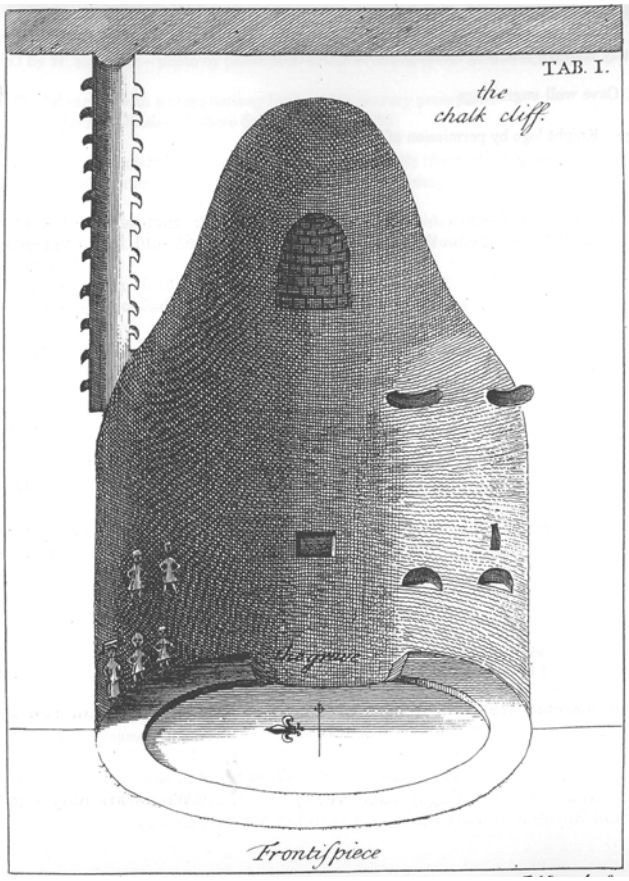
TOBIT CURTEIS ASSOCIATES LLP

CONDITION SURVEY AND DEVELOPMENT OF A CONSERVATION PROGRAMME FOR ROYSTON CAVE, HERTFORDSHIRE



REPORT FOR THE FRIENDS OF ROYSTON CAVE

October 2009

36 Abbey Road Cambridge CB5 8HQ Tel 01223 501958 Fax 01223 304190
E-mail tc@tcassociates.co.uk Web www.tcassociates.co.uk

CONTENTS

1.0 Summary 2
2.0 Introduction 2
3.0 Royston Cave 2
3.1 Structure 3
3.2 Decoration 4
4.0 Discovery and Previous Investigations 7
5.0 Present condition 11
6.0 Causes of Deterioration 15
6.1 Rate of deterioration 15
6.2 Vandalism and intentional changes 17
6.3 Environmental factors 17
6.5 Biological growth 20
6.6 Vibration 22
6.7 Deterioration mechanism 22
7.0 Discussion and Recommendations 24
7.1 Deterioration rate and mechanisms 24
7.2 Recent changes 24
7.3 Conservation recommendations 24
8.0 Limitations 26
9.0 References 26
10.0 Appendix 1: Chalk Analysis 27
11.0 Appendix II: Condition Diagrams and Survey Drawings 28

Report No: RYC01.1a

Date: 21st October 2009

Author: Tobit Curteis Associates LLP
36 Abbey Road, Cambridge CB5 8HQ.
Tel 01223 501958 Fax 01223 304190

ACKNOWLEDGEMENTS

I would like to thank Peter Houldcroft, James Robinson, Sylvia Beamon and Susan Thornton-Bjork for the very extensive information about the recent history of the cave and its deterioration. I am also grateful to English Heritage for their financial support for the current study, and to Malcolm Starr, Robert Gowing, John Stewart, Brian Ridout, Mark Uggles, Matthew Canti, Dave Dugworth and Paul Bryan for information on different aspects of the deterioration, treatment and recording of the cave. The recent photographic recording of the cave was undertaken by Steve Cole and Pat Payne of the English Heritage photographic team for which I am most grateful. I am also grateful to David Park for his comments on the dating of the carving, and to Clifford Price, Christopher Hall and David Odgers for their views on the deterioration mechanisms of the chalk. Thanks are also due to Stanburys, for the detailed surveying and laser modelling of the cave and to Three Valleys Water and Manestream Ltd for the surveys of the water and drainage pipes.

1.0 SUMMARY

Royston Cave is carved into a bed of soft chalk less than a metre under Melbourn Street, in the centre of the town of Royston. Although the cave originally predates the medieval period, it appears that it was enlarged and carved with both Christian and mystical symbols at some point between the 14th and 16th centuries. It was then rediscovered in the middle of the 18th century. No record of the cave before the 18th century is known, but since this time there has been continual deterioration of the carved detail. Over the course of the last fifty years, numerous attempts have been made to understand the deterioration and to repair the damaged carving. However, most studies have ended prematurely and only limited remedial measures have been implemented.

The current study has demonstrated that the primary cause of deterioration appears to be minor dimensional change of the chalk, as a result of fluctuations in the moisture content, resulting largely from periodic flooding. This leads to internal stresses which cause fine cracks to occur, often in the vertical plane between the raised carved detail and the main face of the cave. The fissures are then colonised by microbiological growth and animals, causing the cracks to enlarge and eventually those sections of carving to fall away. It appears that in the past this has been exacerbated by vibration from overhead traffic, although since the opening of the Royston bypass in 1986, this will have been substantially reduced.

In conjunction, damage has being caused to the chalk by worms, which feed on nutrients in the chalk, which have entered as a result of flooding with foul water. The effect of so much worm activity is to cause a loss of cohesion and collapse of certain sections of a softer chalk and a consequent loss of the carved detail. No biocide or other direct treatment appears to be viable due to the possible effect on the chalk and public health and safety issues. At present controlling worm activity can only be achieved by controlling the nutrient source.

Recommendations have been made for a three stage programme of conservation, which involves addressing the underlying causes of deterioration, undertaking remedial measures to stabilise the damaged carvings, and long-term monitoring to assess the effects of the work and to control further damage. The main recommendations are as follows:

- Repairs will be made to the nearby drains to prevent water and sewage infiltration.
- Measures will be undertaken to reduce internal/external air exchange.
- The results of the air exchange controls will be monitored.
- Tests will be undertaken to assess the effect of repair and readhesion tests on the damaged carving.
- Accumulated earth and debris will be removed from the base of the cave.
- A programme of long term condition monitoring will be initiated.

2.0 INTRODUCTION

Situated under the road in the centre of the town, Royston Cave is an intriguing structure, cut into the chalk and decorated in its lower part with a series of religious and mystical figures and symbols. Both its function and date are a matter of considerable conjecture. However, what is clear is that since it was discovered in the mid 18th century, it has deteriorated considerably. Over the course of the last five decades, a number of investigations and programmes of treatment have been undertaken, yet the deterioration has continued. In 2007, the cave was examined by English Heritage and it was recommended that a detailed survey should be undertaken in order to better understand the underlying causes of deterioration, so that effective preventive conservation measures could be designed.

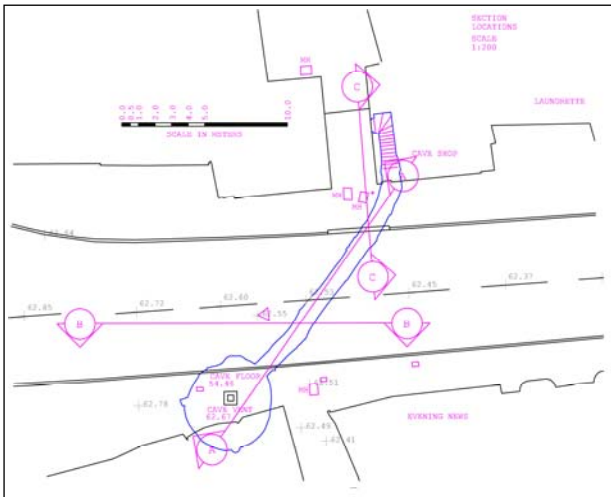
The survey, which was commissioned by the Friends of Royston Cave, with the financial support of English Heritage, was carried out in the summer of 2009 by Tobit Curteis Associates LLP. Copies of this report have been provided for the Friends of Royston Cave and English Heritage.

3.0 ROYSTON CAVE

The small town of Royston is located, some twelve miles to the south west of Cambridge, on the historic crossroads of the Icknield Way and Ermine Street. The town is surrounded by gently undulating agricultural land and while the centre of the town is approximately 63m above sea level, the level rises to over 100m less than a mile to the south.

The town sits on a thick bed of late Cretaceous chalk which runs to the north-east and up to the Norfolk coast. Below this is a bed of gault clay which comes to the surface some way to the north.[1] Although the chalk beds are hundreds of metres deep in some places, very few beds are suitable for building material (the harder chalk known as Clunch, sourced in the lower beds, is one such material) the rest being too soft and friable.[2]

The cave is situated in the centre of Royston just to the south east of the ancient crossroads. It is entered via a tunnel which comes up to the side of No. 8 Melbourn Street. The cave itself is situated on the other side of the road partially beneath No. 3 and No. 5 Melbourn Street, which was formally the post office and is now a betting shop.[3] The cave is Grade I listed.[4]



Figures 1 & 2. Plan and section of the cave

3.1 Structure

The cave is a tall bell like structure, the top of which is approximately 80 cm below the pavement level. *(Figure 1 & 2)* The cave, which has uneven dimensions, is approximately 510 cm in diameter and 750 cm in height. The centre of the cave is approximately 20 cm below a step which forms a ledge around almost the entire circumference of the cave. The base is at approximately 54.4m above sea level and the pavement above is at 62.7m above sea level.

Figure 3. View of the tunnel leading down to the cave. **Figure 4.** View of and the upper part of the cave showing the bricked up top and opening to the pavement, the partially closed ventilation shaft on the right and the original entrance at the bottom.

[1] British Geological Survey, *British Regional Geology, London and The Thames Valley*, London, 1996

[2] Eyers, J., *The Building Stones of Bedfordshire*, www.bedsrigs.org.uk/leaflets/RIGSBuildStones.pdf, accessed on 29/06/09

[3] The cave is at grid reference TL3562940711 and has a postcode of SG8 7BZ.

[4] Historic Buildings Listing 161823

At the top of the cave, there are the remains of a tiled closure, which is now largely lost and there is an open shaft to a grille on the pavement above. The cave is now entered by a tunnel built in 1790 (see section 4, below) which enters on the NNE wall. *(Figure 3)* The original entrance to the cave is the shaft which enters from above on the WNW side at half height and is cut with foot and hand holds. To the north, above the present entrance, is a second smaller shaft that is now closed, with concrete sections at the top, but is thought to have been a ventilation shaft. The lower part of the shaft is built up with carefully cut masonry blocks, some of which have now fallen away. *(Figure 4)*

The walls of the cave are extremely uneven and the structure is asymmetrical. While some of the walls appear to have been intentionally carved, other areas have the appearance of natural formations. The bedding planes of the chalk are clearly visible, running the full circumference of the cave, and the chalk within the different beds sometimes varies in quality.

The extent to which the cave is completely man made or an enlargement of a natural void is unclear. It is also unclear whether there was a man made (or enhanced) structure here prior to the medieval period. It has been suggested that the cave may originally have been a Neolithic flint mine.[5] However, there is very little evidence of flints in the walls as is the case at Grimes Graves, an extensive Neolithic flint mining works some 40 miles to the north east, near Thetford. If the cave is indeed Neolithic in date, it appears more likely that it may have been a marl pit, for the mining of building chalk.[6]

3.2 Decoration

The main area of carved decoration is in a band on the lower 200 cm of the cave walls. *(Figure 5)* This comprises a number of recognisable Christian scenes including Crucifixions, the figures of St Christopher and St Catherine, St Lawrence, the Holy Family, a knight thought to be St George, and a number of crowned figures. *(Figures 6, 7, 8 & 9,)* There are also many figurative and decorative motifs apparently with mystical symbolism, including a prancing horse and a female fertility figure.[7]

The main figures and scenes have been carved by reducing the surrounding chalk surface and stand proud of the recessed surface by up to 25mm (e.g. St Catherine). Other figures have been carved in areas of the recessed surface either by simple incisions, creating what is effectively a line drawing, or by cutting around the figure creating some level of relief, but with a surface at the same level as the surrounding chalk (e.g. the female fertility figure).

There have been suggestions that the upper part of the cave was also decorated with carvings, but these have largely been lost. There is evidence of a timber floor structure surviving at half height in the cave, but there is little evidence of detailed figurative decoration of the type seen at the base of the cave, although some small incised faces and symbols are present. *(Figure 10)*

The highly corroded remains of nails were found in a number of areas over some of the openings at half height in the cave. *(Figure 11)* This appears to suggest that something, possibly a material, was attached over these openings and that they were hidden or closed off. The significance of this is unclear, although it does suggest that some form of ceremonial activity might have taken place at this height in the cave.

---

[5] Beamon 1992

[6] I am most grateful to Dr Peter Topping for his comments on this matter.

[7] VCH 1912

Figure 6. (Previous page) Panoramic view of the carved lower walls of the cave.

Figures 7, 8 & 9. (Left & above) Details of the carving including St Catherine, the Crucifixion, St Lawrence, the horse and the female fertility symbol.

Figures 10 & 11 (Above) An incised face at half height in the cave and corroded nails around the openings.

The iconography in the cave has been the subject of a number of extensive studies from the moment it was discovered, some of which have been highly acrimonious.[8] In recent years a number of detailed studies have suggested links with the Order of Knights Templar, whose presence in Royston is well documented, as well as with the Order of Masons.[9]

Polychrome decoration was observed in a number of areas, most commonly at low level on the background to the figures, where yellow, or sometimes red, areas of paint were observed. *(Figure 12)* Small fragments were seen on some of the figures, as well as in some of the incisions. *(Figure 13)* There is some debate as to whether the polychromy is original or whether it was applied after the cave was rediscovered. Elemental analysis undertaken in the 1970s showed the presence of chromium (which would suggest a later date) although it is not clear whether this was part of the pigment layer or a contaminant.[10]

Analysis undertaken during the current study showed the presence of red and yellow ochre. [11] The paint layers were weakly bound and disrupted and there was no physical evidence to indicate whether the pigment was original or applied at a later date. However, the condition of the chalk surface indicates that significant material loss has occurred in most areas. It seems unlikely therefore that original paint would have survived when so much of the chalk did not. It is possible that fragments of pigment interstices may have been protected better, but there is no consistency in different areas. Therefore, it seems likely that much of the polychromy presently visible was applied at a date later than the carvings themselves were made. Whether this occurred in two separate phases (early and late applications) is not apparent from physical evidence.

Figures 12 & 13 (Above) Pigment on the background of the figures and in the incisions.

Throughout the cave, there are widespread areas of incised graffiti. By far the largest concentration of graffiti was on the lower part of the cave on and amongst the figures. *(Figure 14)* In many cases, the graffiti included dates from the mid to late 19th century. *(Figure 15)* In addition to graffiti showing text and dates there are a number of incised figurative elements including hearts within hands, a symbol of charity with Masonic links. In the case of the older graffiti and incisions, the deterioration was such that it was extremely difficult in places to distinguish

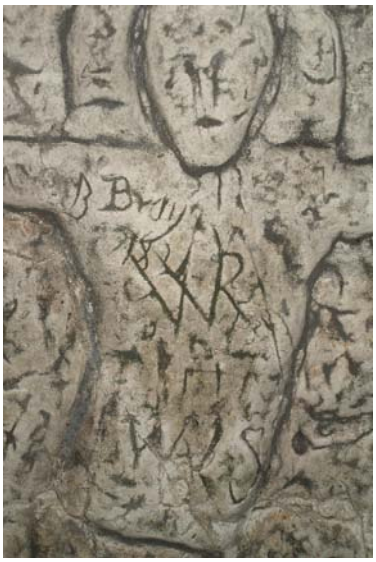
[8] Stukeley 1742

[9] Op. Cit. Beamon 1992 and Houldcroft 2004

[10] Op. Cit. Beamon 1992

[11] A programme of paint analysis was undertaken in order to examine the nature of the pigment. Cross sections were mounted in clear polyester resin and examined under normal and ultra violet illumination at up to x400 magnification. Dispersed samples were mounted in an adhesive of a known refractive index and examined in transmitted light at up to x1000 magnification. Microscopic analysis was undertaken on a Leitz Diaplan with an additional Volpi Intralux 5000-1 fibre optic light source. Pigment and materials identification was made on the basis of visual examination.

between original and later incised decoration. It also appears possible that some of the figures have been manipulated or re-carved, in an attempt to tidy them up, or make them conform to a particular set of meanings.[12]



Figures 14 & 15 (Above) Incisions and graffiti on the figures and background.

Accurately dating the carving is extremely difficult. Due to the friable nature of the chalk and the loss of so much detail, little material evidence survives and stylistic comparisons are hard to make. In addition, the graffiti and the possible manipulation of some of the images, which has occurred since their discovery, further complicates the situation. It seems possible that the main relief figures are original and the incised figures were added later, but there is no clear evidence of whether this was significantly later or as a second early phase. From what can be seen, it seems likely on stylistic grounds that the carving dates to the 14th rather than the 13th century as has sometimes been suggested. However, it is possible that some of the carvings were added as late as the 16th century.

4.0 Discovery and Previous Investigations

The following table summarises the main events since the rediscovery of the cave in the 18th century, which have relevance for its the deterioration and present condition.

Date	Event
1742	The cave was discovered in the summer of 1742, when alterations were being made in the Butter Market, situated above the cave. Excavations revealed a millstone a foot below the surface, which was lifted to show a shaft which led down into the cave (the present north west shaft). The cave was found to be full of earth and rubbish, which was subsequently removed, in the expectation that the cave contained treasure. It was observed that the small shaft on the north east side, thought to be a ventilation hole, was built up with masonry blocks, initially thought to be bricks.[13] The cave was subsequently examined and published by the Rev. William Stukeley. [14] *(Figure 16)*
1790	In 1790, the present access tunnel was built by a Mr Watson, who lived in the town house on the other side of the street, and visitors were charged to enter the cave. It is understood that during the early 19th century, access to the cave was often uncontrolled as can be seen from the extensive graffiti of this period.[15] The date at which the tiled roof of the cave was destroyed and the ventilation shaft to the pavement constructed, is not known.
1858	The cave was again examined and published by Joseph Bedlam.[16] *(Figures 17 & 18)*

[12] There has been considerable discussion among authors as to which of the incised features are original and which are applied at a later date.

[13] Bedlam, J', *The Royston Cave: Being The Substance of a Report some time presented to the Royal Society of Antiquaries*, London (1884)

[14] Stukeley, W., *Palaeographia Britannica or discourses on Antiquities in Britain no.I, Origines Roystonianae, or an account of the Oratory of lady Roisia, Foundress of Royston discovered in Royston in August 1742.*

[15] Op. Cit, Houldcroft, 2008

[16] Bedlam, J', *The Royston Cave: Being The Substance of a Report some time presented to the Royal Society of Antiquaries*, London (1884)

1888	In 1888 work was being carried out on a cellar beneath the new post office on the north side of Melbourn Street and a hole was inadvertently made in the wall of the cave on the upper east side. This was subsequently bricked up and the cellar used for the storage of coal.[17]
1924	In March and October 1924 surveys were undertaken by the Department of the Environment. The March report stated that, while the cave was very damp and the chalk soft, the carvings were in "a very fair state of preservation" and that no remedial work was necessary, although an annual inspection was recommended. The report on the October inspection reiterated the point about damp and recommended increasing ventilation by opening panels in the main door.[18]
1951	In March and November 1951 two further inspections were made by the Department of the Environment. These recorded that the moisture levels were still high and that some surface flaking had taken place. It was also observed that the microclimate was likely to be stable and warned against drying the cave by excessive ventilation, because of the risk of the deterioration accelerating. It was noted that, as a result of the use of electric lighting, rather than the previously used oil lamps, the blackened surface was becoming "clean". This would appear to indicate that surface loss was taking place. In addition, the report refers to the inappropriateness of the black cement repairs, indicating that these were undertaken in the period between 1924 and 1951. [19] It was also recommended that a complete photographic survey should be undertaken. It seems likely that these are the images now held in the Royston Museum and published by Beamon in 1992.[20]
1972	In December 1972, the cave was photographed in detail by the Courtauld Institute and the images lodged with the Conway Library.[21]
1972 & 1973	In June 1972 and May 1973 resistivity studies of the floor of the cave were carried out by the Department of Geodesy and Geophysics at the University of Cambridge and subsequently, in March 1976, archaeological investigations were undertaken. Although a number of holes were identified in the floor of the cave, as well as various artefacts from the 18th and 19th centuries, no finds associated with the early history of the cave were identified.[22]
1980	In 1980 the cave was inspected by conservators from the British Museum. It was observed that the high humidity in the cave was not in itself a particular risk, but that the infiltration of liquid water was likely to cause damage. They noted that significant damage had occurred in recent decades, and attributed this to the excessive moisture problems and, possibly, to the vibrations from the traffic on the road above. Recommendations were made to try and prevent liquid water infiltration, including repairs to the pavement and the installation of below ground drainage systems. It was recommended that no consolidation of the carvings should be carried out until the environmental conditions were satisfactory. [23]
1980s & 1990s	During the 1980s and early 1990s there were a number of inspections carried out by English Heritage, which noted increasing deterioration and discussed possible approaches to control.[24] This included an inspection by the architect Bernard Fielden which noted an increase in microbiological growth. It is understood that during this period, Cecil Rhodes Partnership (surveyors) were appointed to oversee the treatment of the cave.
1996 & 1997	In 1996 a set of photographs was taken by the Royal Commission on Historic Monuments and in 1997, a second set of images was taken by English Heritage. At this time also, the east shaft was opened up to the pavement above and rebuilt with concrete slabs at the top. Repairs were also made to the post office damage on the north east wall and short plastic drain pipes were installed in order that accumulated water would fall clear of the walls. Following the removal of the scaffolding it is understood that the walls were brushed down by the scaffolders.[25]
2001	A survey of the cave and a programme of emergency treatment was undertaken by Hirst Conservation.[26] Treatment included the repair of exposed or vulnerable edges using deep mortars of 1:2:1 NHL2 hydraulic lime: silver sand: whiting and surface fills of 1:1:1.7:0.3 NHL2 hydraulic lime, whiting, marble dust, brick dust. These repairs remain in place and are relatively

[17] DOE unpublished report 1924.
[18] DOE unpublished report 1924, October Appendix.
[19] DOE unpublished report and covering letter December 1951
[20] Op. Cit. Beamon, 1992, Figures 22 & 27
[21] The catalogue entries at the Conway Library are B73/12-37
[22] Beamon, S. and Donel, L. "An Investigation of Royston Cave", *Proceedings of the Cambridge Antiquaries Society*, LXVIII, (1978) pp.47-58
[23] British Museum report, 1980
[24] Malcolm Starr, summary of English Heritage records September 1978 – July 2006
[25] Pers. Com. Peter Houldcroft
[26] Hirst Conservation, *Royston Cave, Preliminary Investigation And Emergency Treatments*, March 2001

	hard in comparison to the original material. Areas of delaminated chalk carving were faced with acid free tissue adhered with PVA. This is no longer present although the cracks remain. It is not clear when it was removed.
2002 - 2004	Between 2002 and 2004, some environmental monitoring was undertaken by Hirst Conservation. It is understood that this was hampered by the periodic failure of monitoring equipment and the numeric data has not been seen by the author.[27] The conclusions of the study are discussed below, but the possibility of introducing low level heating and ventilation to control microbiological growth was considered, and its risks discussed.
2004	In January and May 2004 investigations of biological deterioration were undertaken by Environmental Buildings Solutions Ltd.[28] This concluded that there was infestation with common webbing cloths moth (Tineola bisselliella) which was causing damage to the carving. It also noted that there was blue green algae, lichens, mosses and moulds. These were largely in the lower 100cm of the cave but there was evidence for previous infestation higher up. Recommendations were made to clean off the moth infestation, prevent water ingress and introduce low level heating, and to undertake further environmental monitoring. The report also stated that chemical biocide treatment was not necessary. [29]
2007	A further investigation of the biological deterioration was undertaken by Brian Ridout at English Heritage in 2007. This identified Spring Tails (Collembola), fungus gnat (Speolepta leptogaster), spiders (Nesticus cellulanus) and, large numbers of small 'brandling worm' (Eisenia foetida). No common webbing cloths moths were observed. It was concluded that while some biocides were available which could kill the worms, such as Carbayl, Benomyl, Carbenzadim and Thiophanate methyl, there was a real question as to whether these could be effectively applied to the contaminated areas and the effect that this might have on the, already weak, chalk. [30]
2008	As part of the present study, a complete photographic survey of the cave was undertaken by the English Heritage photography department in December 2008.[31] A detailed topographical survey was also carried out by Stanburys, who also undertook close range laser scanning and produced a highly accurate 3-D model of the cave. *(Figure 19 & Diagrams 6 - 10)* A survey of the local drainage system was undertaken by Manestream Ltd and a survey of the water pipes was undertaken by Three Valleys Water. [32]

[27] Hirst Conservation, summary report for the Rhodes Partnership, 15th April 2004

[28] Environmental Building Solutions Ltd., *Royston Cave, Royston, Hertfordshire, Diagnostic Non-Destructive Biological Investigation and Survey*, January & May 2004

[29] It is understood that the work from the 1990s until 2004 was overseen by the Rhodes Partnership, surveyors.

[30] Ridout, B., *The Deterioration Of Medieval Chalk Carving At Royston Cave, Royston*, June 2007

[31] I am most grateful to Steve Cole and Pat Payne of the English Heritage Photography Department for undertaking the photographic survey.

[32] www.stanburys.com. A copy of the 3D survey is included on the CDROM in hard copies of this report.

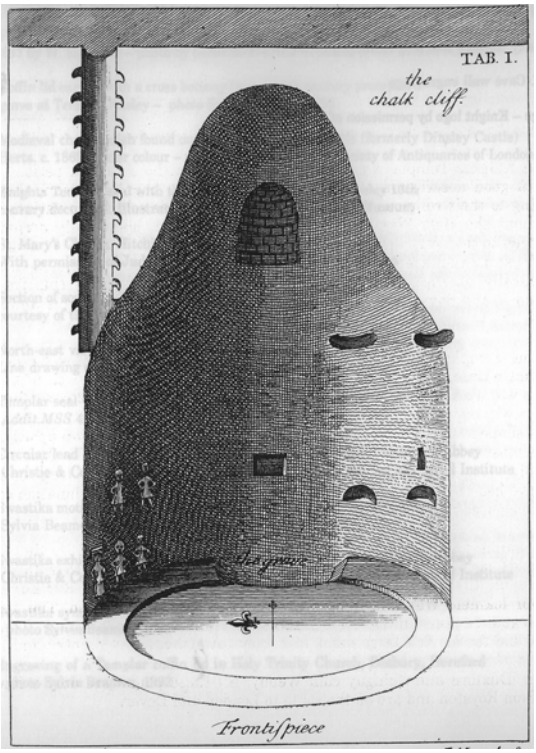


Figure 16. (Above) Drawing of the cave published by Stukeley in 1742.

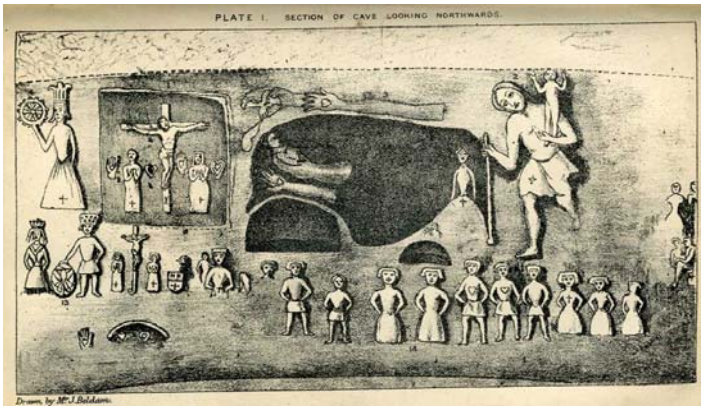


Figure 17 & 18. (Above) Drawing of the carving on the lower walls of the cave published by Bedlam in 1854.

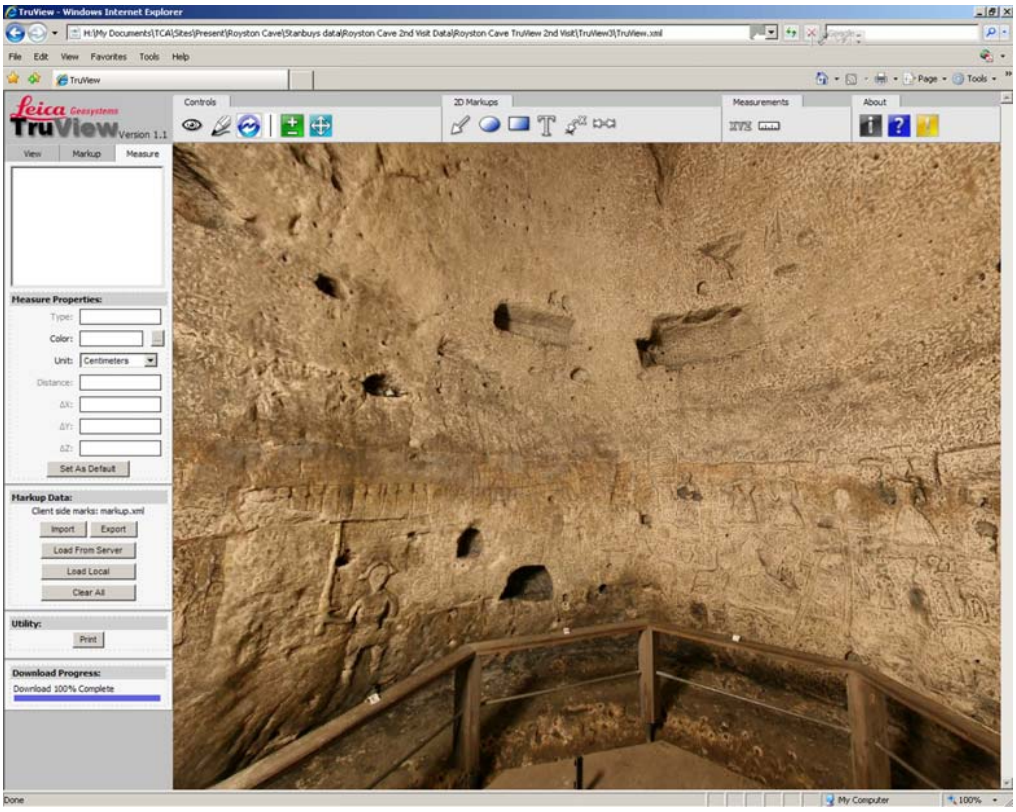


Figure 19. (Above) Close range laser scanning undertaken by Stanburys.

5.0 PRESENT CONDITION

It is understood that the structure of the cave is largely stable.[33] There are some areas where sections of masonry are loose, particularly around the edge of bedding planes higher in the cave, and there are numerous historic cracks, both horizontally along the line of the bedding planes, and vertically up the walls of the cave. However these appear largely to be old, and there is little sign of recent movement. *(Figure 20 & Diagrams 1 - 6)*

Figure 20. Damage to the upper parts of the walls. **Figure 21,** Deterioration of sharp edges has caused the loss of facial features

Different areas of the cave surface have, at various periods, been cut back to different levels. This is reflected in the varying levels of tool marks which are seen throughout the cave. In all areas, there has been significant loss of fine detail and sharp edges, due to the loss of cohesion and powdering of the chalk surface which has apparently occurred over a long period of time. Therefore, what would have been hard edges and sharp details, all now appear soft and rounded, and in some cases figurative elements are almost entirely lost. This is particularly noticeable with details such as facial features. *(Figure 21)*

Figure 22. (Left) Washing of the walls below the damage on the north east side.

Figure 23. (Right) Loss of a large area of stone above the figure of St George.

Figures 24 & 25. (Below) Loss of small decorative elements such as heads.

[33] Pers. Com. James Robinson

The upper parts of the wall, beneath the post office cellar damage on the north east side, show signs of long term water infiltration, with hard calcified flakes of chalk on the surface and the soft material washed out behind. A significant proportion of the dirt and worm casts observed elsewhere have been washed down in this area. *(Figure 22)*

The most serious damage to the carved detail has been caused by delamination and loss of large sections of raised carving. This has tended to occur on the most detailed areas, such as heads and arms, but has also occurred on other areas of background. As a result, losses vary between large flakes of stone, sometimes up to half a metre in length, *(Figure 23)* to small figurative details. *(Figures 24 & 25)* The damage appears to have taken place over a considerable period of time, and while some date to the original discovery of the cave, other areas have occurred in the last couple of years.

A close examination of the surface in raking light showed that in many areas, fine hairline cracks had opened up behind areas of raised detail, suggesting that the deterioration mechanism is ongoing, and further loss is likely to take place. *(Figures 26 & 27)*

Figures 26 & 27. (Left) Recent cracking indicating areas of potential loss on the head of St John and the crown of St Catherine.

The whole of the available surface has suffered from extensive graffiti. This is most extreme on the lower part of the walls, where access has been easiest since the cave was opened up in the 18th century. However, there are traces of graffiti on the upper part of the cave walls and also in the north shaft, which was the original entrance. Some of the graffiti comprises simply names and dates, while in other cases, crude figurative or decorative details have been incised.

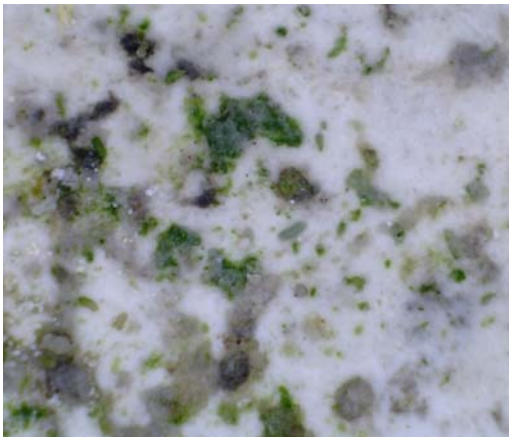
Much of the surface of the cave is covered with fine worm casts. These vary considerably in size and colour. In many areas on the surface of the stone there are deposits of casts less than 1mm in thickness, which accumulate in indents and interstices and are hard to distinguish apart from each other. *(Figure 28)* In other areas the casts are in small individual groups. *(Figure 29)* Colours also vary from white to brown and black depending on the location and the material consumed by the worms. On the floor of the cave and on the low step there is a thick accumulation of mud and black worm casts which entirely covers the chalk. *(Figure 30)*

Figures 28, 29 & 30. Different types and distributions of worm casts on the walls and floor of the cave.

While the accumulation of worm casts is disfiguring, far more serious is the structural damage caused by the worms burrowing through the chalk. This has left some areas with a honeycomb appearance and, in certain sections, has led to the loss of large areas of detail. *(Figure 31)*

Figures 31. Loss of cohesion and detail due to worm damage

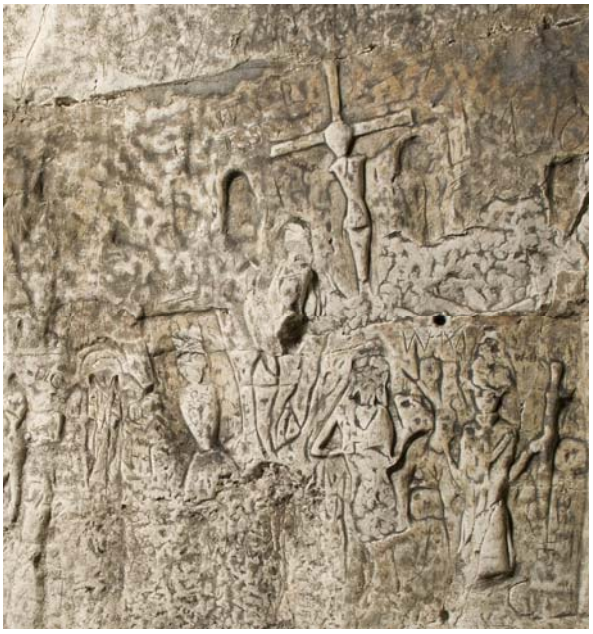
Extensive areas of microbiological growth were observed, mostly on the lower part of the cave. *(Figure 32)* Much of the material is black or brown and is hard to distinguish from the dirt layer which has accumulated on the lower 100cm of the cave walls. Some areas of green growth were also observed, but these are generally small patches distributed over large areas. This was most noticeable on the eastern section by the figure of St George. *(Figure 33)* Green microbiological growth was also observed in the entrance tunnel near to the upper door and the fluorescent lights, indicating the photosynthetic nature of the organisms.



Figures 32 & 33. Small areas of microbiological growing on the lower part of the wall on the east side. (Photomicrograph x200 magnification)

The painting is extremely fragmentary as a result of considerable mechanical damage, including graffiti and surface abrasion. The polychromy that survives is sometimes protected from abrasion in small interstices with more exposed material having been lost. The paint generally has a weak level of cohesion, and the level of adhesion to the substrate is low. However, although it remains vulnerable to mechanical damage, the high moisture content means that it is not powdering or flaking.

Over much of the east side of the cave there is a brown stain on the chalk and painted surface. *(Figure 34) (See Diagrams 1 - 5)* This had previously been thought to be some form of dirt or water staining, particularly as part of it is located below the "post office" damage, where water leakage has been common. In addition, because of the location of the stain low on the wall, it is virtually indistinguishable from the dirt which has accumulated on the base of the wall, which is probably the result of water splashing. (In the diagrams both areas are included, as they are generally impossible to tell apart).



Figures 34 & 35. Brown staining and coating on the east wall. Note the small patches of coating on the robes of the figure of the bishop

However, the nature and distribution in some areas suggests that the staining may, in part, be the remains of an historic coating or consolidant of the type often used in the 19th and early 20th centuries for treating damaged

stonework and wall paintings. *(Figure 35)* Under UV illumination on site it was found that the coating had a weak greenish fluorescence. However, UV illumination in cross section did not show a discrete coating. Apart from the discolouration, there are no obvious patterns of deterioration associated with this phenomenon and so, at this stage, more in depth investigations of the material are not felt to be necessary.[34]

The floor of the cave, as well as protruding sections of carving, are often covered with dirt and debris which has fallen into the cave from the grille in the pavement above. After only a week of the survey, the upper lift of the scaffolding showed a considerable accumulation of debris from this source, clearly demonstrating the volume of material entering the cave via this route. *(Figures 36 &37)*

Figures 36 & 37. Accumulated debris and worm casts on the cave step, and the material which fell through the grille onto the scaffolding boards in less than a week.

6.0 CAUSES OF DETERIORATION

The carved decoration in the cave has deteriorated, both as a result of historic mechanisms, which are no longer active, and more recent or current mechanisms which continue to cause deterioration.

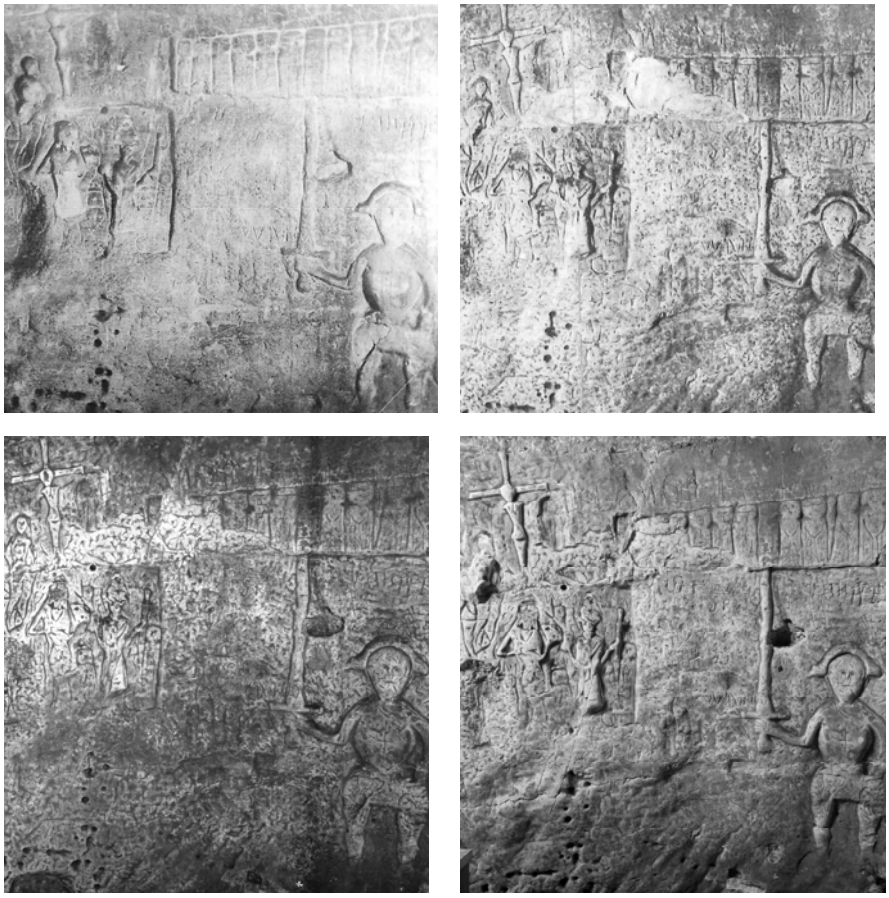
6.1 Rate of deterioration

Given the subterranean location of the cave, it is likely that deterioration has occurred since it was first constructed. However, because of its subsequent burial and the lack of any documentary records, the rate of deterioration can only start to be assessed from the time that it was rediscovered in the 18th century. However, the 18th and 19th century records are limited and are only really suitable for identifying gross change. Assessing the rate of more subtle deterioration can only take place from the advent of photographic records in the 20th century.

The earliest photographs seen as part of the present survey date to 1911.[35] One of the images shows the area to the left of the figure of St George. Here, it is important to note the condition of the small incised figures above the sword of St George. *(Figure 38)* A photograph of the same area in c.1952 shows very severe loss of a large section of the surface of this area, indicating rapid deterioration. *(Figure 39)* However, images of the same area in 1997 and 2009 show little change. *(Figures 40 & 41)*

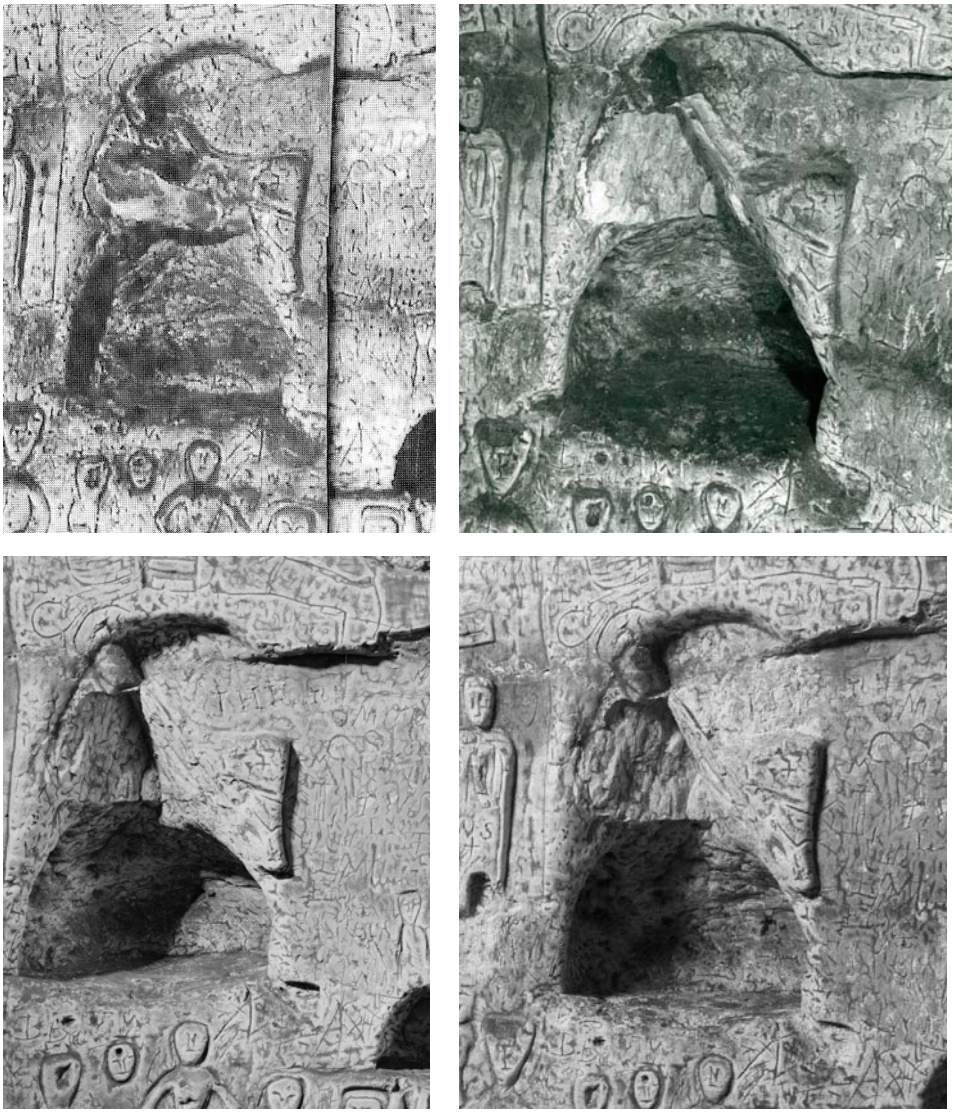
This should not be taken to indicate that serious deterioration in the cave is merely historic. An image in c.1952 of the “Sepulchre “ area on the west side of the cave clearly shows two reclining figures. *(Figure 42)*
When it was photographed in 1973, a large section on the lower left had fallen away, taking with it most of the figures. *(Figure 43)* In 1997, there had been no further gross deterioration, and the graffiti to the immediate right of the figures was still visible. *(Figure 44)* However, by 2009, this was almost totally illegible due to worm damage. *(Figure 45)*

[34] Instrumental analysis could be used to determine the nature of the material and, by implication the reason for its application.
[35] Photographs of c.1911 by R. Clark are published in Op. Cit. Beamon 1992



Figures 38, 39, 40 & 41. (Left to right) Images of the north east side of the cave in 1911, 1952, 1997 and 2009. Note the loss of the large areas of stone on the upper right between 1911 and 1952.

Figures 42, 43, 44 & 45. (left to right) Details of the sepulchre on the SW area of the cave in 1952, 1972, 1997 and 2009. Note the loss of the reclining figures between 1952 and 1972 and the loss of the graffiti between 1997 and 2009.



Numerous other examples of this type of progressive, but uneven, deterioration can be seen in the photographic documentation and the present survey has shown many areas where deterioration remains active.

What this demonstrates is that the deterioration is neither uniform, nor at a steady rate throughout the cave. Different sections of carving have clearly suffered varying rates of deterioration during different periods, depending on the underlying causes. Nevertheless, it is interesting to note that there has been little loss of large cohesive sections of stone since the first half of the 20th century.

6.2 Vandalism and intentional changes

By far the most visible example of vandalism is the graffiti which can be found over most of the lower area of carving, and in some places on the walls above. It seems likely that this occurred from the earliest times that the cave was open to the public in the 18th century and then continued throughout the 19th century. No 20th century dates have been seen, and it is assumed that, by this time, greater care was taken with the way in which the public were allowed into the cave. As discussed above, in many cases, the graffiti merely takes the form of names and dates. However, there are numerous areas where there are incised symbols and even figures.

It is possible that, alterations or “enhancements” were made to some areas of carving soon after the cave was rediscovered and open to the public. However, it is almost impossible to determine where this may have taken place, due to subsequent deterioration.

It is also possible that additions were made to the original carvings, prior to the cave having been filled in. Again, it is not clear what these might be, but the different types of carving discussed in the previous section of this report indicate that this might well have been the case.

6.3 Environmental factors

It appears that a significant number of the deterioration mechanisms encountered in the cave are associated with environmental factors, principally water in its liquid and vapour phases.

6.3.1 Microclimate

At different periods in the cave's history, there will have been significant changes in the environmental conditions. The most notable variation is likely to have occurred between the periods when the cave was open (as it was originally and was again from the 18th century), and when it was filled with earth. However, at all times, it is unlikely that the cave would have been anything but extremely damp.

A study of the microclimate in the cave, carried out between 2002 and 2004, indicated that the microclimatic conditions within the cave were extremely stable. Over the course of the year, the ambient temperature remained between approximately 14°C and 18°C and the relative humidity fluctuated between 98% and 100%. The dew point temperature remained relatively high and stable during this period and it appears likely that both superficial and interstitial condensation would have occurred regularly.[36] Spot readings taken during the course of the present survey showed RH levels of 92 – 94 % with temperatures of 13-14°C. Further long term monitoring has not been undertaken, but this may indicate that the moisture levels have decreased since measures were implemented to control flooding in 2000. (See below)

In the absence of other influences, the cave structure will provide good hygral and thermal buffering between the external conditions, which will be typically unstable, and the internal conditions which will be very stable. Air exchange with the external environment, either as a result of visitor use or deliberate ventilation intended to influence the internal environment, will destabilise the conditions, encouraging evaporation and absorption of moisture from the chalk substrate. It was not clear from the available data the extent to which this might be a significant deterioration factor.

In the past it has been suggested that air exchange should be increased and low level heating introduced in order to try and “dry” the cave and reduce microbiological activity. However, the results of the present survey suggest that such an approach might accelerate deterioration as evaporation from the chalk surface increased. In addition, as the cave will always be subject to ground water infiltration, the “drying” is unlikely to be stable or sustainable. Therefore, this approach is not recommended in the current report.

---

[36] Hirst Conservation , environmental monitoring results and covering letter, 15th April 2004. The environmental survey suffered from regular data loss as a result of equipment failure and sensor accuracy levels were not stated. On some occasions, very unusual local conditions were observed in some areas of the cave, but it seems likely that these are associated with anomalies in the monitoring system rather than genuine microclimatic variations.

6.3.2 Flooding

Records suggest that periodic flooding had occurred since the late 19th century and there is no reason to believe that it has not, in fact, been a problem throughout the history of the cave. During the 1990s in particular, the cave was subject to severe flooding on a number of occasions and water was observed running down the north east walls, but not on the south and west sides. This is understood to have been largely the result of the failure of the drainage system in the alleyway between No. 3 and No. 5 Melbourn Street, and blockages from the drainage pipes in this area, which allowed water to enter the cave through fissures in the chalk.[37] In addition, significant infiltration took place through the area of damage caused by the post office cellar, leaving the obvious line of damage on the north east wall of the cave. Water ingress was also observed from the roof of the lower part of the tunnel.[38] In 1998, severe flooding occurred and the water was found to be contaminated with sewage.[39] Further serious flooding occurred in 2000 and it is understood that the water level was up to 50cm above the height of the floor.[40]

Repairs were made to the drainage pipes and the alleyway was repaired and resurfaced in 2001. *(Figure 46)* Repairs were also made to the damaged area of the wall by the post office cellar, and plastic pipes were installed to throw any continuing leakage water clear of the wall. This appeared to have the desired effect and the level and frequency of flooding was reduced significantly. However, during heavy rain, some flooding is still understood to take place. During the course of the survey, some minor leakage was noted at the top of the ventilation shaft, *(Figure 47)* and during periods of heavy rain, small amounts of water were found to be running down the lower walls of the entrance tunnel. In addition, some rainwater falls through the open pavement grille.

Figure 46.The repaired passageway above the north east side of the cave.
Figure 47. Minor leaks on top of the ventilation shaft.

-

An electrical capacitance survey indicated high levels of superficial moisture in all areas of the cave, with a slight increase towards the upper part of the walls. Variations were observed where the nature and condition of the chalk changed, and the marginally higher levels recorded towards the top of the cave may be due to this, rather than a variation in the water source. [41]

---

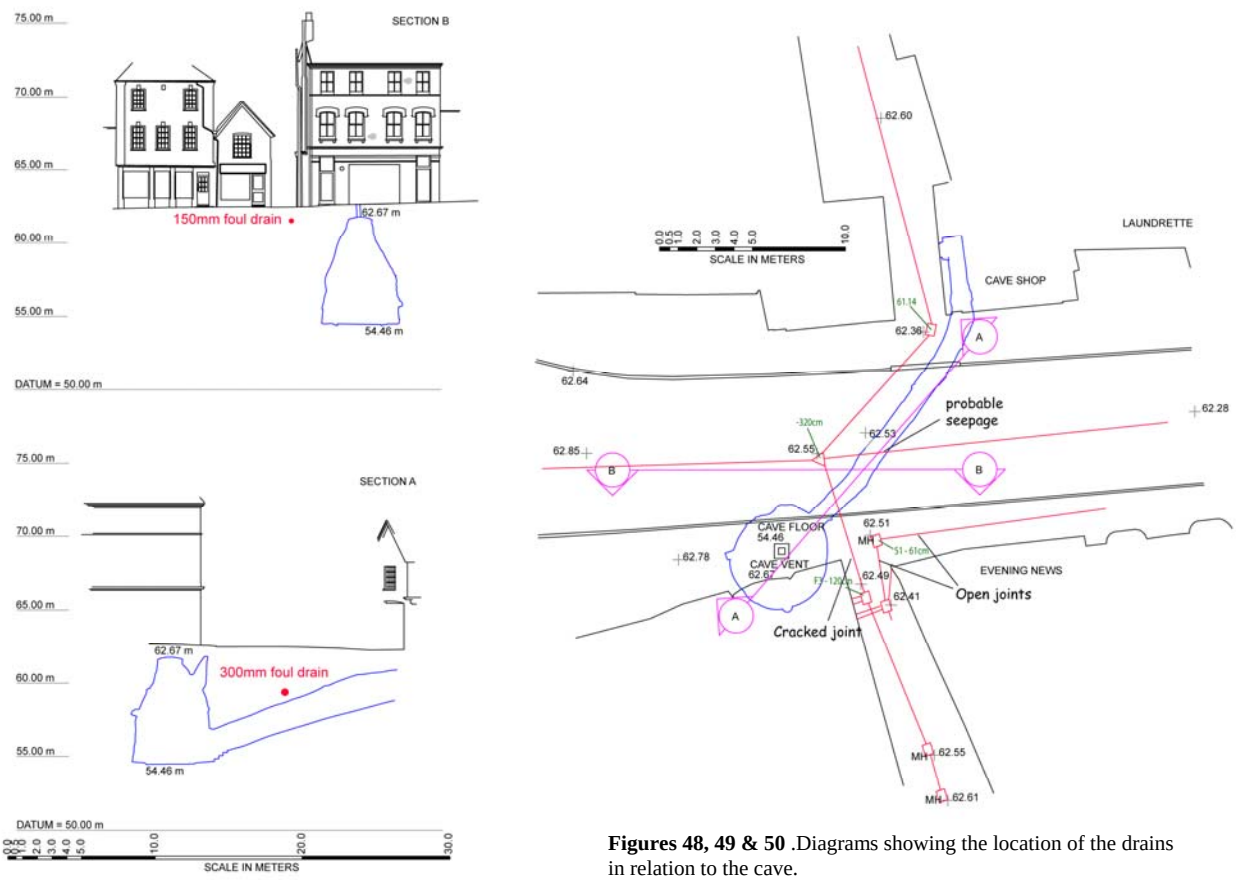
[37] The alleyway is immediately to the north east of the cave.
[38] Houldcroft, P., *The Flooding of Royston Cave*, unpublished report, September 2000.
[39] It is understood that tests were carried out by Anglia Water.
[40] The local fire service were called in to pump out the cave.
[41] Readings were taken with a Brookhuis FMW electrical capacitance meter.

6.4 Drainage

A CCTV survey of the accessible drainage pipes in the vicinity of the cave was undertaken on 01/06/09 and 06/09/09 by Manestream Ltd with instruction from Tobit Curteis Associates. *(Figures 48, 49 & 50 and Diagram 11)* The aim of the survey was to establish the drainage routes in the vicinity of the cave, their condition, and any clear areas of failure.[42]

The results showed that there was a main drain, which runs along the centre of Melbourn Street, at a depth of approximately 320cm below road level. This places it at less than 50 cm above the roof of the tunnel, close to the entrance of the cave. The other main pipes run from the courtyard on the north side of the road, next to the entrance of the cave into the main drain in the centre of the road, and from the cul-de-sac on the south side of the road to the same junction of the main drain. These pipes are considerably shallower at approximately 120cm below ground level. All of these pipes are shown on the Anglian Water Services map and appear to be either foul water or combined foul and surface water drains.

In addition, a surface water drain was identified on the south side of the road at the entrance to the cul-de-sac with the pipe heading downstream to the east. A further pipe, headed to the south into the cul-de-sac, but this terminated in old brickwork after less than a meter.



Figures 48, 49 & 50 .Diagrams showing the location of the drains in relation to the cave.

The results of the survey showed that most of the pipework was in a condition regarded as acceptable for drainage functions. However, much of the pipework is old and there were general deficiencies and loose joints in many sections, which allow mild seepage. While this is not considered a particular problem in drainage terms, in this particular application, it is more significant than would otherwise be the case. In particular, deficiencies in the main drain, which would allow seepage immediately above the roof of the tunnel is of particular concern.[43] Water ingress has been observed in this area in the past and foul water contamination has been suspected due to the odours

Damage to the pipes was also observed on the south side of the road, immediately to the west of the cave (the pipe running from F3 to the main drain), where a broken joint would lead to direct leakage near to the top of the

[42] Manestream Ltd, *CCTV report, Melbourn Street, Royston*, Ref 030897-DP, 01/06/09

[43] The survey in the main drain was limited to approximately 5m to the east and west of the junction, due to blockages in the drain preventing the camera progressing further to the east or west.

cave. This was classified as defect grade 5 (in need of urgent repair). Grade 5 damage to the pipes joints in two pipes of the surface water drainage (S1), immediately to the east were also identified.

A survey of the water pipe which runs over the cave along the centre of Melbourn Street, has also been undertaken by Three Valleys Water, and this has confirmed that no significant leakage is taking place from this pipe.[44] It was not clear that the indirect survey technique would identify seepage, of the type discussed above, for the drains.

6.5 Biological growth

6.5.1 Nature of the biodeterioration

Damage from biological sources appears to fall into two categories. By far the most serious is the damage caused by worms, while a lesser level of damage, albeit an unsightly one, has been caused by algal and other lower plant growth.

As discussed above, the main damage appears to be caused by the worms ingesting chalk contaminated with nutrients and then excreting the chalk. In some areas whole sections of the chalk surface are eaten away and the detail is lost. In other areas the effect is to destroy the cohesion of the area of chalk so that it eventually collapses. In addition, the worm casts deposited on the surface of the cave are often visually disturbing.

Although the damage is widespread it appears generally to occur in discrete areas, either around bedding plains or on different irregularities in the chalk. *(Figures 51 & 52)* These appear to be areas where the chalk is softer, but they may also have a greater concentration of nutrient contamination from sewage leakage.

Figures 51 & 52.Areas of soft chalk damaged by worm activity.

There appear to be two types of worm involved in the deterioration. The larger worm, which is purple and up to 20mm long, has been identified as the brandling worm (Eisenia foetida) and is generally found on the lower part of the cave. *(Figure 53)* Higher on the walls there are fine transparent worms, generally less than 8mm long which have yet to be identified.[45] *(Figure 54)* The damage mechanism to the chalk appears to be broadly the same in both cases, although the scale of the damage cause by the larger worms is obviously greater.

A large number of greenish slugs were also observed on the surface of the chalk during the course of the present investigation. Insects identified during the examination by English Heritage in 2007 are Spring Tails (Collembola), fungus gnat (Speolepta leptogaster), and various spiders (Nesticus cellulanus).[46] A survey carried out in 2004 suggested that there was an infestation with common webbing cloths moth (Tineola bisselliella) which was causing damage to the carving.[47] However, no further evidence for this type of insect has been found.

---

[44] The survey is understood to have been undertaken using manual and mechanical sounding techniques. Email 29/06/09 Paul Pettitt (Three Valleys Water Engineer) to Tobit Curteis

[45] The worms are currently being examined by Ridout Associates.

[46] Ridout, B., *The Deterioration Of Medieval Chalk Carving At Royston Cave, Royston*, June 2007

[47] Environmental Building Solutions Ltd., *Royston Cave, Royston, Hertfordshire, Diagnostic Non-Destructive Biological Investigation and Survey*, January & May 2004

Figures 53 & 54.Macro detail of the brandling worms and photomicrograph (x200 magnification) of the unidentified worm.

On the lower parts of the walls, there was extensive evidence of algael and other lower plant growth. A survey carried out in 2004, identified penicillium chrysogenum, aspergillus niger and trichoderma viride, as well as mosses, lichens and blue green algae.[48] This was at its worst during the 1990s, when changes were made to the wiring in the cave and the lights were left on for a long period of time. *(Figure 55 & Diagrams 1-5)* This allowed the growth of large areas of green microbiological growth in the vicinity of the lights, particularly on the north and east sides, where the flooding had been worst.

Figure 55. Microbiological growth on the east side of the cave in 1997.

Microbiological growth of this type is not only aesthetically damaging, but depending on the particular organism, it can cause physical deterioration as it secures itself to the structure, and chemical deterioration from the by-products of its lifecycle.[49]

It is understood that the main algael growth was tackled, largely successfully, by turning off the cave lights and using biocidal UV lamps.[50] Green algael growth of this type can still be seen in the tunnel, in the vicinity of the lights. However, in this case, while there are still some small areas of growth, it is largely under control.

---

[48] Op. Cit. Environmental Building Solutions 2004. No mosses or lichens were observed during the subsequent survey.
[49] Caneva, G., Pia Nugari, M., and Salvadori, O., *Plant Biology for Cultural Heritage, Biodeterioration and Conservation*, Getty Conservation Institute, (2009)
[50] Pers. Com. Peter Houldcroft

The combination of plants, animals and organic contaminants in the relatively benign and stable microclimate of the cave has created a protected ecosystem which appears to be largely self-sustaining.

6.5.2 Control issues

A review of the possible methods of control was undertaken as part of the present study. The most important aspect of long term control appears to be the removal of excessive moisture and the nutrient source, by preventing flooding. However, while this might reduce the long term deterioration, the active worm population continues to cause considerable damage and will need to be addressed directly.

The 2007 English Heritage study suggested the possible efficacy of biocides with active ingredients, including Carbayl, Benomyl, Carbenzadim and Thiophanate methyl. However, concern was raised as to the possible effects on the chalk. Initial enquiries with manufacturers indicate possible difficulties in three main areas. Firstly, more stringent Health and Safety requirements have resulted in a number of previously available biocides being withdrawn. Secondly, the type of biocide that might be suitable is generally licensed for application to plants, not subterranean rock structures, which may be considered a greater risk to the water table. Therefore, the legality of this type of application would need to be confirmed. Thirdly, no data was available as to the effect of the active ingredient, the inert ingredients or the carrier solvents on the chalk substrate.[51]

Indirect treatments, such as the use of carbon dioxide or other gasses to exclude oxygen were considered. However, the way in which this could be achieved in the cave was not clear, nor was the time period necessary to kill the worms. Tests could be undertaken to establish the effects of oxygen reduction on worms, but this would be a time consuming piece of work. In addition, the risk to public health and safety of introducing a large and uncontrolled volume of carbon dioxide, is significant.

Measures to produce conditions inconducive to the worms, such as altering the pH of the chalk or introducing a saline solution, might kill the worms or force them to move away from the chalk surface. However, the impact of either solution would probably be highly deleterious to the chalk carvings.

Therefore, it appears that no simple solution for the control of the worms exists and further research will be necessary to establish how best this can be achieved. At present, practical control measures appear to be limited to reducing the nutrient sources by ensuring that no further sewage leakage takes place.

6.6 Vibration

Over the course of the period during which investigations of the cave have been taking place, concern has been raised on a number of occasions about the possible effect on the carvings of vibrations caused by traffic using the roads above.

No systematic study of vibration patterns has taken place, but, it is evident that when heavy goods vehicles pass over or park on the road above, there is noticeable low-frequency vibration within the cave.

Prior to the 1980s, most traffic heading on the A505, would have passed through Royston and directly over the cave. In 1986, the Royston bypass was opened, and much of the heavy traffic would have diverted to the out of town route. Nevertheless, a considerable number of heavy goods vehicles continue to use Melbourn Street, and a number park in the vicinity of the cave, in order to make deliveries.

From the study of the historic rate of deterioration, there is no obvious correlation with changes in traffic flow above the cave. However, this is a relatively crude tool for assessing the possible effects of vibration on deterioration. Nevertheless, in the context of the other deterioration factors which have been examined as part of the present study, it seems more likely that vibration will be an exacerbating factor, rather than a primary factor, in the failure and loss of large sections of the chalk carving.

6.7 Deterioration mechanism

The most serious deterioration in the cave appears to fall into three categories 1) sudden loss of large cohesive sections of raised chalk carving, 2) longer term deterioration and loss of superficial details and 3) loss of cohesion and collapse as a result of biological attack.

---

[51] I am most grateful to James Hadlow of Bayer Crop Science and Mike Neil of DuPont for their comments on the suitability of biocide applications in this context.

The existing information on the microclimatic conditions and the flooding issues suggests that the cave experiences fairly stable, but high, relative humidity, and that condensation probably occurs on regular occasions. In conjunction with this, the cave is subjected to periodic severe wetting due to flooding. This latter situation is less common than was previously the case but remains active. Therefore, the moisture content of the chalk will vary between saturation and just below saturation.

The first type of deterioration bares many of the hallmarks of salt activity, resulting from crystallisation and dissolution of hygroscopic salts and the resulting deterioration of the surrounding structure. However, the moisture content of the chalk appears to remain constantly above the zone of deliquescence where most activity would be expected (60% - 80%). In addition, there is no evidence of salt efflorescence, and tests for nitrates, sulphates and chlorides using Merckoquant test strips indicated very low or negative results.

A review of conservation literature on the response of soft chalk structures to changes in moisture content produced very little material, as this type of chalk is, for obvious reasons, rarely used for works of art. An assessment of geological literature indicated that there is little research into this type of short term micro-deterioration, although there is considerable study of large scale change over millennia. Enquiries made in the field of material science produced little useful comparative information.

Despite the paucity of published research, the empirical evidence suggests that the chalk may suffer a dimensional response to small changes in moisture content (swelling and contraction) which causes stress within the structure, which lead to eventual failure and cracking. Whether this is due to contaminants in the chalk, or simply the response of the chalk matrix itself, is not clear at this stage.

A crude test was undertaken by placing a detached section of chalk from the lower part of the cave in a beaker of water. Within three hours a series of cracks had opened up in the same plane as the surface of the chalk (opposite to the bedding plane). *(Figure 56)* This appeared to suggest that there were interfaces within the chalk which were vulnerable either to the changes in moisture content or to the resulting internal stress.

Figure 56.Cracks in a chalk fragment immersed in water.

In the cave, small fissures created by this mechanism appear quickly to become colonised by the various micro and macro biological growth accelerating the rate of deterioration. Analysis was undertaken to examine whether variations in the purity of the chalk might be responsible for this phenomenon. However, the results indicated that the chalk was fairly pure with very little clay or other contaminants. (Appendix 1)

The second type of deterioration, the slow loss of chalk surface detail, also appears to be associated with fluctuating moisture conditions, although the effect is to cause a loss of cohesion and moderate surface loss, rather than the cracking and structural loss described above.

The third type of deterioration, micro and macro biological, also appears to be influenced by moisture content, although not to the same extent. Worm damage appears worst in areas of softer chalk and those where a higher moisture content exists. The worms then feed on the nutrients in the chalk and excrete the digested substrate, causing a loss of cohesion and the collapse of an area of structure. It is also likely that damage is occurring as a result of by-products of algael and other microbiological growth. However, the resulting damage is on a far smaller scale.

7.0 DISCUSSION AND RECOMMENDATIONS

7.1 Deterioration rate and mechanisms

The review of the photographic records over the last one hundred years indicates that deterioration of the chalk carvings has been taking place throughout this period. While there are insufficient data sets to say that the deterioration has been at a constant rate, it is clear that significant and measurable deterioration has taken place throughout this time. However, as the deterioration mechanisms appear to respond to external influences, it is reasonable to assume that within particular periods, the rate of deterioration will have increased and decreased.

The information now available suggests that the principle mechanism for sudden loss of significant carved details is the formation of a fissure in the chalk, resulting from stresses caused by minor cycles of expansion and contraction, in response to changes in moisture content. This is then colonised by plant growth and animal activity until the crack is sufficiently large to allow the weight of the detached section to fall away. Although this process is relatively slow, it appears to be constant and ongoing.

In conjunction with this, chronic deterioration is taking place in some areas of softer chalk, as a result of worm populations ingesting chalk and nutrients and progressively undermining the cohesion of the stone. This leads either to delamination and loss of specific elements or to general loss of cohesion and collapse of an area of surface. The effect of algael and other microbiological growth should not be ignored but is far less significant.

Environmental monitoring data suggest that the relative humidity remains high and fairly stable, as would be expected in a subterranean space of this type. Air exchange with the exterior will inevitably destabilise the conditions, and it is probable that condensation will occur on a regular bases. However, it seems likely that the most significant influence on the moisture content of the chalk will have been the periodic flooding. The resulting wetting and drying cycles will probably have caused the chalk to vary between saturated and just below saturated.

In addition, the flooding appears to have been partly responsible for the contamination of the chalk with nutrients which sustain the worm population.

7.2 Recent changes

Considerable change is apparent in the conditions recorded in the late 1990s and early 2000s (both in written reports and photographic records) and those seen today. The level of microbiological growth is considerably reduced and the relative humidity appears to be lower. Anecdotal evidence also suggests that the cave “feels drier” than it did earlier. The most significant intervention which has taken place since this time is the repair of the drains and alleyway above the north west section of the cave. As a result, the regularity and severity of flooding has been significantly reduced.

During this period, there has been some further deterioration of the carving, but this has generally been on a small scale, rather than some of the gross loss seen in previous decades. Nevertheless a number of areas were identified where deterioration is advanced and future loss remains a serious risk.

7.3 Conservation recommendations

The long term conservation of the cave can be viewed in three distinct phases 1) Preventive measures to control the underlying causes of deterioration 2) Treatment, to stabilise damaged areas and 3) Long term assessment, to monitor the condition of the cave and control new deteriogens before significant damage occurs.

7.3.1 Preventive measures

Drainage: The primary cause of deterioration appears to be the unstable moisture content of the chalk. Repairs to the drains and alleyway in 2001 appear to have addressed the main source of liquid water. However, the recent drainage survey indicated that there is likely to be continued seepage from pipes in the vicinity of the cave and in particular immediately above the tunnel. In addition there were three areas of damage where serious leakage was likely. Therefore, it is recommended that the broken pipes are repaired and the pipes in close proximity to the cave are lined to prevent seepage.

Air exchange: Tests should be undertaken to assess the effects of a reduction in internal/external air exchange. The grille at the top of the cave should be sealed to prevent unnecessary air leakage. This would also have the advantage of preventing the ingress of debris and rainwater. The vents in the door could also be sealed, although it is unlikely that this will significantly affect the conditions in the cave itself. In order to evaluate the effect of

these changes to the microclimate, a programme of environmental monitoring should be undertaken, prior to and after the changes are implemented.

Lighting: Lighting, both within the cave and the tunnel, should be kept to a minimum in order to prevent unnecessary photosynthesis in, potentially damaging, microbiological growth.

7.3.2 Treatment

Although it is intended that minimal interventive treatment should be undertaken in the cave, there are a number of areas which will need to be addressed. In order to reduce the risk of further loss of dethatched sections of carving, readhesion and repairs will be necessary for the most vulnerable areas. The accumulated dirt from the floor will also be removed to minimise the area of habitat available for worms and other organisms. No large scale cleaning or other measures to alter the superficial appearance of the cave are recommended.

Repair and readhesion: Previous interventions have shown the difficulties of repairing and supporting detached fragments of carving. Because of the deterioration mechanism, it is essential that any adhesive introduced between the detached section and the substrate has sufficient adhesive qualities but minimal effect on the hardness or porosity of the chalk. This means that most adhesives, both organic and inorganic are unsuitable. One possible adhesive is Calosil, a suspension of nanoparticles of calcium hydroxide in ethanol or isopropyl–alcohol.

While, there is a long history of consolidation of limestone and chalk using calcium hydroxide in the form of limewater, this would be very damaging in this case due to the extremely high volumes of water needed to deliver tiny amounts of calcium hydroxide. The use of Calosil appears to offer far better results as the volumes of calcium hydroxide are considerably higher (<50% rather than <1%) and little or no water is involved.

Although the use of nanolimes such as Calosil is not uncommon in Germany and Italy, the history of their use in the UK is limited. Therefore, although there is no reason to expect any adverse reaction, it is recommended that a number of small tests are undertaken and their effect evaluated over time.

In areas where the detached sections are particularly large, or where the crack remains open to allow access to further micro and macro biological growth, small repairs should be made with a mortar comprising lime putty, powdered chalk and an hydraulic additive such as Bavarian trass.

Removal of dirt from the floor: All earth and other residual material on the floor, the step at the base of the cave and the base of the large voids in the cave wall should be removed. Initial tests show that this can be done mostly by mechanical means. However, in some cases, it would be necessary to moisten the final layer of earth and other material, in order to allow more gentle removal from the degraded chalk below.

7.3.3 Long term Assessment

In conjunction with the treatment of the cave, a programme of long-term condition assessment should be implemented. Initially, the condition assessment will continue as part of the present programme of work and will include an assessment of the effect of preventive and treatment measures on the condition of the fabric, as well as the level of worm casts accumulated in the test trays.

Following the completion of the treatment programme, it is recommended that an inspection of the cave is undertaken after one year and then on a five yearly basis. In addition to a general condition assessment, this should include a careful comparison of the condition of the surface of the carvings with that recorded in the most recent, 2008, photographic survey.

After a period of 10 years, it is recommended that the close range 3-D laser scanning is repeated, and a software comparison of the two data sets is undertaken to establish where changes in surface topography have taken place.

7.3.4 Presentation

The photographic record and 3-D laser model of the cave, which have been produced as part of the current investigations, provide a wide range of opportunities for presentation and educational material. Careful consideration should be given to how this is best used, but it is recommended that a package of presentation and educational measures are included as part of any forthcoming conservation programme.

The availability of this type of recording could allow far wider access to the cave without the increased risk to its physical stability which might occur if large numbers of additional people were to visit the site. The nature of the

imaging allows it to be used for presentational material on site, or as off-site material, for instance in the local museum, as well as deployment on the Internet.

8.0 LIMITATIONS

The condition examination was limited to those areas which were safely accessible. It is possible that the condition might vary in areas which could not be examined. Comments on the condition of the cave structure are in general terms only. Where the condition is not clear this should be assessed by a suitably qualified and experienced architect or engineer.

9.0 REFERENCES

BGS 1996	British Geological Survey, *British Regional Geology, London and The Thames Valley*, London, (1996)
Beamon 1978	Beamon, S. and Donel, L. "An Investigation of Royston Cave", *Proceedings of the Cambridge Antiquaries Society*, LXVIII, (1978) pp.47-58
Beamon 1992	Beamon, S, *The Royston Cave, Used by Saints or Sinners*, Ashwell, (1992)
Bedlam 1884	Bedlam, J, *The Royston Cave: Being The Substance of a Report some time presented to the Royal Society of Antiquaries*, London (1884)
Caneva et al. 2009	Caneva, G., Pia Nugari, M. and Salvadori, O., *Plant Biology for Cultural Heritage, Biodeterioration and Conservation*, Getty Conservation Institute, (2009)
Eyers 2009	Eyers, J., *The Building Stones of Bedfordshire*, www.bedsrigs.org.uk/leaflets/RIGSBuildStones.pdf, accessed on 29/06/09
Houldcroft 2004	Houldcroft, P. A., *Medieval Mystery at the Crossroads*, Royston (2004)
Stukeley 1742	Stukeley, W., *Palaeographia Britannica or discourses on Antiquities in Britain no.I, Origines Roystonianae, or an account of the Oratory of Lady Roisia, Foundress of Royston discovered in Royston in August 1742*.
VCH 1912	Victoria County History, 'Parishes: Royston', *A History of the County of Hertford: volume 3* (1912), pp. 253-265

10.0 APPENDIX 1: CHALK ANALYSIS

Tests were undertaken to determine the chemical content of the chalk, and in particular whether there was a high level of clay or other impurities, which might encourage swelling/shrinkage or contaminants which could generate differential stresses if dimensional change occurred. (i.e. if shrinking and swelling took place and the material contained hard, non-responsive nodules within the softer responsive structure, stresses could occur which might encourage cracking and failure.).

Hydrochloric acid tests produced a vigorous effervescence and left virtually no residues, indicating a very high percentage of calcium carbonate. In order to obtain a more accurate determination of chemical composition, a number of instrumental analyses were undertaken at the English Heritage Ancient Monuments Laboratory. Initially, backscatter imaging was undertaken in an attempt to produce an elemental map of the surface of the sample, which might show a material variations, indicative of variations in density. However, this approach did not produce useful data.

Therefore, EDXA was undertaken on the surface of the sample so that calcium concentrations (and therefore probable density) could be measured. The results showed very little variation in calcium concentration, with only very small inclusions of silicone, magnesium and aluminium, possibly indicating a very low clay content. The density of the material was then calculated on the basis that pure calcite is 40.05% calcium, and the density of calcite is 2.71 g/cm^3. See figures 53 & 54, below. While this technique does not produce precise densities, it was thought likely that the variation was very little at +/-0.05 g/cm^3 throughout the sample. This implied that hard nodules of the type discussed above were not preset on the surface of the sample.

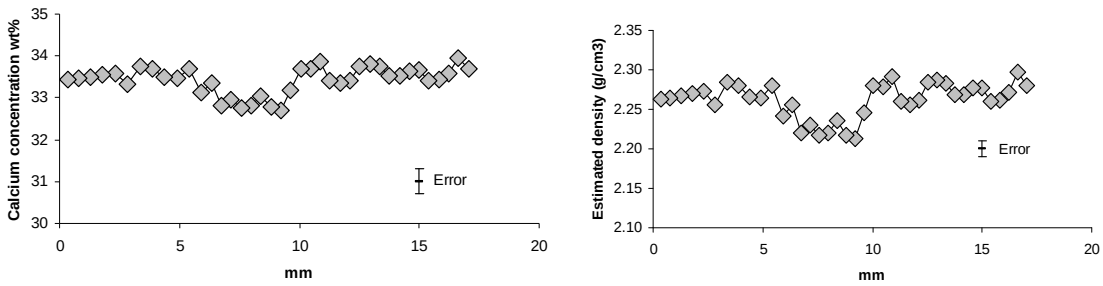
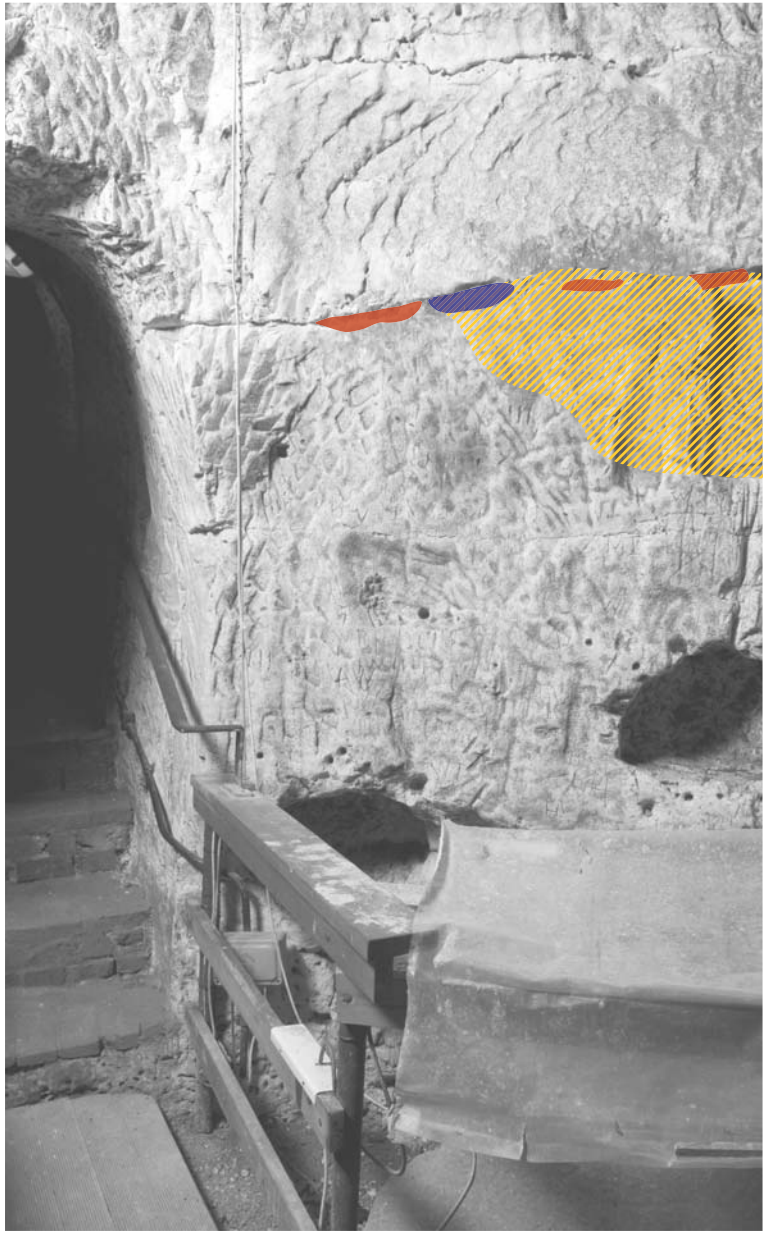


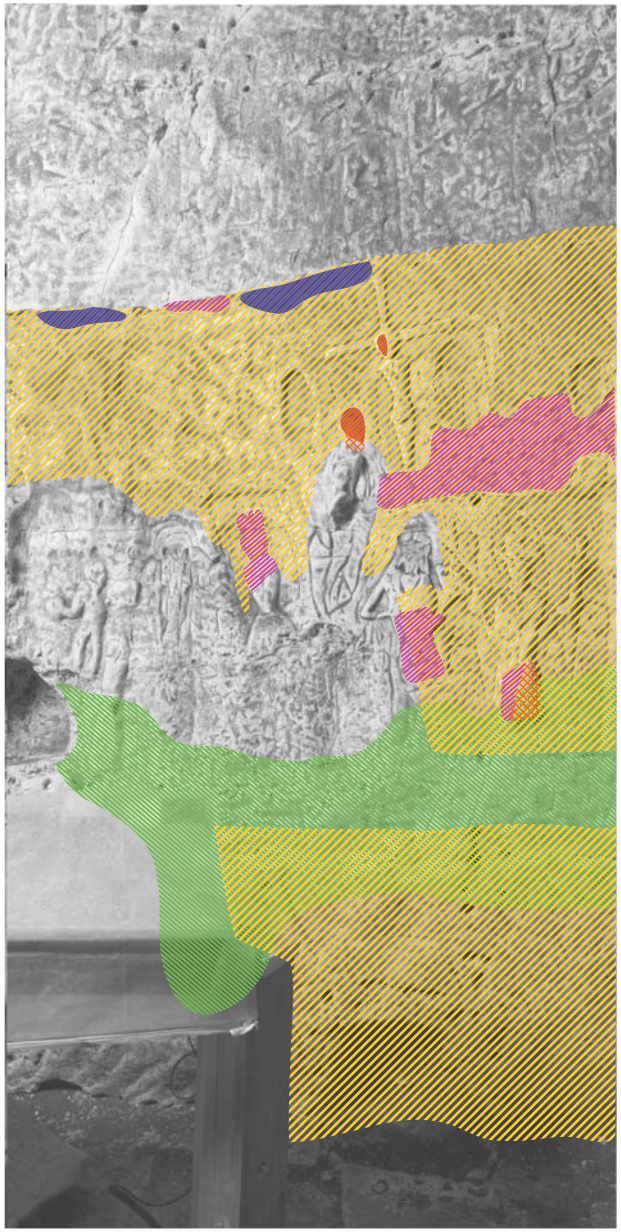
Figure 53 & 54. Calcium concentration and estimated density .

In summary therefore, the cave appears to be constructed of a relatively pure chalk with very little clay or other impurities, and no significant irregularities in density.[52] It should be noted however, that this was a single sample from a single bedding plain. It is possible that at the edges of bedding plains, and in different plains, the conditions may vary.

[52] I am grateful to Matthew Canti and Dave Dugworth for undertaking the analysis and interpretation of results.

Tobit Curteis Associates
36 Abby Road, Cambridge, CB5 8HQ
T: +44 (0)1223 501958 F: +44 (0)1223 304190
E: tc@tcassociates.co.uk W: www. tcassociates.co.uk





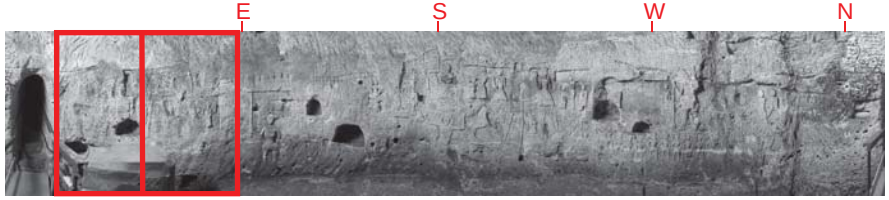
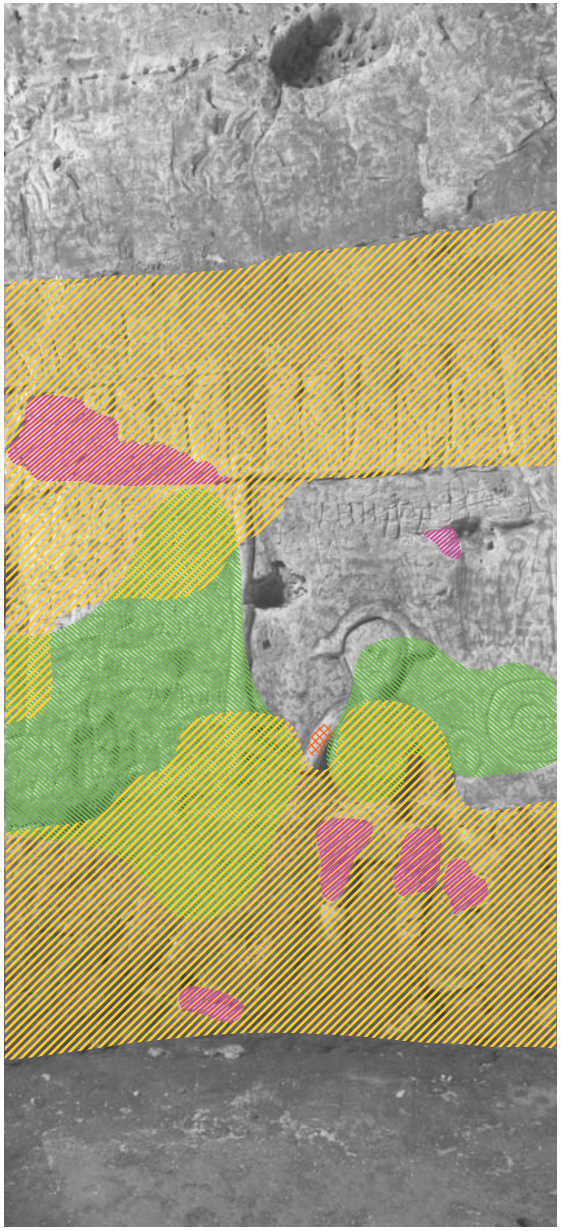


Diagram: 1.0	**Site:** Royston Cave	**Date:** June 2009	**Scale:** Not to scale

- Darkened area of coating
- Area of delamination and loss
- Present cracking or delamination
- Cement repairs
- Surface losses since 1997
- Green MBG 1997
- Brown surface material

Tobit Curteis Associates
36 Abby Road, Cambridge, CB5 8HQ
T: +44 (0)1223 501958 F: +44 (0)1223 304190
E: tc@tcassociates.co.uk W: www. tcassociates.co.uk



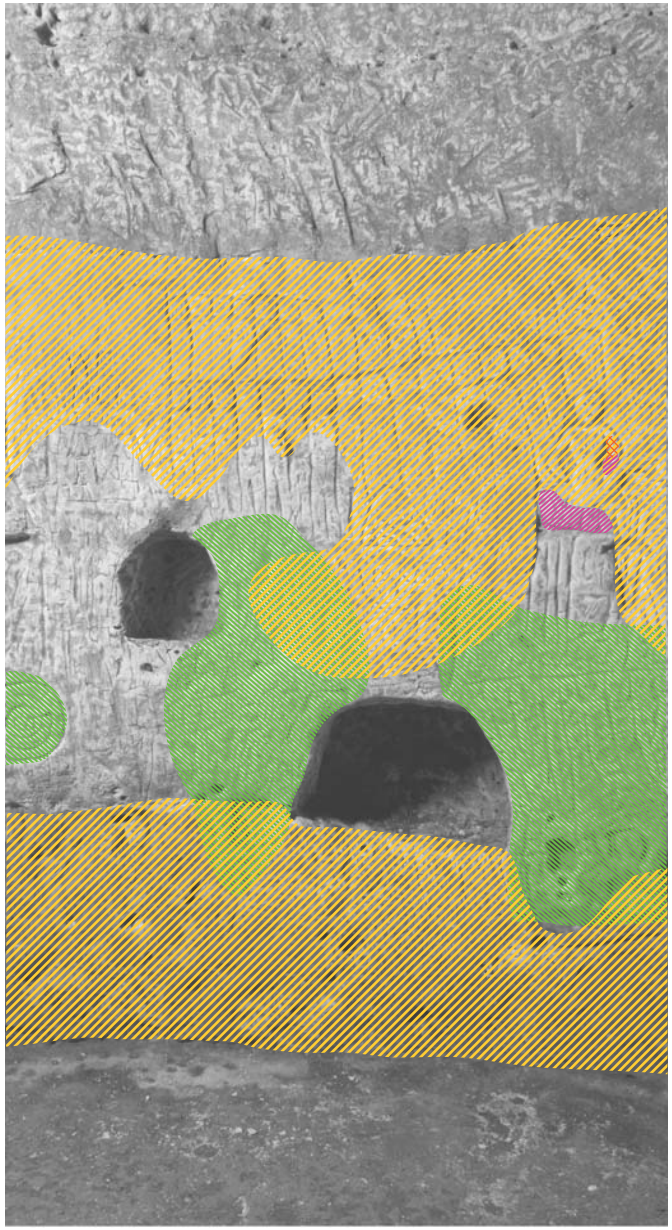


Diagram: 2.0	**Site:** Royston Cave	**Date:** June 2009	**Scale:** Not to scale

- Darkened area of coating
- Area of delamination and loss
- Present cracking or delamination
- Cement repairs
- Surface losses since 1997
- Green MBG 1997
- Brown surface material

Tobit Curteis Associates
36 Abby Road, Cambridge, CB5 8HQ
T: +44 (0)1223 501958 F: +44 (0)1223 304190
E: tc@tcassociates.co.uk W: www. tcassociates.co.uk

Diagram: 3.0	**Site:** Royston Cave	**Date:** June 2009	**Scale:** Not to scale

- Darkened area of coating
- Area of delamination and loss
- Present cracking or delamination
- Cement repairs
- Surface losses since 1997
- Green MBG 1997
- Brown surface material

Tobit Curteis Associates
36 Abby Road, Cambridge, CB5 8HQ
T: +44 (0)1223 501958 F: +44 (0)1223 304190
E: tc@tcassociates.co.uk W: www. tcassociates.co.uk

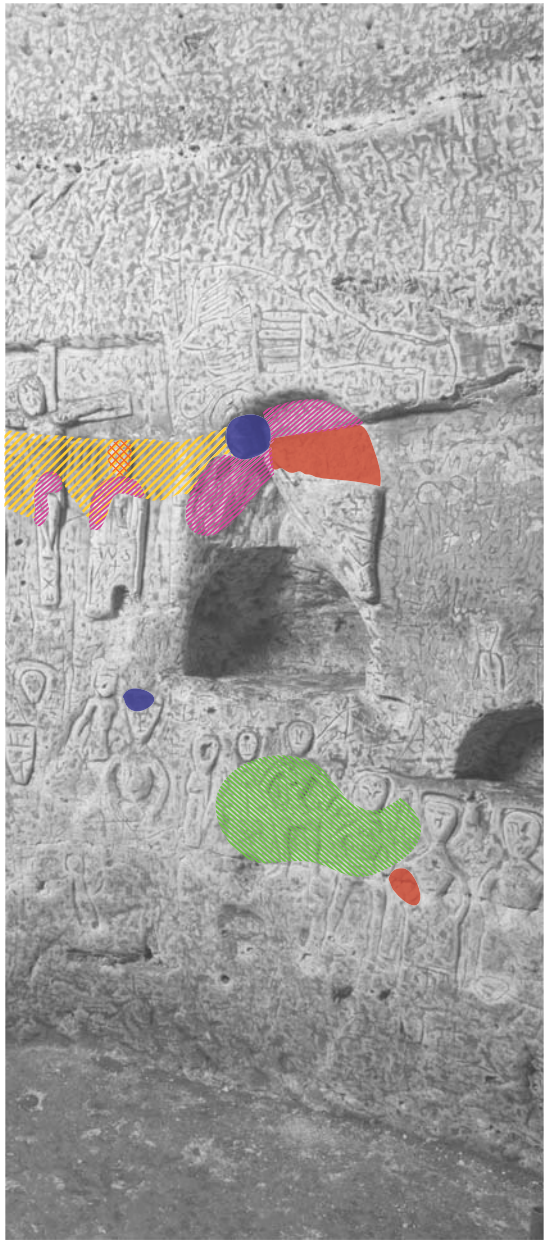
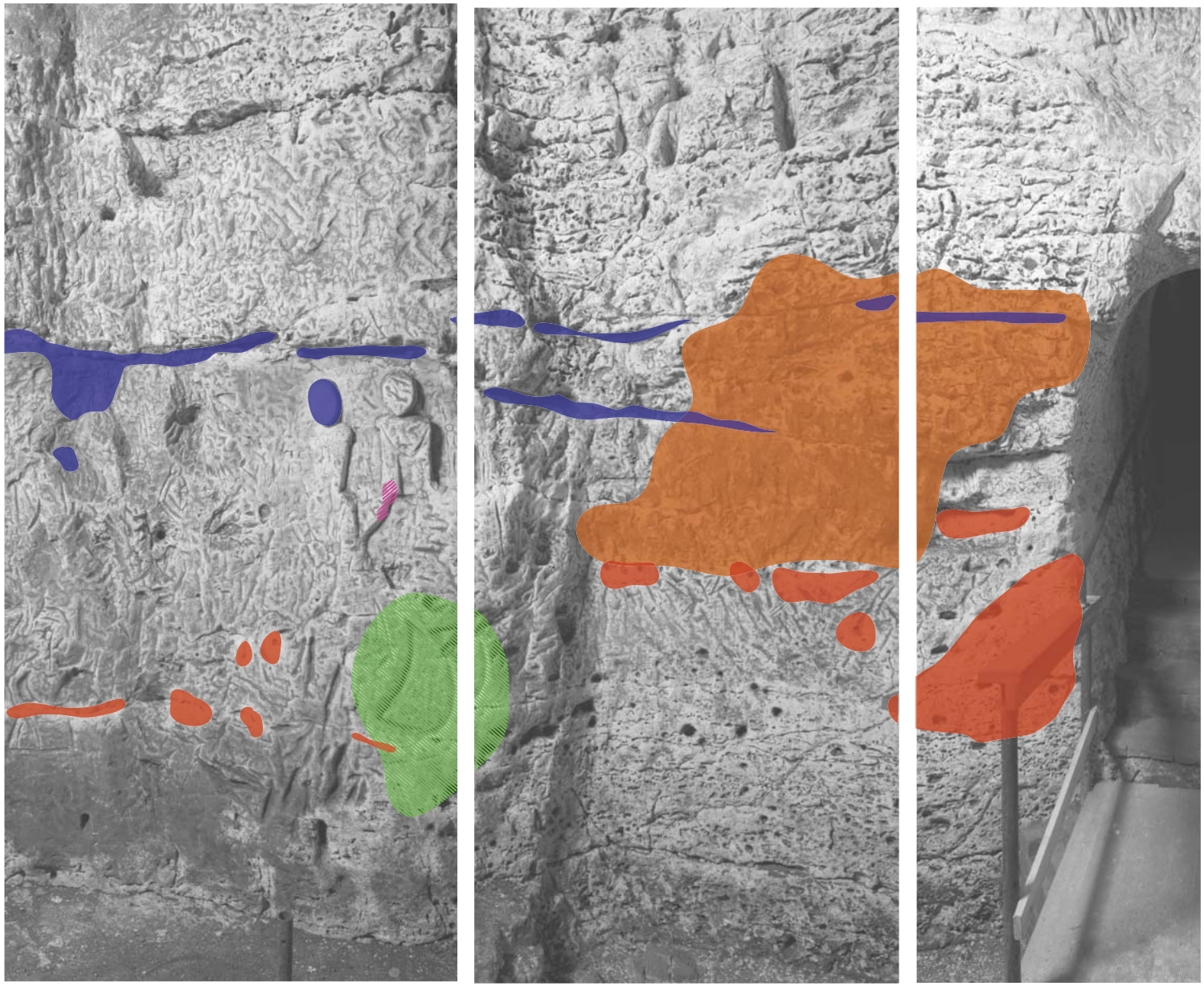


Diagram: 4.0	**Site:** Royston Cave	**Date:** June 2009	**Scale:** Not to scale

- Darkened area of coating
- Area of delamination and loss
- Present cracking or delamination
- Cement repairs
- Surface losses since 1997
- Green MBG 1997
- Brown surface material

Tobit Curteis Associates
36 Abby Road, Cambridge, CB5 8HQ
T: +44 (0)1223 501958 F: +44 (0)1223 304190
E: tc@tcassociates.co.uk W: www. tcassociates.co.uk



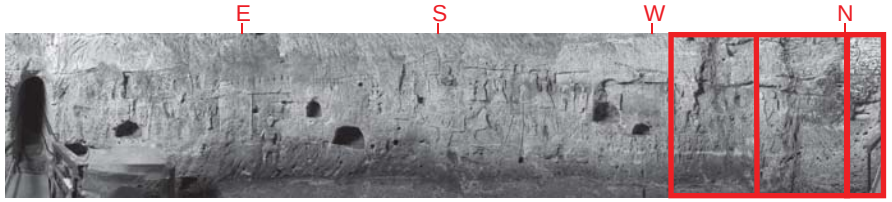
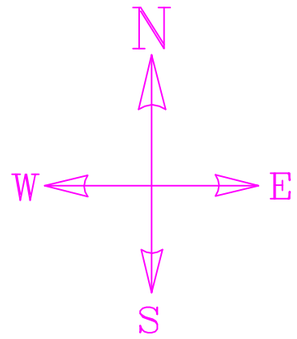


Diagram: 5.0	**Site:** Royston Cave	**Date:** June 2009	**Scale:** Not to scale

- Darkened area of coating
- Area of delamination and loss
- Present cracking or delamination
- Cement repairs
- Surface losses since 1997
- Green MBG 1997
- Brown surface material

Diagram 6.0

Figured dimensions only are to be taken from this drawing. All dimensions are to be checked on site before any work is put in hand. Some trees may not be included on the drawing due to inaccessibility.



LEGEND

MANHOLE = MH

Mark	Revision	Drawn	Date	Chk'd	App'd

Stanburys Ltd
estate management solutions

IPEC House - 25 Church Street - Baldock - Herts
Tel: 01462 894144 - Fax: 01462 894992
www.Stanburys.com

Originator	Discipline
Stanburys Ltd	Estates Surveying

Site
ROYSTON

Facility
ROYSTON CAVE

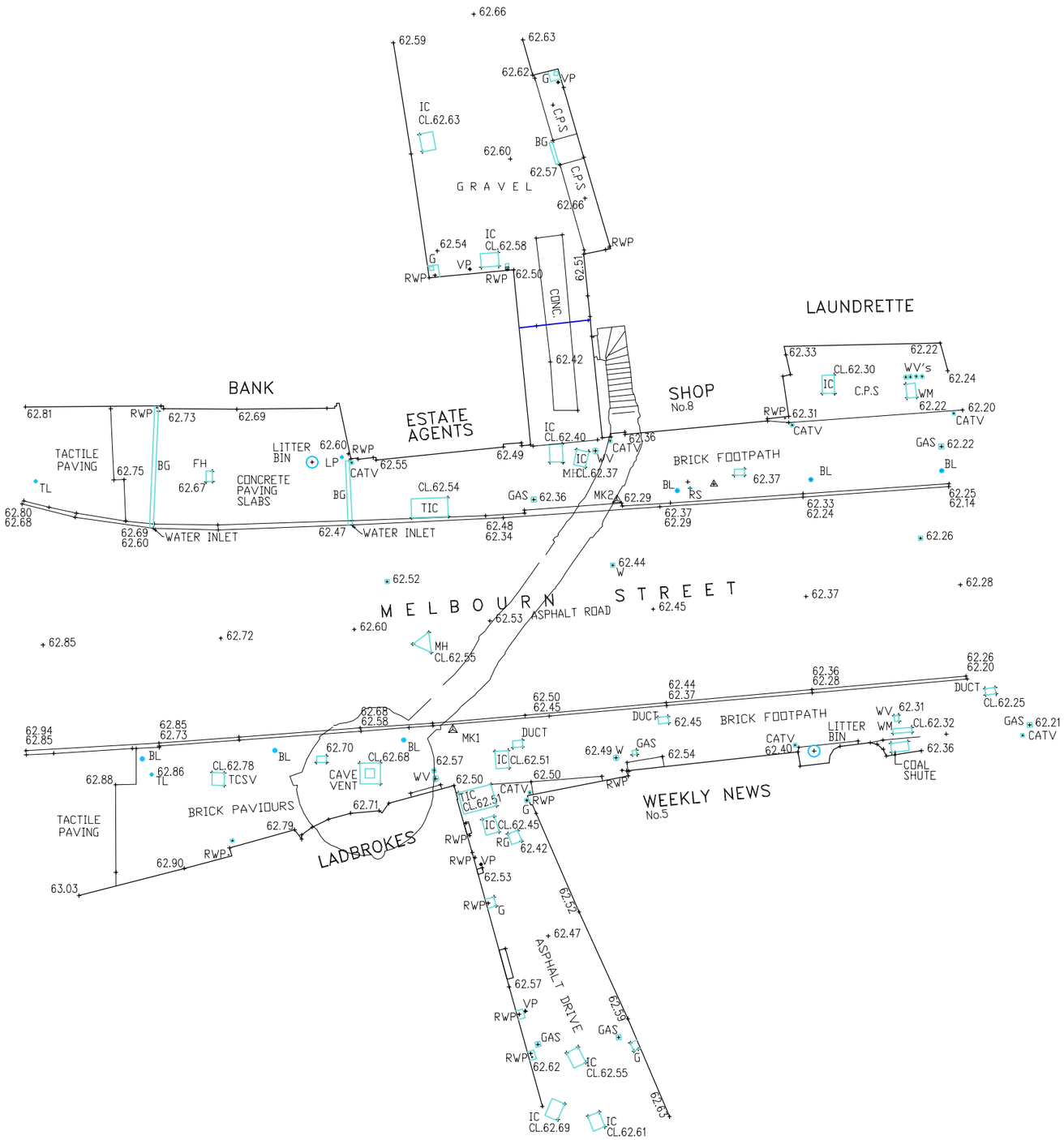
Drawing Title
POSITION
TOPOGRAPHICAL SURVEY

Scale
1:100 @ A1

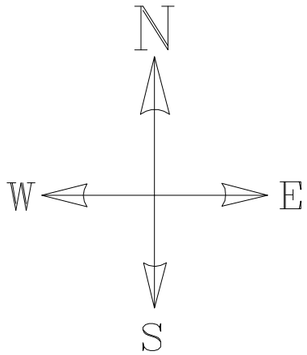
Site	Asset	Facility	Doc Type	Originator	Doc No.
1-	RSTN	CAVE-	GA-	S4-	001 01

Status
EXISTING

Diagram 7.0



Figured dimensions only are to be taken from this drawing. All dimensions are to be checked on site before any work is put in hand. Some trees may not be included on the drawing due to inaccessibility.



NOTE:
SURVEY TIED INTO NATIONAL GRID OSTN02 AND OSGM02 FOR HEIGHT USING GPS EQUIPMENT

Mark	Revision	Drawn	Date	Chk'd	App'd
1	01	NIK	05/08/09	NIK	NIK

ABBREVIATIONS (Where applicable)

BG ..... Box Gully
BL ..... Bollard
CPS ..... Concrete Paving Slabs
ECB ..... Electricity Control Box
EJB ..... Electricity Cable Junction Box
IC ..... Inspection Cover
IL ..... Invert Level
BW ..... Post & Barbed Wire Fence
BKW ..... Brick Wall
PWM ..... Post & Wire Mesh Fence
LP ..... Lamp Post
MH ..... Manhole
MKR ..... Marker
P ..... Post
RG ..... Road Gully
RS ..... Road Sign
SC ..... Stop Cock
SV ..... Sluice Valve
T ..... Tree
TL ..... Traffic Lights
WM ..... Water Meter
WV ..... Water Valve

IPEC House - 25 Church Street - Baldock - Herts
Tel: 01462 894144 - Fax: 01462 894992
www.Stanburys.com

Originator: Stanburys Ltd
Discipline: Estates Surveying
Site: ROYSTON
Facility: ROYSTON CAVE
Drawing Title: POSITION TOPOGRAPHICAL SURVEY
Scale: 1:100 @ A1
Site Asset Facility Doc Type Originator Doc No.: 1- RSTNCAVE-GA-S4-001 02
Status: EXISTING

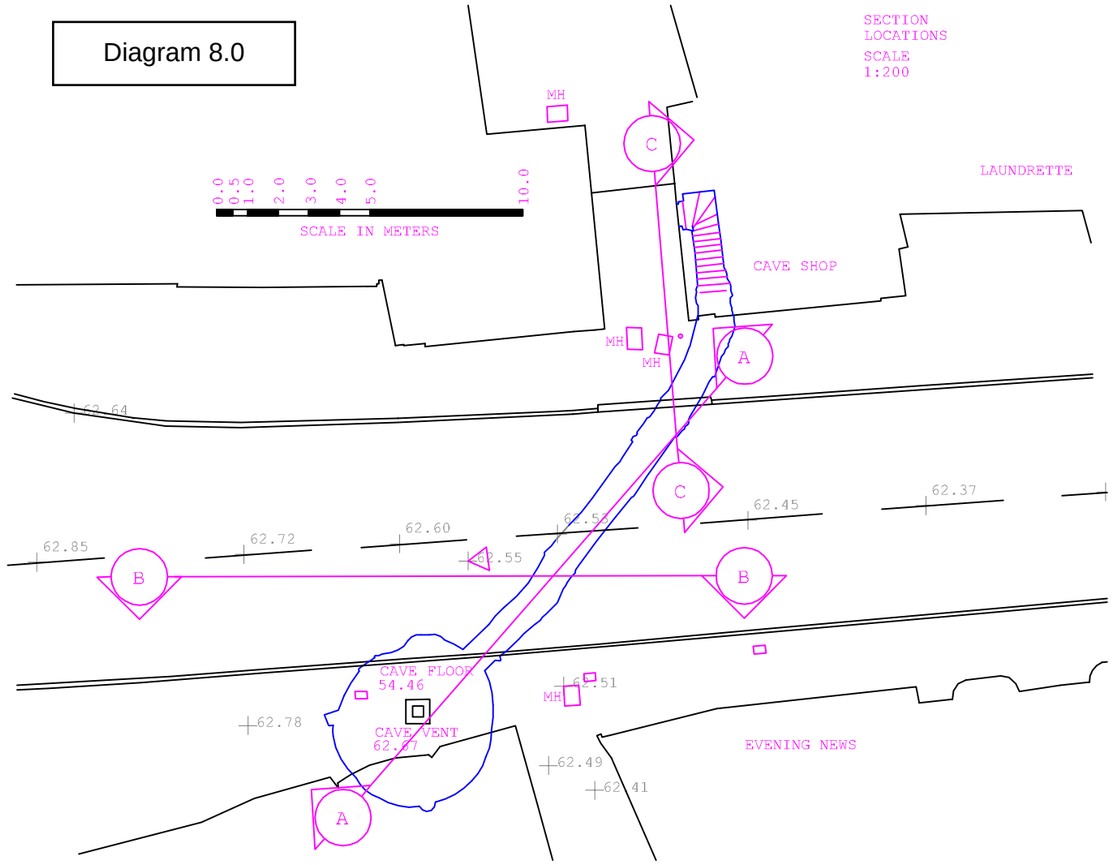
SURVEY STATION SCHEDULE

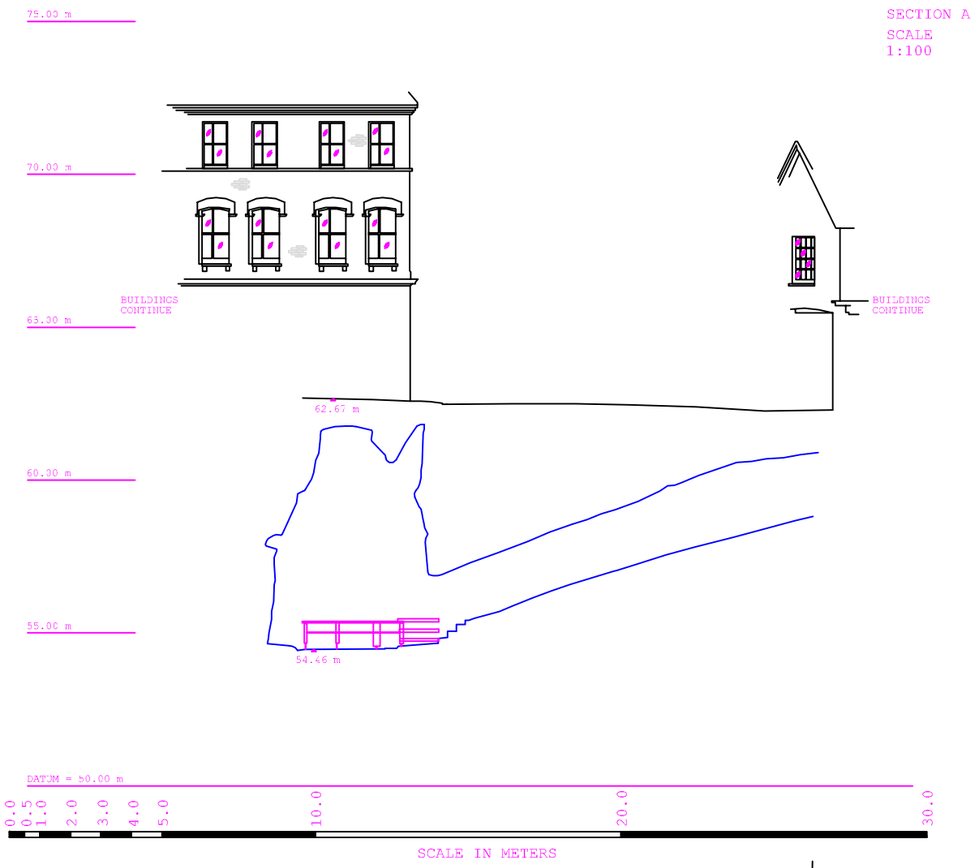
STN No	EASTINGS	NORTHINGS	ELEVATION	REMARKS
GPS1	535658.729	240712.641	61.987	HILTI IN BRICK FOOTPATH
GPS2	535587.142	240707.255	62.871	HILTI IN TRAFFIC ISLAND
MK1	535621.530	240701.624	62.537	HILTI IN BRICK FOOTPATH
MK2	535627.779	240710.370	62.307	HILTI IN BRICK FOOTPATH

0m 2m 5m 10m 20m

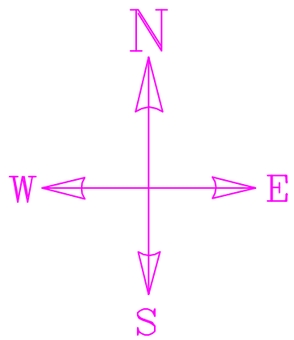
SCALE 1:100

Diagram 8.0





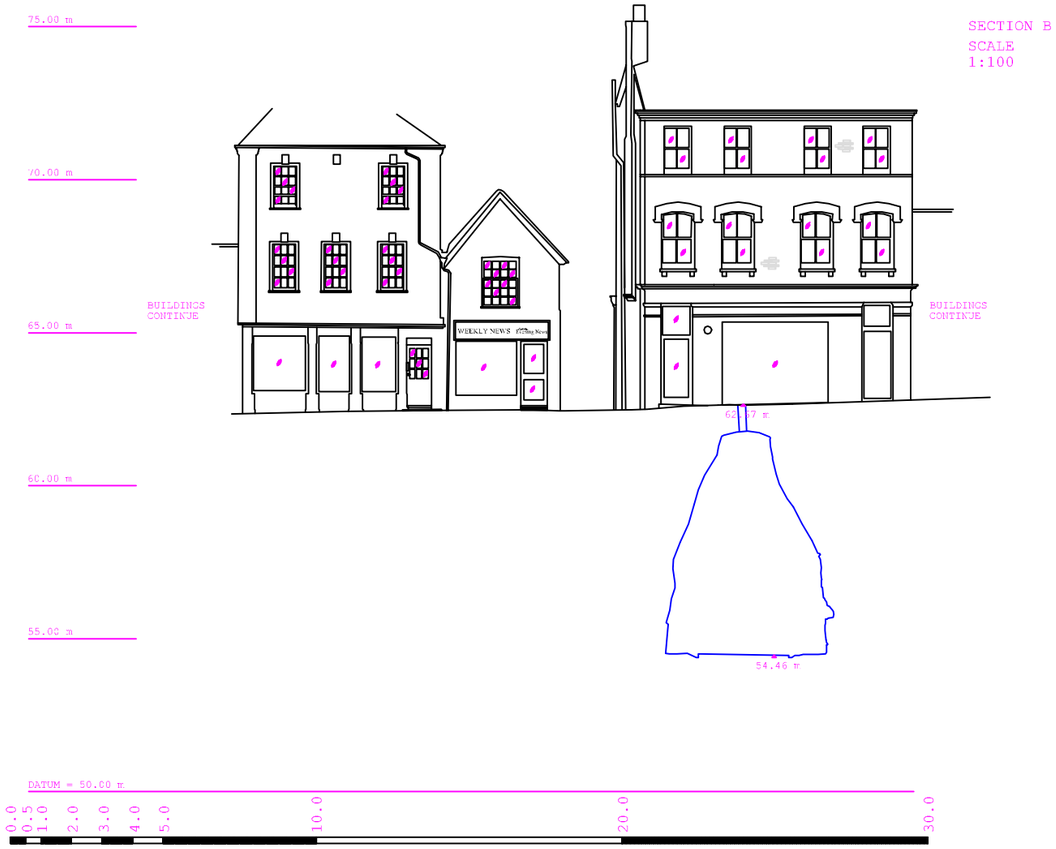
Figured dimensions only are to be taken from this drawing. All dimensions are to be checked on site before any work is put in hand. Horizontal building dimensions may not be accurate, due to sections being drawn not parallel to face.

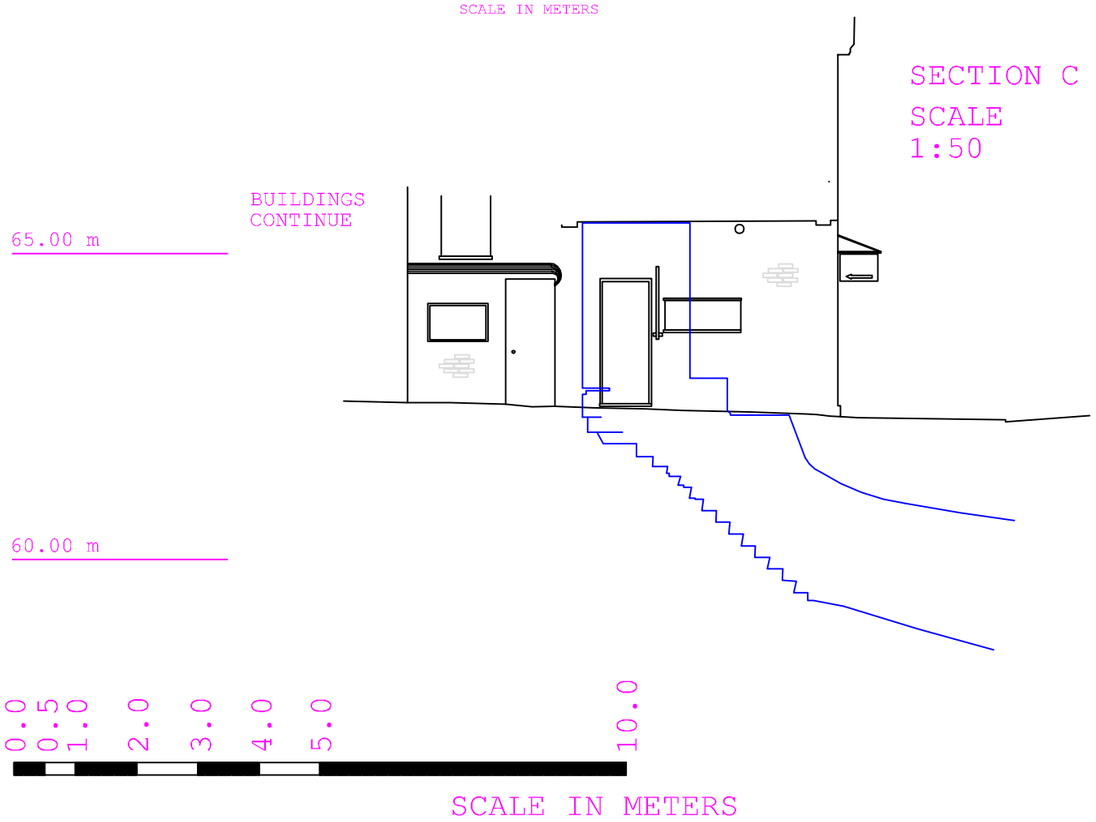


LEGEND

MANHOLE = MH

LEVEL = 54.46 m





Mark	Revision	Drawn	Date	Chk'd	App'd

Stanburys Ltd
estate management solutions

IPEC House - 25 Church Street - Baldock - Herts
Tel: 01462 894144 - Fax: 01462 894992
www.Stanburys.com

Originator	Discipline
Stanburys Ltd	Estates Surveying

Site: ROYSTON

Facility: ROYSTON CAVE

Drawing Title: PLAN AND SECTION DRAWINGS

Scale: VARIES @ A1

Site	Asset	Facility	Doc Type	Originator	Doc No.	
1-	RSTN	CAVE-	EL-	S4-	002	01

Status: EXISTING

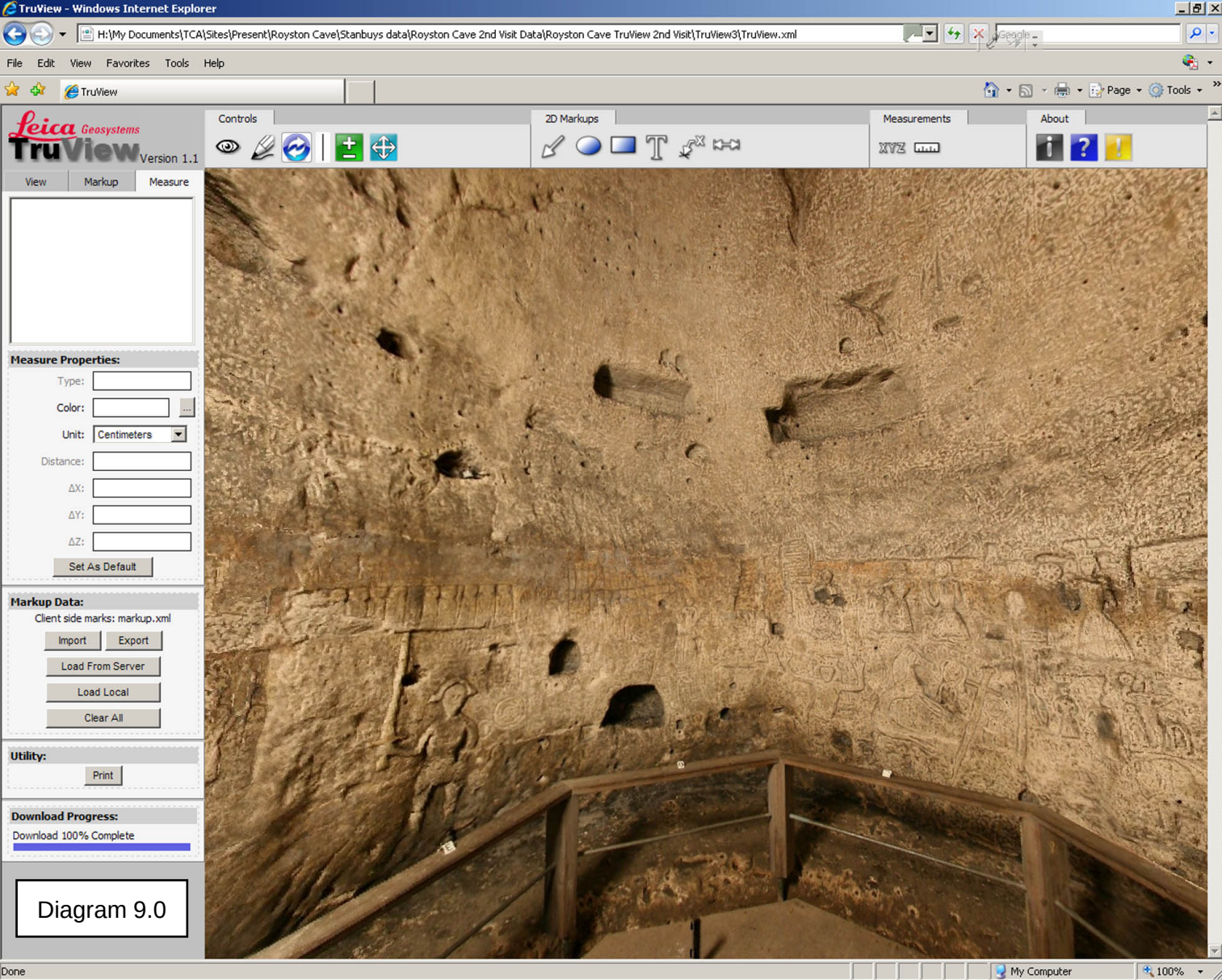
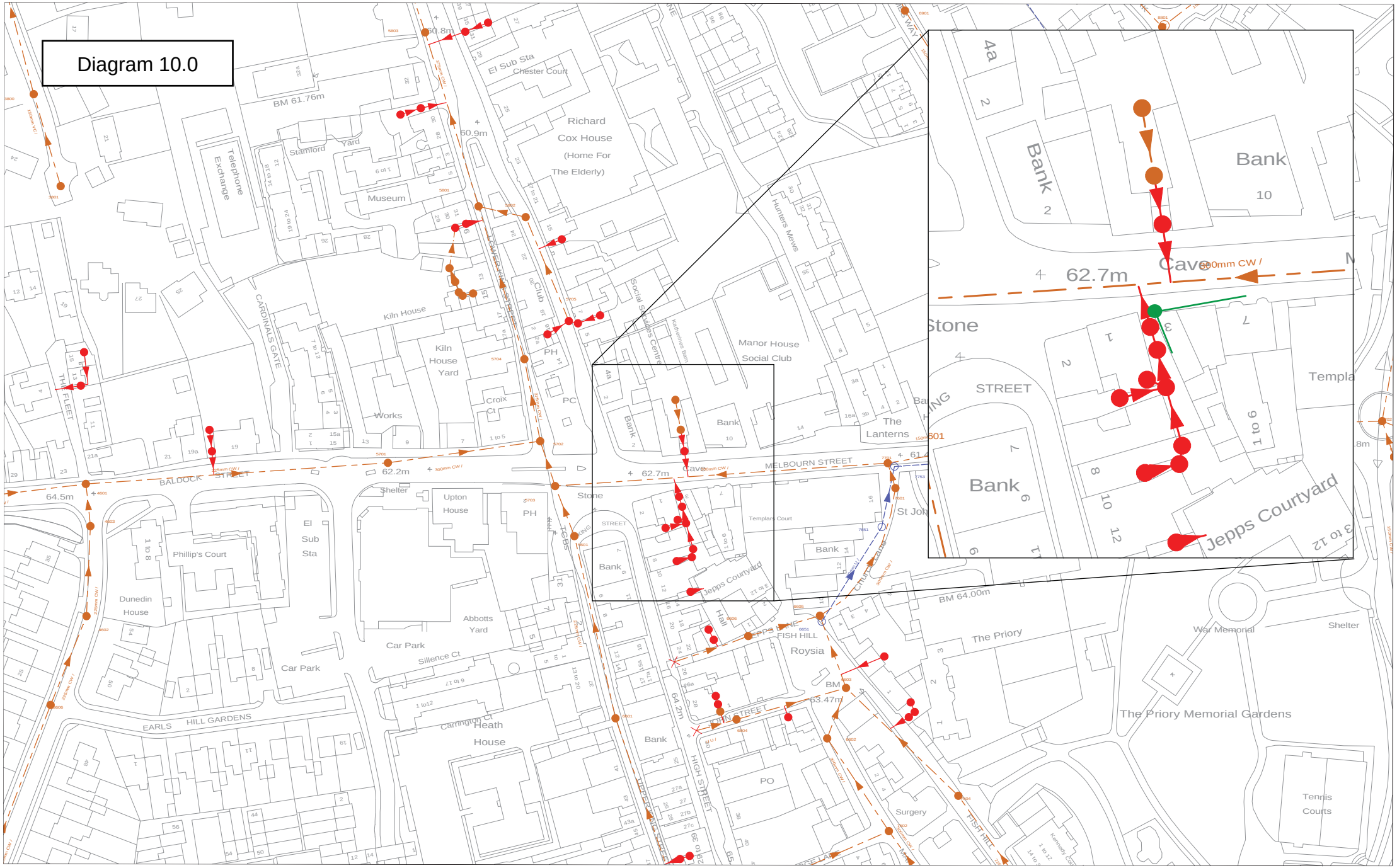

TruView - Windows Internet Explorer
H:\My Documents\TCA\Sites\Present\Royston Cave\Stanbuys data\Royston Cave 2nd Visit Data\Royston Cave TruView 2nd Visit\TruView3\TruView.xml
File Edit View Favorites Tools Help
TruView
Page Tools
Leica Geosystems
TruView Version 1.1
View Markup Measure
Controls
2D Markups
Measurements
About
Measure Properties:
Type:
Color:
Unit: Centimeters
Distance:
ΔX:
ΔY:
ΔZ:
Set As Default
Markup Data:
Client side marks: markup.xml
Import Export
Load From Server
Load Local
Clear All
Utility:
Print
Download Progress:
Download 100% Complete
Done
My Computer
100%

Diagram 9.0

Diagram 10.0



Map Centre 535631, 240720 Scale: 1250 Date: 05/05/2009 13:39 Data updated: April 2009

This plan is provided by Anglian Water pursuant its obligations under the Water Industry Act 1991 sections 198 or 199. It must be used in conjunction with any search results attached. The information on this plan is based on data currently recorded but the position must be regarded as approximate. Service pipes, private sewers and drains are generally not shown. Users of this map are strongly advised to commission their own survey of the area shown on the plan before carrying out any works. The actual position of all apparatus MUST be established by trial holes. No liability whatsoever, including liability for negligence, is accepted by Anglian Water for any error or inaccuracy or omission, including the failure to accurately record, or record at all, the location of any water main, discharge pipe, sewer or drain or disposal main or any item of apparatus. This information is valid for the date printed. The plan is produced by Anglian Water Services Limited, trading as Geodesys from Ordnance Survey © Crown Copyright, 100018507. This map is to be used for the purposes of viewing the location of Anglian Water plant only. Any other use of the map data or further copies are not permitted. This notice is not intended to exclude or restrict liability for death or personal injury resulting from negligence.

GEODESYS
Land & Property Information

Asset Information Team
Geodesys
PO Box 486
Huntingdon
PE29 6YN

SEWER ASSET LEGEND

Surface Sewer	Gravity Sewer
Foul Sewer	Vent Column
Combined Sewer	Manhole (Combined)
S104/Private Sewer	Manhole (Foul Water)
Decommissioned Sewer	Manhole (Surface Water)
Rising Main	

Property Address: THE CAVE BOOK SHOP, 8, MELBOURN STREET ROYSTON, SG8 7BZ

Customer: TOBIT CURTEIS ASSOCIATES LLP

Title: A777015(1) (Caroline Jefferies)