where of large size it appears to have been developed in more thickly bedded limestones, perhaps mainly reef knoll facies of the Milldale Limestones, and this may be one of the main controlling factors in the development of the ore deposit.

There is extensive development of early, pre main phases of ore mineralisation, hydraulic fractures filled with white calcite in proximity to the pipe. There are at least two and sometimes more than three phases of calcite veining developed and these features developed while the area was undergoing active deformation. Their development is likely to be a precursor event to the main pipe development and infilling. It is highly likely that the miners understood that these calcite veins indicated the nearby presence of pipe.

The saddles described by Watson (1860) as an important part of the Ecton ore deposit may in fact only be a small, subsidiary element of the deposit and not representative of the ore body as a whole. He 'visited' the mine, if indeed he did at all, when it was at an advanced stage in its working life more than 50 years after the most productive phase of mining had ended when the main pipe was exploited and large parts of it were probably flooded. During the 1790s there was an extended phase of activity whereby the walls of the pipe were stripped back in order to extract any remaining ore and in the search for any remaining missed pockets or branches. It is obvious from the pipe as explored by UNEXMIN that this had happened. It may be that during this phase of working it was mainly the saddle deposits that he described that were being exploited at a greater depth than explored in 2019, and that the folds were zones that the ore fluids could penetrate in migrating from the pipe forming peripheral ore deposits.

9.4.6 Conclusions

The ten UNEXMIN dives at Deep Ecton have provided a wealth of new information on the geology of the mine by the remote exploration of the mine workings not seen since the late 1850s and never studied by a ‘modern’ geologist. As suspected they have confirmed that the structural geology of the mine is complex, but, while beyond the scope of this report, large amounts of data are available that will allow a detailed structural study to be undertaken in due course.

The larger parts of the pipe appear to be mainly or entirely within more thickly bedded limestones that are probably a reef knoll facies part of the Milldale Limestones. This may well have formed a favourable host rock for the pipe mineralisation which may have been partially controlled by the structural geology.

The exploration to date confirms that the mine was thoroughly stripped of all ore prior to closure.

The dives have only explored a small fraction, much less than 10%, of the flooded workings at Deep Ecton but have provided a wealth of information as well as some tantalising glimpses of what remains to be explored.

9.5 References

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