

# **Silbury Hill Conservation Works**

**Geological Desk Study and Report of Field Visits**

**Skanska Construction UK Ltd.  
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## SUMMARY

Silbury Hill is the largest man-made mound in Europe and was built around 4,500 years ago. Following two collapses which opened up a hole in the top of the hill in 2000, an investigation was undertaken to determine the stability of the hill. This included work carried out by Skanska for English Heritage, the custodians of Silbury Hill. The investigations determined that the hill was not in danger of immediate collapse, but would require some conservation works to guarantee its long term stability.

Skanska will be carrying out conservation works on Silbury Hill in Wiltshire for English Heritage during 2007. The works will include backfilling the various tunnels dug into the hill by archaeologists with chalk to return the hill to its pre-1776 condition. English Heritage require that the chalk for the backfilling be sourced from the same chalk members that were used to obtain chalk by Neolithic man to build Silbury Hill. The relevant members are the Holywell Nodular Chalk Member of the Middle Chalk Formation and probably the Zig Zag Chalk Member of the underlying Lower Chalk Formation. Both of these chalk members are present at the Lafarge Beggar's Knoll Quarry, near Westbury in Wiltshire, which is the preferred source for the chalk fill.

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## 1. INTRODUCTION

Silbury Hill in Wiltshire lies near the villages of Avebury and West Kennet and is the largest artificial pre-historic mound in Western Europe. It is also probably the best known example of a rare Neolithic feature now classified as a “monumental mound”. The hill is a Scheduled Ancient Monument (SM 21707) and forms a key component of the Stonehenge and Avebury World Heritage Site. Silbury Hill was one of the first monuments to receive protection under the Ancient Monuments Protection Act 1882.

In addition to being a Scheduled Ancient Monument, Silbury Hill is also a Site of Special Scientific Interest and was given protection under Section 28 of the Wildlife and Countryside Act 1981.

Silbury Hill is a mound some 160m in diameter and was mostly built of chalk rubble on top of a spur of Chalk projecting into the Kennet valley. The chalk used to build the hill was derived from a ditch which encircles the base of the mound and also from a now buried quarry or possibly a further ditch now buried in the outer part of the mound which was used to provide material during the early stages of construction.

The reason why Silbury Hill was built has been studied for over three hundred years. Between the sixteenth and eighteenth century a number of antiquarian accounts on Silbury Hill were published. In addition, between 1776 and 1970 a number of archaeological investigations have been carried out on the hill to try and discover the secrets of the hill and its surrounding ditch. It is these intrusive investigations which have led to potential instability of Silbury Hill as a structure.

Skanska and English Heritage are working in partnership to undertake the final phase of conservation works at Silbury Hill. This will include the re-excavation of the most recent tunnel dug in the side of the hill between 1968 and 1970, and other excavations in the hill and then completely backfilling these with chalk rubble from the same zones within the Chalk that were used to build Silbury Hill. The works will include re-excavation of the temporary shaft crater plug installed by Skanska in 2001, following the appearance of a hole in the top of the hill at the site of the 1776 Duke of Northumberland shaft, and its complete backfilling with chalk. The conservation works will guarantee the long term stability of Silbury Hill as an important monument to our Neolithic ancestors for generations to come.

This Geological Review is aimed to demonstrate that Skanska can meet English Heritage's requirement that chalk fill used is from the same members in the Chalk Group as those used to build Silbury Hill.

## **2. SCOPE OF THE GEOLOGICAL REVIEW**

English Heritage have set a requirement for the Silbury Hill Conservation works that the chalk fill that will be used to infill the archaeological tunnels and shaft shall be sourced from the same member or members within the Chalk Group that were the source for the chalk fill used to build Silbury Hill. The reason for this is to restore the hill as closely as possible to its state before the various archaeological investigations were carried out. The backfilling of the tunnels and shafts will remove the risk of future collapse of these damaging Silbury Hill and avoid the need to maintain any security measures, such as steel doors or plates, to prevent members of the public accidentally or deliberately gaining access to the interior.

Skanska Civil Engineering, a division of Skanska Construction UK Ltd., have instructed Skanska Technology to carry out a Geological Review of Silbury Hill in advance of the main conservation works. The Review has the following aims:

1. Carry out a Desk Study of the Geology of Silbury Hill and the Surrounding Area.
2. Make a field visit to Silbury Hill to study chalk outcrops adjacent to Silbury Hill to determine the identity of the Chalk members. This was later extended to include examining cores from one of the seven boreholes sunk through Silbury Hill into the underlying Chalk during 2001 and reviewing the borehole logs from all four of these boreholes which penetrated into the Chalk.
3. Make a site visit to the Lafarge Beggar's Knoll Quarry near Westbury, which is the proposed source of the Chalk fill, to confirm the availability of the equivalent chalk members to those present at Silbury Hill.
4. Prepare a Technical Report containing the results of Items 1 to 3.

Skanska Civil Engineering requires the Technical Report to be completed by the end of 2006 / early 2007. The Main Conservation Works are due to take place during 2007.

### **3. BRIEF HISTORY OF SILBURY HILL**

#### **3.1 Introduction**

Silbury Hill is a Scheduled Ancient Monument (SM 21707) and forms a key component of the Stonehenge and Avebury World Heritage Site. The hill is located 1.5km to the south of Avebury, with its stone circle, and 1km west of West Kennet in Wiltshire. The closest large town is Marlborough, which lies approximately 9km to the East. Immediately to the south of Silbury Hill runs the main A4 Bath Road. West Kennet Long Barrow lies just around 1 kilometre to the south-east of Silbury Hill.

Silbury Hill itself is a site of Special Scientific Interest (SSSI) and is surrounded by a fence at its base to protect the unique chalk downland flora from damage by people climbing the hill. Figure 1 shows a view of Silbury Hill looking south-east.

#### **3.2 The Construction of Silbury Hill**

Silbury Hill is built on a spur of the Chalk projecting into the Kennet valley, where the valley curves round from north-south to east-west. Its base level is approximately 150m AOD. The site itself is low-lying and because of its size Silbury Hill can be seen from several directions, although it does not dominate the whole area. The hill is circular in shape and forms a flat-topped or truncated cone. The top of the hill is some 39m above the main ditch which encircles the base. It is estimated that Silbury Hill contains around 350,000 cubic metres of chalk and soil of which around 250,000 cubic metres of material was quarried, moved and placed by hand (Malone, 1994). It is the largest man-made mound in Europe and rivals the smaller Egyptian pyramids in size.

Studies of Silbury Hill since the Eighteenth Century have determined that Silbury Hill was constructed in three phases, each of which enlarged the hill constructed during the previous phase. The dates for the three phases of construction of Silbury Hill come from radiocarbon studies on samples of wood and vegetation from inside the mound. It should be noted that Whittle (1997) only identifies two phases of construction, but it is now known that there were three phases.

Silbury Hill began life as a mound less than 40m in diameter and around 5m high. It is thought to have been constructed around 2,660 BC. This early mound was built on

the existing land surface from a mix of gravel, turves, soil and chalk, at least part of which was riveted by wooden stakes. It is believed that construction started during the summer months because of the presence of flying ants within the turves at the base of the mound. Over the basal turf layer were four layers of soil.

Around 2,500 BC, a larger mound was built over the original one. This included the excavation of the first ditch around the perimeter of this larger mound. The ditch was up to 14m wide and 7m deep, enclosing an area of around 110m in diameter. The chalk rubble from the ditch and a quarry near the site was used to enlarge the mound which may have been arranged in a complex series of reinforced walls designed to produce a conical shape. The enlarged hill was around 17m in height and contained some 28,325 cubic metres of chalk and soil.

Soon after Phase 2 had been completed, the mound was enlarged yet again to produce Silbury Hill as it is today. The top of the hill is around 39.5m (130 feet) high above the base of the ditch. The third phase of construction involved infilling the ditch dug during Phase 2 and excavation of a new one to enclose a larger area. The new ditch was around 7m deep. The ditch dug during Phase 2 is buried below the present Silbury Hill and was encountered in the 1969 tunnel.

The structure is believed to have been very stable and shows that prehistoric man had a good understanding of soil mechanics and slope engineering as far back as 2,500 BC. It is believed that basic wooden scaffolding was erected to assist with the construction process.

Silbury Hill as it currently stands covers an area of 2.2 hectares and comprises around 350,000 cubic metres of chalk and soil, dug by hand using simple stone, bone, antler and wooden tools and moved in wicker baskets. In its day, Silbury Hill was one of the most labour intensive sites in prehistoric Europe.

In later times Silbury Hill was used as a Roman surveying point and a Saxon lookout and stronghold.

### **3.3 A Summary of the Archaeological Investigations of Silbury Hill**

Several archaeological investigations have been carried out on Silbury Hill in 1776-1777, 1849, 1867, 1886, 1922 and 1968-1970. The most important of these are the vertical shaft sunk by the Duke of Northumberland and Colonel Drax in 1776-1777, a horizontal tunnel dug in 1849 by John Merewether, Dean of Hereford and the 1968 Atkinson tunnel.

The Duke of Northumberland shaft is believed to have been backfilled with tree trunks and branches with a chalk cap. This was a common method for backfilling old well shafts at the time. The portal end of the 1849 tunnel was closed at the end of the investigation, but the tunnel is believed to have been left unfilled. The outer end of the 1849 tunnel collapsed in 1915, making access possible. Members of the public were able to crawl through the Merewether tunnel into the heart of Silbury Hill until 1923 when the entrance was sealed with a metal plate to prevent access.

The most recent investigation in 1968-1970 was sponsored by the BBC and involved re-establishing the 1849 tunnel to investigate the interior of the mound, the top of the mound and the surrounding ditch. This tunnel is known as the Atkinson Tunnel after Professor Richard Atkinson of Cardiff University, who supervised its excavation. The Atkinson Tunnel generally followed the alignment of the 1849 tunnel and had steel colliery arches installed at intervals to support the walls and roof of the tunnel. This tunnel was backfilled on completion of the archaeological investigations and the portal was sealed with a metal plate. The investigations carried out over the years have been made in order to investigate the date and methods of construction of Silbury Hill and determine whether or not the hill has anything inside it.

### **3.4 An Overview of Skanska's Involvement with Silbury Hill**

In 2001 Skanska carried out a site investigation on Silbury Hill following the opening of a hole in the top of the hill at the site of the Duke of Northumberland's shaft. During May 2000 a hole up to 40 feet deep (12m) was found to have opened up in the top of the hill. A second collapse during December 2000 deepened the hole further. A review of historical photographs, including a 1934 aerial view of Silbury Hill, plus a sketch section through the hill dating from 1849 suggested that this was not the first time a hole had appeared in the top. It is believed that the previous holes had simply been backfilled with chalk to make the top of the hill safe. Figure 2 shows the 1934 aerial view reproduced from English Heritage's web site.

Following the collapse in 2000, English Heritage became concerned about the stability of Silbury Hill. They commissioned Cementation Skanska to carry out an investigation of the hill to look for voids inside it. The investigation included sinking a number of boreholes and carrying out a survey using geophysical techniques (3-D Tomographics) to look for voids inside the mound. The hole in the top of the hill was temporarily backfilled with lightweight polystyrene blocks and capped with chalk. Several reports were written on conclusion of the works which also featured in an episode of the BBC Southern Eye television series, entitled “The Hill with the Hole”, which reported on the works English Heritage and Skanska had carried out.

In late 2006 Skanska re-excavated the buried portal of the Atkinson tunnel to determine the specific tunnel invert and crown levels and internal dimensions, and inspect the condition of the portal end of the tunnel. These works were carried out in advance of the main conservation works which are programmed to take place in 2007.

## **4. GEOLOGY OF THE MARLBROUGH DOWNS**

### **4.1 Introduction**

Silbury Hill lies to the west of Marlborough within what are commonly known as the Marlborough Downs, which are usually defined as the area of land to the north of the Vale of Pewsey and the south-east of a valley where the underlying Oxford and Kimmeridge clays form the floor. The Marlborough Downs themselves are formed by the presence of the Cretaceous age Chalk Group.

The Chalk Group overlies older Cretaceous Strata including the Upper Greensand and Gault formations and the Lower Greensand Group. Although there are Palaeogene (early Tertiary) age sediments present in the Marlborough Downs, they are absent from the area around Silbury Hill. The closest Palaeogene deposits lie to the south-east of Marlborough. However, part of the Clay-with-Flints may be of Late Neogene age rather than Pleistocene.

Clay-with-Flints can be found overlying the Upper Chalk on the tops of hills and ridges. Valley Gravels and Alluvium can be found overlying the Middle and Lower Chalk in valleys.

### **4.2 The Chalk Group**

#### **4.2.1 Introduction**

The Upper Cretaceous in Britain is marked by the deposition of the Chalk Group. In Late Cretaceous times, global sea levels rose progressively, flooding most of Europe including the UK. Reduction in the area of land above sea level resulted in a major decrease in the volume of sediment being eroded from the land and transported to the sea by rivers. The reduction in volume of terrigenous material (sediment from the land) allowed the deposition of increasingly pure calcareous deep water sediments, which would eventually form the Chalk. The seas around Britain were probably between 100 and 500m deep during Late Cretaceous times, although they were probably shallower over the submerged London Platform and mountainous areas such as Wales and the Scottish Highlands. The high sea levels during the Late Cretaceous are believed to be mainly due to the complete absence of ice caps at the North and South Poles. The seas were also warmer than the present, which is



indicated by isotope studies and the fossil record, which includes corals, brachiopods and echinoderms.

Palaeomagnetic data puts Britain at a latitude of between 32° and 35° North during the Upper Cretaceous, which is roughly the same as present day Morocco.

Chalk, which makes up the bulk of the Chalk Group, is a very fine-grained, pure limestone, which may contain up to 98% calcium carbonate (CaCO<sub>3</sub>). The calcium carbonate is of the form of a low magnesium calcite. The remaining 2% or so of material is comprised of clays and some fine grained quartz. Up to 90% of the calcium carbonate is composed of tiny calcite plates from the disintegrated skeletons of a particular type of unicellular algae called coccolithophoroids, which were abundant in the Late Cretaceous chalk seas. On death the calcite plates from these algae sank down in the water column to the sea floor, forming vast thicknesses of chalk mud over time.

Coccolithophoroids were the main source of food for shrimp-like creatures called copepods. One recent theory is that in order for the tiny coccoliths to sink to the sea floor and accumulate, the living algae were eaten by copepods, and it is their faecal pellets which include the tiny coccoliths that sink to the sea floor and accumulate as calcareous mud.

The calcareous mud was progressively buried by younger sediment and turned into chalk. The remainder of the carbonate sediment is composed of complete coccoliths, other calcareous nanofossils, ostracod valves and shell debris from macrofossils such as bivalves. Average sedimentation rates are thought to have been between 2.0 and 2.4 cm per year or alternatively 20 to 40 metres per million years.

The marl seams within the Chalk, which are more abundant in the Lower Chalk Formation, are a mixture of chalk and clay. Some of the marl seams can be several cm thick and can be traced laterally for many kilometres. Many of the marl seams within the chalk are decomposed ash from volcanic eruptions which was thrown up into the atmosphere and later settled through the water column to the sea floor. When weathered the volcanic marl seams are often a reddish-brown colour, which contrasts with the adjacent white or off-white chalk. When fresh, for example when seen in borehole cores, the volcanic marl seams are commonly shades of green and grey in colour. The non-volcanic marls represent periods where there was an influx of clay into the depositional area, for example during storms.

The macrofossil fauna within the Chalk is not as diverse as in other limestone units, such as the limestones of the Jurassic, and includes organisms such as brachiopods, inoceramid bivalves and echinoderms, which have shells composed of a stable form of calcite. The guards of belemnites can also be found in some zones, e.g. the Plenus Marls. Other mollusc groups such as gastropods, ammonites and most other bivalves have shells composed of aragonite, an unstable form of calcite, which was generally destroyed by dissolution, meaning that these fossils themselves are generally absent from the Chalk Group, apart from some of the clayey layers in the lower part, where they are preserved. Some ammonites have been found preserved as moulds infilled with chalk.

The formations making up the Chalk Group contain at intervals what are known as “hardgrounds”. Hardgrounds are omission surfaces, representing periods when there was no deposition of sediment on the sea floor. This allowed the sea floor to lithify (harden). Strictly speaking it is the omission surface only that is the hardground. However, in chalk stratigraphy the term is commonly applied to the underlying chalkstone as well. Omission surfaces can be identified by differences in the chalk sediment above and below the interface. Typically the chalkstone below the omission surface is around 0.3m thick and is commonly stained orange-brown by iron oxide, pink-brown by apatite or greenish by glauconite. Logging hardgrounds is effectively logging periods of non-deposition. Hardgrounds commonly show evidence of boring by marine creatures within the top surface, indicating prolonged exposure on the sea floor. The borings are usually infilled with sediment forming trace fossils. In the Upper Chalk and the top part of the Middle Chalk the burrows may be infilled with flint forming “flint burrows”.

The Chalk Group is not uniform across the whole of Britain. Broadly speaking the distribution of the group can be divided into two main provinces based on lithology and fossil content, with an intermediate region between the two. The Southern Province covers southern England, including the Thames Valley and the Wessex Basin. The Northern Province covers the Chalk in Yorkshire. The intermediate region covers East Anglia. The Silbury Hill area lies within the Southern Province.

The Chalk Group is traditionally divided into three formations, the Lower Chalk, Middle Chalk and Upper Chalk. An alternative newer scheme refers to the Lower Chalk as the “Grey Chalk Subgroup” and combines the Middle and Upper chalks together as the “White Chalk Subgroup”. It should be noted that the White Chalk Subgroup also includes the Plenus Marls at the base, which are traditionally included

in the Lower Chalk Formation. For ease of reference, the former classification has been used in this Desk Study.

#### 4.2.2 The Lower Chalk Formation

The Lower Chalk Formation is made up of impure chalk with up to 30% clay content in the lower part. It is generally grey in colour when freshly exposed due to the present of finely disseminated pyrite. It weathers to a buff colour. Marl bands are common.

In Southern England the Lower Chalk is comprised of two main members, the West Melbury Marly Chalk at the base and the Zig Zag Chalk Member above.

The West Melbury Marly Chalk Member is typically a glauconitic marl with some marly chalk and chalk. The lower part is typically composed of a greeny-grey coloured glauconitic sandy marl, up to 1m in thickness. This band marks the base of the chalk and is referred to in older references as the “Chloritic Marl”. The band contains distinctive small dark chocolate-brown coloured phosphatic concretions and phosphatised fossils, which typify this marl in Wiltshire. The fossil content includes the sponge *Stauronema carteri* and some molluscs. The top of the underlying Upper Greensand Formation may be marked by a rusty streak. Above the marly layer there is typically up to a couple of metres of a flaggy grey-brown coloured marl which contains quantities of glauconite and fine quartz sand, both of which decrease in quantity upwards.

Above the flaggy marl is up to 30m of a bluish-grey marly chalk which is referred to in older references as the “Chalk Marl”. This is a series of firm marl bands alternating with tough marlstone and occasionally with strong limestone bands, which ring when struck with a hammer. The bulk of the marly chalk is jointed into flags and blocks. The fossil content is dominated by brachiopods including *Rhynchonella martini*, *Rhynchonella grasiana* and *Terebratulina striata*. These all have shells composed of stable calcite. There are also red-brown coloured casts of ammonites including species of *Turrilites*, *Acanthoceras* and *Schloenbachia*. The shells of these were originally composed of less stable aragonite, which was subsequently dissolved.

In the Vale of Pewsey to the West, at the top of the marly chalk are two or more massive bands of limestone, which are good for long range correlation across Southern England. The higher of the two limestone bands is commonly referred to

as the “Tenuis Limestone” because it contains the large bivalve *Inoceramus tenuis*. The top of the Tenuis Limestone is taken as being the top of the West Melbury Marly Chalk Member.

The West Melbury Marly Chalk Member in many ways can be regarded as a transition between the underlying Upper Greensand and the Zig Zag Chalk Member above.

The Zig Zag Chalk Member is pale-grey to off-white chalk with thin marls. This member was given this name by Bristow (1989) to cover the firm chalk that overlies the West Marlbury Marly Chalk Member. The “Zig Zag” refers to the marl-chalk alternations. The lower part comprises around 25m of marly chalk with a series of marl-chalk rhythms. The base is often marked by what is commonly known as the “Cast Bed”. This is a band of brown silty chalk with a rich fauna of composite moulds of various aragonite shelled molluscs (shell material dissolved), particularly gastropods. The calcite shelled bivalve *Oxytoma seminudum* is common in this band. There are also a number of small brachiopods including *Modestella geinitzi*.

The chalk which makes up the upper part of the Zig Zag Chalk Member is soft to medium hard, greyish or off-white, blocky chalk. It includes numerous tiny iron oxide concretions, which are weathered iron pyrite. At intervals there are layers of harder, greyish coloured gritty chalk containing much shell debris from *Inoceramus* bivalve shells and dark green to black glauconite.

The top of the Lower Chalk Formation is marked by a series of slightly greenish grey alternating marls and clayey limestones known as the Plenus Marls. The base of each marl seam represents an erosion surface. There is usually a well marked erosion surface at the base. The Plenus marls are more fossiliferous than the underlying pale grey or off-white Zig Zag Chalk Member and contain the calcite guards of the diagnostic belemnite *Actinocamax plenus*, which occur in the upper part. The other common fossil is the bivalve *Inoceramus pictus*. In the Marlborough area the Plenus Marls are typically up to a metre in thickness and rest on an erosion surface cut into the top of the under-lying Zig Zag Chalk Member. The Plenus Marls are a distinctive marker unit which is used as the boundary marker between the Lower Chalk and Middle Chalk formations.

The Lower Chalk Formation does not usually contain flints, which are generally found in the Upper Chalk Formation and the New Pit Chalk Member of the Middle Chalk Formation.

In the Marlborough Downs area the Lower Chalk is typically 46 to 73m thick.

### **4.2.3 The Middle Chalk Formation**

The Middle Chalk Formation, unlike the underlying Lower Chalk, is predominantly composed of pure white chalk. It has two members, the Holywell Nodular Chalk Member making up the lower part and the New Pit Chalk Member the upper.

The Holywell Nodular Chalk Member is composed of medium hard to very hard shelly nodular chalk with sparse flints. This member is typically around 10m thick in the Thames Valley region. The lowest 2m of the member is particularly nodular and indurated (hardened by pressure and / or cementation) and is comparable to the Melbourn Rock in Cambridgeshire. The lower part of the Holywell Nodular Chalk can be patchily stained yellow or orange due to the presence of iron oxide. The iron oxide can be present as definite concretions and was originally Iron Pyrite.

Nodular chalks are those containing discrete dispersed nodules, which were produced by local cementing of pockets of chalk sediment below the sediment-water interface. In true nodular chalks, the nodules were not re-worked in any way after the cementing had taken place, because they show no signs of exposure or re-working on the sea floor. Where nodular chalks have been re-worked they form intraformational conglomerates with clear signs of the re-working. Nodules vary in their degree of distinctness, with some having sharp margins whereas others merge into the surrounding matrix. In terms of strength they can be either soft and friable or hard and dense. The hardest are strong porcellaneous limestone. Nodular chalk bands are commonly terminated by omission surfaces, representing periods where there were periods of no sediment was deposited, at their upper limits. In the Middle Chalk borings in the top of the omission surface can be preserved as burrow flints.

The upper part of the Holywell Nodular Chalk Member is gritty, nearly white in colour and contains an abundance of shell material from inoceramid bivalves. The bedding in the upper part is defined by thin grey marl layers. In the Marlborough area the contact between the base of the Holywell Nodular Chalk and the underlying Plenus Marls (Lower Chalk Formation) is usually clean and slightly undulate.

A useful marker band in the Holywell Nodular Chalk Member is a thin dark marl band containing microcrinoid debris and higher up a thin dark marl band containing numerous intraclasts (small fragments of calcareous material derived from local

erosion and rapid deposition of the sea floor), which is named as the Compton Pebble Marl (Gale, 1996). The upper part of the member contains 14 separate identifiable shell beds containing abundant shell debris and disarticulated valves of the inoceramid bivalve *Mytiloides mytiloides*.

The New Pit Chalk Member is typically softer than the underlying Holywell Nodular Chalk Member and comprises smooth, massively bedded chalk with marl seams, and rare flints near the base. It is usually pure white in colour, though may be slightly pale green. In general it only contains rare bivalve and brachiopod fossils. These include the bivalve *Inoceramus labiatus* (also named *Mytiloides labiatus*), the echinoids (sea urchins) *Discoidea dixonii*, *Conulus subrotundus* and *Cidaris hirudo* and the brachiopod *Rhynchonella cuvieri* (also named *Orbirhynchia cuvieri*).

The Middle Chalk is typically 37 to 46m thick in the Marlborough Downs area.

#### 4.2.4 The Upper Chalk Formation

In Southern England, the top of the Upper Chalk Formation has been removed by erosion, or in the case of the London Platform, the sequence is condensed. The maximum recorded thickness of the Upper Chalk in the Thames Valley is 100m.

The Upper Chalk Formation is present in the Marlborough Downs, however it does not outcrop within 400m of Silbury Hill. Therefore the bulk of the Formation has not been described. The text in this section concentrates on the lowest Member in the Upper Chalk Formation, the Lewes Chalk Member, which includes the Chalk Rock at the base.

In most of the Thames Valley, including the Marlborough Area, the base of the Upper Chalk is marked by the Chalk Rock, a condensed sequence of glauconised hardgrounds and chalk stones. In the Warminster area the Chalk Rock may be as thin as 1m and composed entirely of cemented hardgrounds.

Typically in the Marlborough Downs area the Chalk Rock is between 1 and 5m in thickness and contains up to seven recognised hardgrounds. The topmost of the hard grounds, the Hitch Wood hardground, contains a diverse assemblage of fossils including gastropods and ammonites preserved as moulds. The ammonites include the heteromorph *Hyphantoceras reussianum*.

The type section for the Chalk Rock is at an old quarry 1km west of Ogbourne Maizey, north of Marlborough, where it is around 4m thick. Six of the hardground surfaces are well defined and have been named. The lowest of the hardgrounds is the Ogbourne Hardground, which is one of the three best developed hardgrounds within the Chalk Rock. It is strongly convoluted, poorly phosphatised and strongly glauconised. Locally the hardground can be overlain by a thin band of glauconised pebbles of locally eroded calcareous material, though this is rarely present in the Marlborough area. The chalkstone making up the hardground is usually stained a rusty orange colour by iron oxide. The next hardground, the Pewsey Hardground has a distinctive lithology and fauna. The top surface is convoluted and well-phosphatised. Typically the chalkstone has a pinkish colour, due to the presence of the phosphate mineral apatite. There is some glauconite, particularly on the tops of convolutions (bosses) where it is dark and commonly glossy when fresh. The Pewsey Hardground has a more limited geographic distribution than the Ogbourne Hardground, but is present throughout the Marlborough Downs. The top of the Chalk Rock is marked by the Hitch Wood Hardground on which there is a flint nodule horizon which marks the base of chalks in the rest of the Lewes Chalk Member.

The Lewes Chalk Member is a series of nodular hard chalks with flints and local chalkstone. The chalks are fossiliferous. The member is overlain by the Seaford Chalk Member, which comprises a series of white soft chalks with flints.

The Seaford Chalk Member is the youngest chalk member that is present in the Thames Valley Region.

In the Marlborough Downs area the Upper Chalk is typically around 107m thick including the Chalk Rock.

### **4.3 Palaeogene and Neogene Strata**

The only Palaeogene and Neogene (Tertiary) age strata present in the Marlborough area are inliers of Eocene (Palaeogene) age Bagshot Sands over the Reading Formation of the Lambeth Group. The closest outcrops to Silbury Hill lie around 6 km to the south-east of Marlborough and around 12 km to the east-south-east of Silbury Hill.



### 4.3.1 The Reading Formation

The Reading Formation of the Lambeth Group (formerly known as the Reading Beds) is up to 5m thick in the Marlborough area. It lies unconformably on top of eroded Jurassic and Cretaceous strata. The Reading formation comprises colour mottled clays, silts and sands. The sediments were laid down on marshy mudflats which were crossed by river channels. The variable coloration is thought to be due to weathering and soil formation (pedogenesis), which took place shortly after deposition.

### 4.3.2 The Bagshot Formation

The Bagshot sands, part of the Bagshot Formation of the Bracklesham Group, where present, rest unconformably on top of the underlying Reading Formation. The Bagshot sands are typically up to 4 to 5m thick and comprise orange or pale yellow fine-grained cross-bedded sands with some thin pale grey clay beds. Deposition is believed to have occurred in a warm, shallow-marine environment.

The sands can locally include ironstones in the Thames Valley region. The fossil content includes fish teeth, casts of shells and the large chambered foraminifera *Nummulites laevigatus*.

## 4.4 Quaternary Strata

The Quaternary Period started 1.64 million years ago. The bulk of the period is covered by the Pleistocene Epoch, which ended 10,000 years ago and included the Pleistocene “ice age”. In fact the Pleistocene comprises a series of cold or “glacial” phases alternating with warmer or “interglacial” phases. The climatic record for the UK indicates that some of the interglacials were in fact warmer than the current climate. The last 10,000 years is thought to be one of these interglacial phases and is referred to as the Holocene.

During the Pleistocene the chalk was completely frozen. During summer months surface water flowed over the frozen chalk surface without seeping into the ground. This led to the carving out of a number of gully like valleys in the Chalk escarpments in the Marlborough Downs.



#### 4.4.1 Clay-with-Flints and Valley Gravels

The clay-with-flints is a term applied to a range of deposits that occur on top of areas of the high chalk downland across the Thames Valley area. It is present in the Marlborough area where it can be up to around 1m thick. Although generally referred to as a Pleistocene deposit, formation of the Clay-with-Flints is thought to have commenced during the Neogene (late Tertiary) and continued during much of the Pleistocene.

Clay-with-Flints typically comprises a reddish-brown clay or sandy clay containing abundant flint pebbles. Some of the flints are fresh and un-abraded, indicated by the presence of the white cortex being intact. In addition to the flints there is often a small proportion of pebbles of other lithologies including sarsen sandstone. The clay or sandy clay fraction was derived from the insoluble residue left after the dissolution of the Chalk and material from eroded Palaeogene sediments, which are now no longer present in the area.

The Clay-with-Flints lies unconformably on the eroded top of the Chalk and the base is often highly irregular. It commonly infills solution features in the underlying Chalk.

In the Marlborough area, the deposits referred to as Valley Gravels are thought to be Clay-with-Flints which have been worked on by periglacial action during the Pleistocene. As such they are not true Clay-with-Flints, which is why the British Geological Survey have mapped them separately, and no Clay-with-Flints is shown at or adjacent to the Silbury Hill site. True Clay-with-Flints is an interfluvial deposit which is usually found on top of the Upper Chalk. Interfluvial areas are areas of high land between two streams belonging to the same drainage system. The closest Clay-with-Flints mapped as such by the BGS lies over 2 km from Silbury Hill on top of the Upper Chalk ridges or hills.

#### 4.4.2 Loess

Loess consists of wind-blown silt, which was laid down during cold dry periods during the Quaternary. The fine grained silt is usually sourced from glacial tills or outwash deposits and is common in areas surrounding glaciated districts, where there is a good source of fine material and little vegetation growing. Loess is typically unstratified and uniform in grading with characteristic vertical prismatic jointing. It is generally calcareous and can contain small concretions.

At Silbury Hill the relict topsoil is largely loess. In Whittle (1997), a tested sample was noted to be slightly sandier than is typical for loess, however, the sand sized fraction is only a few percent of the total.

#### **4.4.3 Slope Deposits**

On the chalk slopes, erosions deposits, often collectively referred to as “head” on geological maps, form an important part of the Pleistocene age deposits. Pits and cuttings in the slopes of the Marlborough Downs commonly show thin veneers of granular chalk detritus lying between the in-situ chalk and the overlying turf. The slope deposits were formed from rain washing weathered chalk material down the slope. They can be locally thick enough to be bedded, with the bedding following the underlying ground surface.

#### **4.5 Holocene Strata**

The Holocene Epoch covers the last 10,000 years of time, including the period where Man evolved and started leaving his mark on the landscape. The principal Holocene deposits present in the Marlborough Down area are fluvial deposits along the river valleys. Lenses or beds of peat can also be found locally in the Thames Valley area.

##### **4.5.1 Alluvium**

Alluvium is mostly composed of silt and clay deposited by streams and rivers. Seams of sand and gravel mark periods where the flow rates were higher and usually correspond to flood events.

Alluvium does contain fossils, usually a mix of molluscs, ostracods, insect remains, mammal bones and teeth. Wood and plant material, including pollen grains, are often present. The pollen can be studied under a microscope to determine the species of the trees or plants. The floral assemblage present can be used to determine the climatic conditions at the time.

The alluvium from the Early Holocene onwards may contain artefacts from early Man, of Mesolithic (Middle Stone) Age onwards. Later on during the Holocene when Man started to clear woodland and cultivate the land increased soil erosion from the slopes lead to increased deposition of alluvium in the rivers. This

particularly relates to the late Iron Age and the Roman Period onwards. The artefacts and fossils within the alluvium can be used to date it.

From carbon dating of wood fragments below Silbury Hill, the hill was built some time during the Neolithic (New Stone Age), which lasted between 5,500 and 4,000 years ago (2,500 to 2,000 years BC).

## **5. GEOLOGY OF THE SILBURY HILL SITE**

### **5.1 Introduction**

Silbury Hill was built on a spur of the Middle Chalk Formation projecting into the Kennet valley. The BGS map indicates that the hill lies just to the north of the presumed boundary between the Middle Chalk and Lower Chalk. The boundary line itself is shown as being masked by the presence of a layer of Recent Alluvium overlying Valley Gravels within the River Kennet valley.

### **5.2 Summary of the Quaternary Geology**

Cornwall, et al. in Whittle (1997) indicates that below Silbury Hill there is Clay-with-Flints and some Loess (wind blown silt), both of Pleistocene age, resting unconformably on top of the Middle Chalk. There is around 1m of Clay-with-Flints, over which lies a thin layer of brown loess. The Clay-with-Flints is shown as Valley Gravels on BGS Sheet 266. Canti et. al. (2004) suggest that the BGS use of Valley Gravels may be more appropriate because the deposit may have been re-worked by periglacial action following deposition.

A summary of the Quaternary geology at the Silbury Hill site is provided in Canti et. al., (2004), which is based on Cornwall et al. in Whittle (1997). This was based on investigations carried out at the Silbury Hill site between 1968 and 1970 and is reproduced in Table 1 below.

As an aside, Canti et. al., 2004 states that there is no BGS Geological memoir for Sheet 266 – Marlborough and refers to the 1903 Memoir for the adjacent Reading sheet (Sheet 268). In fact there is a Memoir for Sheet 266 which was published in 1925 (White, 1925).

*Table 1. The Quaternary Geology at the Silbury Hill Site (Based on Canti et. al., 2004).*

<b>Stratum</b>	<b>Typical Thickness (m)</b>	<b>Description</b>
Relict Topsoil	0.03 – 0.10	Stone-free fine textured soil variously described as fawn, blue or blue-grey, but darker under the primary mound at the centre of the hill. Remains of vegetation found on its upper surface.
Valley Gravels / Alluvium	0.02 – 0.04	Compacted mass of small flints embedded in an iron stained clay matrix.
Valley Gravels (re-worked Clay-with-Flints).	Up to 1.0m	Reddish-brown clay or sandy clay containing abundant flint pebbles.

The Valley Gravels rest unconformably on the underlying Chalk. Whittle (1997) does not describe any of the strata below the Valley Gravels (re-worked Clay-with-Flints) other than the fact that the underlying chalk was used to build Silbury Hill.

The cores from four boreholes sunk during 2001 from the top of Silbury Hill penetrated the under-lying topsoil and Valley Gravels down to a depth of around 20m into the underlying chalk (Canti et. al., 2004). The cores from these boreholes were retained by English Heritage. Copies of the borehole logs from these four boreholes plus sections of core from one of the boreholes were examined as part of the Geological Review.

## **5.3 Summary of the Chalk Geology**

### **5.3.1 Review of Available Information**

From copies of email correspondence between Mark Kirkbride of Skanska Civil Engineering, Peter Hopson of the British Geological Survey and Rob Harding of English Heritage the chalk used to build Silbury Hill is believed to come from the Zig Zag Member of the Lower Chalk Formation and the Holywell Nodular Chalk Member of the Middle Chalk Formation. This fits in with the BGS Map for

Marlborough, which shows the edge of Silbury Hill lying on the boundary between the Middle Chalk and the Lower Chalk.

There is no 1 to 10,000 scale geological map for the Silbury Hill area. Silbury Hill would lie in the north-eastern corner of Sheet SU 06 NE had this sheet been published. The older County Series of 1 to 10,560 scale (six inch to the mile) geological map sheets are available for Wiltshire. Silbury Hill can be found on Sheet Wiltshire 28 SW. However, this map does not show any additional information to that shown on the 1 to 50,000 scale sheet, only showing the area enlarged. In fact the 1 to 10,560 scale does not even show the inferred boundary between the Middle and Lower Chalk formations below the alluvium at the Silbury Hill site.

Malone (1994) states that blocks of “hard lower chalk” were used to construct the walls of the steps that were built during Phase 3 of the construction of Silbury Hill. These blocks are believed to have been sourced from a quarry near to Silbury Hill. Finer material, referred to as “silt”, was later used to infill all but the uppermost of the steps to produce the conical shape that Silbury Hill has today. The finer material was sourced from the huge quarry area that lies to the north and west of Silbury Hill.

### **5.3.2 Field Visit to Silbury Hill**

It was known that there was some exposure of the Chalk close to Silbury Hill and a field visit was made on 20<sup>th</sup> November 2006 to examine the exposures. The aim of the field visit was to try to determine which of the Chalk Members are present at the Silbury Hill site and therefore would have been used as the source of the chalk that was used to construct the hill. A series of photographs were taken during the field visit, which are included in this report.

Access to the area around Silbury Hill was gained from the viewing area next to the small car park off the A4 to the West of Silbury Hill. Silbury Hill itself is surrounded by a wire fence to prevent access because it is a Scheduled Ancient Monument and a Site of Special Scientific Interest (SSSI). The area around the hill is covered in long grass and other plants. During the visit, a walk was made around the hill to look for any exposures of the Chalk. The only ones found were on a steep face to the south-west of Silbury Hill and to the north of the A4. This north-facing steep face is believed to be the old quarry face left behind when Silbury Hill was built. The steep face is heavily over-grown with thick grass and only several small exposures of the topsoil, subsoil and underlying chalk were found. All were low exposures up to a maximum of 0.5m in height, up to around 8m maximum in length

and were heavily weathered. Many of the exposures were of the topsoil and chalky subsoil only. Four of the exposures included the underlying chalk. They can be identified on an aerial photograph on the English Heritage web site. A copy of this has been annotated to show the exposure locations and is included as Figure 3. A photograph, included as Figure 4, taken during the field visit of the steep face looking south also shows the locations of the four exposures.

These exposures are described in turn starting at the eastern end of the steep slope.

### **Exposure 1.**

This is the closest of the four exposures to the foot of Silbury Hill. The exposure appears to have been created by possible slippage or local erosion of the topsoil and subsoil. This had formed an exposure approximately 8m long and a maximum of 0.5m in height. The turf and topsoil were shown in section at the top of the face and were around 0.1 to 0.15m in thickness. The chalk exposed here had been mostly weathered to a creamy buff colour in the lower part. The upper part of the exposure had been weathered to a blue-grey colour or to a creamy buff with blue-grey spotting. When fresh the chalk was white in colour. This was determined by knocking and cleaning up two small areas with a geological hammer to remove the weathered surface. The white chalk showed occasional tiny patches of orange-brown iron oxide staining from oxidised pyrite.

The chalk showed cm scale vertical and horizontal discontinuities which gave the exposure a blocky appearance. Figures 6 to 9 show views of exposure 1. In most cases a geological hammer is included in the view for scale.

### **Exposure 2.**

This was approximately 5m to the west and at a slightly higher level than Exposure 1. Two smaller exposures slightly to the east towards the top of the steep face were of topsoil and chalky subsoil only. The exposure was approximately 6m long and up to a maximum of 0.3m in height.

The chalk exposed here was similar to that seen in Exposure 1. Most of the exposure, apart from the top 0.1m, was weathered to a blue-grey colour. The top part had been weathered to a creamy buff with much blue-grey coloured spotting. Again the chalk was white in coloured when freshly exposed and had the same blocky

appearance as that in Exposure 1. Figure 10 shows a view of creamy-buff coloured chalk looking south-east with an A5 sized note book for scale.

### **Exposure 3.**

This exposure was approximately 20m to the west of Exposure 2, and at roughly the same level as Exposure 1. It was up to around 8m long and had a maximum exposed height of 0.2m.

The chalk was mostly weathered a creamy-buff colour with the upper part weathered blue-grey. The chalk looked blocky, with some of the fragments separated by mm scale gaps. The white chalk showed some patchy iron oxide staining in places.

An exposure approximately 3m below Exposure 3 and a further one 3m to the East were both of topsoil and chalky subsoil only. Figure 11 shows creamy-buff coloured chalk in Exposure 3 looking south-east with an A5 sized note book for scale.

### **Exposure 4.**

This exposure was at a lower level than the previous three exposures and was roughly mid-way along the steep slope where it starts to curve round further to the south. It was approximately 10m long and up to 0.5m in height.

Most of the chalk shown in this exposure had been weathered a creamy-buff colour. There was very little blue-grey colouring. Towards the top of the exposure there was a 0.05m thick rubbly band of chalk which had been weathered a light brown colour. This band had a little blue-grey colouring in patches. This band looked to be harder than the rest of the chalk in the exposure. When freshly exposed the chalk was white in colour.

There were fewer exposures on the western half of the steep face. All were of topsoil and chalky subsoil only. Once of the exposures had a single loose sharp flint lying loose on the soil. The sharp form of the flint suggests that it has not been recently sourced from the adjacent chalk outcrop. Two views are included as Figures 12 and 13.



## **Discussion.**

All four of the exposures of chalk in the steep face close to Silbury Hill were low in height, up to a maximum of 0.5m and limited in width to a maximum of around 10m. All four exposures were weathered. The chalk was off-white in colour when fresh at all four exposures, weathering to either a creamy buff- colour or a dark blue-grey. The buff weathering of the chalk suggests the presence of an amount of disseminated weathered Pyrite (iron sulphide) within the chalk.

The chalk generally appeared “blocky” in nature with vertical and horizontal discontinuities (joints and bedding) separating the pieces of chalk. On weathering the pieces of chalk start to lose their angularity and become more rounded. The blocky nature of the chalk may be at least in part due to frost shattering during the Pleistocene. This would explain the rubbly appearance of the top of the chalk in all in the exposures, particularly Exposure 4, below the subsoil.

No evidence of chalk nodules was seen in the exposures. Based on the review of published works, it is generally only the lowest 2m or so of the Holywell Nodular Chalk Member, commonly referred to as the Melbourn Rock, which has well developed hard nodules. The nodules in the Melbourn Rock usually have a yellow-brown tinge and were formed just below the sea floor during a period of non-deposition. The Holywell Nodular Chalk Member above the Melbourn Rock tends to have much less well developed nodules and is an off-white colour when fresh.

Although the bulk of the exposed chalk had a creamy buff-colour on the surface, this colour was formed by weathering of the chalk after exposure. When freshly exposed the chalk was off-white in colour. In addition, when the Melbourn Rock weathers, the softer material between the harder nodules is preferentially eroded out leaving the nodules standing proud of the face. The chalk within the Holywell Nodular Chalk Member is usually shelly and often has a gritty appearance. No shell fragments were noted during examination of fragments of the chalk in the four exposures.

The Plenus Marls at the top of the Lower Chalk formation are usually greenish-grey in colour when freshly exposed, which distinguish them from the white or off-white chalks below. No greenish-grey colouration was seen in any of the four exposures at Silbury Hill. In addition, no belemnite fossils were noted in any of the four chalk exposures. However, given the limited height and width of the exposures it would have been a lucky chance if any belemnites had been found, if any of the exposures

had included the Plenus Marls. The presence of the diagnostic belemnite *Actinocamax* plenus within the Chalk at Silbury Hill would have indicated the presence of the Plenus Marls at the site, which in turn would indicate the presence of the boundary between the Lower Chalk and Middle Chalk formations and the Zig Zag and Holywell Nodular chalk members.

It was noted during the visit to the Beggar's Knoll Quarry at Westbury that the Plenus Marls tend to be much softer than the overlying harder Melbourn Rock. The former would tend to preferentially weather out often leaving the latter overhanging like a shelf.

Useful photographs of typical views of the upper part of the Lower Chalk Formation and the Melbourn Rock (base of the Middle Chalk Formation) are provided within Geddes (2000). It should be noted that the Melbourn Rock is not typical for the whole of the Holywell Nodular Chalk Member.

The Zig Zag Member of the Lower Chalk Formation tends to be a pale grey in colour due to a higher clay content than the overlying off-white Middle Chalk Formation.

No flints were noted in the chalk in any of the four exposures. Given that the Lower Chalk and the lower part of the Middle Chalk have no or very few flints as a rule, this is no surprise (some flints were recovered towards the top of the Chalk in two of the boreholes drilled into the Chalk from the top of Silbury Hill). The loose flints found lying on the ground in the Silbury Hill area will probably have come from a higher level in the Chalk either as the result of erosion or transport by Man.

The bulk of the subsoil below the topsoil is thought to comprise material from a higher level on the chalk ridge to the south, combined with some weathered material from the underlying chalk strata. In essence the subsoil can be regarded as a slope deposit.

The evidence gathered from the four exposures was not on its own conclusive as to which chalk member or members are present in the former quarry face at Silbury Hill. The Melbourn Rock (lowest 2m of the Holywell Nodular Chalk Member) and the underlying Plenus Marls (top of the Lower Chalk Formation) do not appear to be present. The off white chalk is therefore believed to be either from the Holywell Nodular Chalk but above the level of the Melbourn Rock or from the Zig Zag Chalk Member, but from below the level of the Plenus Marls. This assumes that the Zig Zag Chalk is predominantly off-white in colour rather than light grey.

To obtain additional information, contact was made with English Heritage to inspect some of the cores from boreholes drilled at Silbury Hill and to obtain a set of borehole logs for those boreholes which penetrated the Chalk below the hill.

### **5.3.3 The Boreholes sunk at Silbury Hill in 2001**

To supplement the observations made during the field visit to Silbury Hill, English Heritage agreed to make available for inspection the cores from a number of the boreholes which had been sunk at Silbury Hill during 2001. English Heritage had retained these cores in store at their Centre for Archaeology at Fort Cumberland, Portsmouth. A visit was made to Fort Cumberland to examine some of the Cores on 7<sup>th</sup> December 2006.

Boreholes 1 to 7 had all been drilled from the top of Silbury Hill. Borehole 1 was on the northern side of the summit, Borehole 2 on the eastern side, Borehole 3 on the southern side and Boreholes 4 and 5 on the western side. Borehole 4 intersected one of the 1968 side tunnels dug out to the side from the main tunnel alignment. Boreholes 6 and 7 were drilled through the centre of the hill along the line of the backfilled 1776 shaft. Of these, Boreholes 1, 2, 3 and 5 extended down into the in-situ Chalk below Silbury Hill.

English Heritage had arranged for the cores taken from borehole No. 5 to be available for examination. The sections of core that were of real interest were those from the intact chalk below the chalk fill making up Silbury Hill. Boxes 12 and 13 from Borehole No. 5 contained cores from between 32.20m and 37.20m below ground level. Box 12 did not contain the interface between the original ground profile and the very top of the Chalk, which is believed to have been in Box 11. Boxes 10 and 11 had been placed in cold storage because they contain the section including the original Phase 1 mound for Silbury Hill and the original land surface.

The Chalk in Box 12 was off-white in colour. Much of the Chalk comprised chalk gravel and cobbles in a putty chalk matrix. The top 0.6m of the chalk had been weathered to putty chalk with some sub-rounded chalk gravel. Between 32.20 and 32.60m bgl the off-white chalk was mottled light brown. At a depth of 32.70m bgl, a cobble of chalk was present with a slightly undulose top surface. It was thought that this might be a chalk nodule. At a depth of 33.50 a small flat flint was found at the top of the core run. Box 13 mostly contained very weak off-white coloured fractured chalk, which was locally weathered to chalk gravel in a chalk putty matrix.

Copies of the borehole logs for Boreholes 1, 2, 3 and 5 sunk at Silbury Hill were kindly supplied by Fachtna McAvoy of English Heritage and reviewed. Ground levels were not provided on any of the four borehole logs, so it has only been possible to correlate between the four boreholes using depth below ground level, which is depth below the top of Silbury Hill.

Examination of the “made ground” sections of the borehole logs indicates that where the colour of the chalk clasts is described, in the majority of cases the colour is either “white” or “off-white” rather than pale grey. Where it is described as “pale grey” coloured it is usually a mix of off-white and pale grey. The white, off-white or light grey chalk may have yellow-brown or orange-brown mottling or staining due to the presence of iron oxide.

Valley Gravels (reworked Clay-with-Flints) were present in all four of the boreholes for which logs were supplied by English Heritage. Up to 1m was present. In three of the four boreholes, a thin layer of topsoil was present above the Valley Gravels.

Based on the Desk Study, only the top 10m section of the intact Chalk below the original land surface is likely to have been used to source material for construction of Silbury Hill. This is based on what is known about the ditches and quarries around the base of the mound, the quarried area. The borehole logs include up to 20m of the Chalk below Silbury Hill. The chalk sections of all four boreholes were drilled using rotary coring techniques with a water/polymer flush. The descriptions of the Chalk in the borehole logs did not include assigning any of the layers to chalk members or a formation within the Chalk Group.

The Chalk in the four borehole logs is described as being generally off-white in colour with local light grey patching or banding. The top 4 to 6m of the chalk had been weathered to “putty chalk” with clasts of chalk. Putty chalk is a clay formed from completely weathered chalk. In general the percentage of putty chalk present decreased with depth to chalk with putty matrix. The rest of the chalk in the borehole logs varied in strength from very weak to moderately weak with some thin zones where there was putty chalk with chalk clasts. In places some zones of core loss were identified. It is considered that these represent either marl seams or bands which would have been removed by the water / polymer flush used in the rotary coring or further zones of putty chalk. The marl seams and putty chalk are softer than the less weathered chalk and would tend to be more easily removed by the water flush.

In three of the boreholes below around 40.5m to 40.9m bgl, the weak and moderately weak off-white chalk was noted to have occasional fossil fragments. The fossil fragments were not noted as being present in Borehole 1.

The chalk was noted as being nodular in Borehole 1 between 42.60 and 42.80m bgl and in Borehole 5 between 37.10 and 38.40 m and at 43.50 m bgl.

Boreholes 1 and 2 noted the presence of flint gravel in a zone of core loss between 31.48 and 32.48m bgl (Borehole 1) and 31.30 to 31.50m bgl (Borehole 2). The flints were recovered with some chalk clasts. The flints were present within the putty chalk layer below the top of the Chalk. These were the only flints noted in the logs for the four boreholes.

In Borehole 5 between 32.20 and 32.60m bgl, the off-white chalk was noted to be mottled light brown. This was noted when this section of the cores from Borehole 5 were viewed at Fort Cumberland.

The borehole logs suggest that nodular chalk can be found to a depth of 43.50m bgl. This fact coupled with the presence of flints towards the top of the Chalk sequence in Boreholes 1 and 2 suggests that the Chalk down to a depth of at least 43.50m belongs to the Middle Chalk Formation, which corresponds to a proved thickness of at least 12m.

From around 40.5m bgl, the off-white chalk has local light grey coloured banding within it and in three of the four boreholes occasional fossil fragments were noted within the chalk.

The borehole logs do not appear to show any of the diagnostic marker horizons close to the boundary between the Middle and Lower Chalk Formations. The Melbourn Rock is a hard nodular layer up to 2m thick, often with a yellowy or orange colouring. It is expected that this would show up as a distinctive horizon in the cores. The underlying Plenus Marls, which show a greenish-grey colouration, are also distinctive. However, they are softer than chalk being marls and therefore may not have been recovered as well in the cores.

Given that there do not appear to be significant lengths of non-recovery of core and that there is no mentioning of any hard nodular, yellow or orange stained chalk on the borehole logs, this suggests that the lowest 2 metres of the Middle Chalk

Formation, i.e. the Melbourn Rock, and the underlying Plenus Marls (Lower Chalk Formation) were not reached by any of the boreholes drilled from the top of Silbury Hill. This suggests that there is at least 20m of the Middle Chalk Formation below Silbury Hill. The only other explanation would be for the Melbourn Rock and the Plenus Marls to have been poorly represented in the cores and the underlying Zig Zag Chalk Member to be predominantly off-white in colour rather than light grey.

#### **5.3.4 Summary of Findings**

The evidence from the borehole logs, the cores examined from Borehole 5 and the observations made at the four exposures adjacent to Silbury Hill point towards the top 10 metres or so of the Chalk below Silbury Hill being from the Holywell Nodular Chalk Formation, above the level of the Melbourn Rock. This fits in with the British Geological Survey Map of the area which shows the presumed boundary between the Middle and Lower Chalk formations as passing somewhere along the southern edge of Silbury Hill. The presumed boundary is shown as being covered by Alluvium and Valley Gravel (re-worked Clay-with-Flints). A number of the literary sources which refer to Silbury Hill (e.g. Whittle, 1997) state that the hill sits on a spur of the Middle Chalk, which also fits in with the geological observations.

The reference in Malone (1994) that blocks of “hard lower chalk” were used in the construction of Silbury Hill Phase 3 is not at odds with the conclusion that the chalk below Silbury Hill belongs to the Middle Chalk Formation. Given that the boundary between the two chalk formations is believed to be at the Silbury Hill site, blocks of the Lower Chalk Formation could easily have been extracted from the ditch or a quarry on the northern side of the hill. It should also be noted that the four boreholes for which logs were supplied by English Heritage (Boreholes 1, 2, 3 and 5) were all sunk from the flat top of Silbury Hill and may well not have passed through the chalk walls at the outer edges of the steps that Malone states were built of blocks of the Lower Chalk. It also assumes that the chalk blocks referred to in Malone were correctly identified as being sourced from the Lower Chalk Formation.

It is likely that 4,500 years ago, Neolithic Man used chalk from both the top part of the Lower Chalk Formation and the lower part of the Middle Chalk Formation to build Silbury Hill. It is believed that chalk from the Holywell Nodular Chalk Member of the Middle Chalk Formation above the level of the Melbourn Rock was used in the construction of Silbury Hill based on the observations made on site and from the boreholes sunk from the top of Silbury Hill. However, there is insufficient evidence to categorically state whether or not chalk from the Melbourn Rock at the

base of the Middle Chalk Formation and the Zig Zag Chalk Member of the Lower Chalk Formation was used as well. One literary source states that chalk from the Lower Chalk Formation was used, but it is not known how reliable this statement is.

Based on the current available information this means that the source quarry for the chalk fill to be used in the conservation works needs to be able to supply chalk from the Holywell Nodular Chalk Member of the Middle Chalk Formation and the Zig Zag Chalk Member of the Lower Chalk Formation.

## **6. BEGGAR'S KNOLL QUARRY**

### **6.1 Introduction**

The Lafarge chalk quarry at Beggar's Knoll lies approximately 2km south-east of Westbury in Somerset and is around 24 miles from Silbury Hill. The Beggar's Knoll Quarry is the preferred source of the chalk material which will be used for the conservation works because it includes the complete section of the Chalk from the Zig Zag Member of the Lower Chalk Formation up to the Lewes Nodular Chalk of the Upper Chalk Formation.

The Quarry is used to supply Chalk to the nearby Cement works at Westbury. In general a blend of chalk is used with the Middle Chalk, which has typically a 95% calcium carbonate content being blended with the less-pure Lower Chalk, which has a calcium carbonate content of up to 85%.

### **6.2 The Geology of the Beggar's Knoll Quarry Area**

The Beggar's Knoll Quarry can be found to the south-east of Westbury on the recently revised BGS 1 to 50,000 scale sheet for Frome (Sheet 281, 2000). The youngest of the chalk members present at the quarry site is the Lewes Chalk Member of the Upper Cretaceous Formation. Below the Lewes Chalk are the various members making up the Middle Chalk and Lower Chalk formations.

The Lower Chalk Formation in the Frome area is up to 76m thick of which between 38 and 53m is the West Melbury Marly Chalk Member. This is typically a buff coloured marly chalk. The overlying Zig Zag Chalk Member with the Plenus Marls at the top is typically 22 to 38m thick and in the Frome area the Zig Zag Chalk Member is mostly white blocky chalk.

The Middle Chalk Formation is up to 30m thick in the Frome area, of which around 15m is the Holywell Nodular Chalk Member and a similar thickness of the overlying New Pit Chalk Member. The Holywell Nodular Chalk Member comprises white nodular chalk and the New Pit Chalk Member white chalk.

The Lewes Nodular Chalk Member of the Upper Chalk Formation is around 21m thick in the Frome area. It has a porcellaneous chalkstone band at the base, which is



a useful marker. This is the youngest chalk member that the Beggar's Knoll Quarry cuts down through.

### 6.3 The Site Visit to the Quarry

The fill material for the conservation works at Silbury Hill has to be taken from the same chalk members that were the source of the material used to build Silbury Hill in Neolithic times. These are the Holywell Nodular Chalk Member of the Middle Chalk Formation and probably the underlying Zig Zag Chalk Member of the Lower Chalk Formation. The exposure at the Beggar's Quarry should include both of these members and a visit was made on 12<sup>th</sup> December 2006 to confirm this. The visit was facilitated by Simon Holland, Lafarge's Quarry Manager who acted as a guide during the visit.

The first stop (Exposure A) in the quarry was made on one of the upper levels where the exposure at access road level is of the upper part of the Middle Chalk Formation. At the top of the face was the base of the overlying Upper Chalk Formation and the overlying topsoil. The thin Upper Chalk was made up of nodular chalk from the Lewes Nodular Chalk Member, the lowest 2m of which is known as the Chalk Rock. The Middle Chalk present at Exposure A was massive off-white coloured chalk which had recently been exposed by excavation. A few bands of flint and flint nodules were noted. The Chalk belonged to the New Pit Chalk Member. Figure 14 shows a view of Exposure A.

Exposure B was down succession from Exposure A and was of chalk from the lower part of the Middle Chalk Formation. The upper part of the exposure was weathered and had been exposed for around 2 years. The freshly exposed chalk was off-white in colour, whereas the weathered chalk was brownish-grey. The off-white chalk was noted to have some orange-brown iron oxide staining and spotting. A number of thinly laminated marl seams up to around 0.15m thick were noted in Exposure B. Many of the loose blocks had a rounded appearance rather than angular. A few of the smaller blocks of chalk (cobble sized) were found to contain fossils of *Mytiloides* bivalves.

The Chalk in much of Exposure B was massive in appearance. The bands of chalk were separated by horizontal discontinuities spaced between 0.15 and 0.3 m apart. A number of vertical joints broke the rock mass up into large blocks. A few 45° angled joint planes were also noted. Figure 15 shows a view of the Holywell Nodular Chalk Formation in Exposure B.

The lowest 2m of the Middle Chalk Formation is referred to as the Melbourn Rock. It was not possible to access the Melbourn Rock in the part of the Quarry being worked at the time the visit was made. Figure 16 shows a view of the Middle and Lower Chalk formations in this area. The Melbourn Rock can clearly be seen overhanging the weaker Plenus Marls. The Melbourn Rock is clearly visible in the whole Quarry and forms a useful marker band. The Melbourn Rock is not used for making cement, but is retained on site, for use as a fill material for making up the surface of access roads in conjunction with imported stone. Figure 17 shows a pile of chalk nodules from the Melbourn Rock.

Exposure C was in part of the Quarry which has not been worked for several years and included the Melbourn Rock and the underlying Lower Chalk Formation. The Melbourn Rock comprised very hard nodular chalk, which had a slightly yellowy-light brown colour when freshly exposed. Patches of the exposure were a dark brown colour and there was some orange-brown iron oxide staining. The base of the Melbourn was slightly undulose and marks the base of the Middle Chalk Formation.

Below the base of the Melbourn were the softer Plenus Marls at the top of the Lower Chalk Formation. When freshly exposed, the marls were a light, slightly greyish-brown in colour. When weathered they were a darker grey and in places had been weathered to a thinly laminated clay on the surface. Some of the joint planes within the Plenus Marls were stained orange-brown by iron oxide. At Exposure C the harder Melbourn Rock overhung the softer Plenus Marls, forming a shelf.

No fossils were seen within the Plenus Marls at Exposure C. The upper part of the Plenus Marls can contain calcite guards of the diagnostic belemnite *Actinocamax plenus*, however, none were seen in Exposure C. Figures 18, 19 and 20 show views of the Melbourn Rock and the Plenus Marls at Exposure C.

Exposure D was of chalk from the Zig Zag Chalk Member in the top 13m of the Lower Chalk Formation. The exposure, like Exposure C, was in the section of the Quarry which was not being worked at the time the visit was made. When freshly exposed, the Zig Zag Chalk was light grey in colour rather than off-white, like the Middle Chalk. The shade of the grey was noted to be lighter than that of the overlying Plenus Marls. The Zig Zag Chalk Member is referred to at the Quarry as the “Grey Chalk” due to its colour. The grey colour reflects the higher content of impurities compared to the off-white Middle Chalk. Some orange-brown iron oxide staining and spotting was noted. Figure 21 shows a view of Exposure D.

Figure 22 was taken from by Exposure D, looking along the Quarry face. The Melbourn Rock at the base of the Middle Chalk Formation can clearly be seen as a distinct dark coloured band. The hard band can often be seen over-hanging the softer Plenus Marls, as it was at Exposure C.

## 6.4 Discussion

The site visit to the Beggar's Knoll Quarry confirmed that the quarry contains a complete succession of the Middle Chalk Formation and the Zig-Zag Chalk Member of the Lower Chalk Formation. It also includes the lowest part of the Upper Chalk Formation, although this is not relevant for Silbury Hill.

The Middle Chalk Formation exposed at the quarry fitted in with what had been anticipated based on the review of published works. When freshly exposed, the chalk was white in colour, weathering to a brownish-grey colour. Marl seams were noted within the chalk, plus some flint bands and nodules in the New Pit Chalk Member. The lowest 2m of the Holywell Nodular Chalk Member, referred to as the Melbourn Rock, was hard and very nodular and a slightly yellowish light brown in colour. This useful marker band matched the description of it in published works. The overlying chalk in the Holywell Nodular Chalk Member was white in colour and blocky in appearance.

The Zig Zag Chalk Member of the Lower Chalk Formation below the Plenus Marls was a greyish colour, even when freshly exposed. Published works suggested that the Zig Zag Chalk would consist of firm white or off-white chalk and would be blocky in nature. The Zig Zag Chalk seen at the Beggar's Knoll Quarry could be described as being blocky. In colour it is probably best described as light grey in colour, with the grey colouration coming from the clay content in the chalk. It was noted that after a couple of days drying out in the office, the colour of a sample of the Lower Chalk had lightened in shade.

## **7. GEOTECHNICAL PROPERTIES FOR CHALK**

### **7.1 Introduction**

Although the Chalk may appear at first sight to be a homogeneous white rock with flint nodules and bands, in reality the material has a wide range of physical properties, and as such it is not surprising that the engineering properties are variable as well. In addition to the variation in physical properties of the chalk material itself, the presence of flint bands, and discontinuities also affect the engineering characteristics of the rock mass.

For the purpose of this Review, it is generally the properties of chalk as a fill material which are relevant, because the Conservation Works at Silbury Hill involve the placement of chalk as a fill material. The in-situ properties of the chalk at the source quarry are less relevant because the material is simply being excavated and loaded into lorries for road transport to Silbury Hill.

### **7.2 Index Properties**

Laboratory tests on samples of chalk from trial pits or rotary cores have been used to determine the values of geotechnical parameters for in-situ Chalk. Table 2 below contains typical ranges of a number of parameters. It is based on Table 4.2 in Lord et. al. (2002).

Due to the wide range of values for some of the geotechnical parameters, the ideal solution is to obtain values for samples of the actual chalk that is being considered to produce “design values” specific to the site. For the Silbury Hill Conservation Works, the ideal would be to test samples of chalk from the relevant Chalk Members at the source quarry.

Some of the parameters are noted to be difficult to accurately determine. One such parameter is in-situ water content, because of the rapid rate at which water evaporates after it has been excavated.

Table 2. Typical Ranges of Index Properties for the Chalk Group (Based on Lord et. al., 2002).

Property		Units	Range
Dry Density	$\gamma_d$	Mg/m <sup>3</sup>	1.29 to 2.46
Porosity	$n^*$	%	9 to 52
Voids Ratio	$e^*$	-	0.10 to 1.10
Saturated Moisture Content	$m_{sat}$	%	4 to 40 <sup>+</sup>
Calcium Carbonate Content		%	55 to 99
Specific Gravity	$G_s$	-	2.69 to 2.71
Liquid Limit	$w_L$	%	18 to 53
Plasticity Index	$I_p$	%	4 to 30
Liquidity Index	-	-	-2.25 to +2.50
Point Load Index	$I_{s(50)}$	MPa	0.01 to 1.15
Unconfined Compressive Strength	$q_u$	MPa	0.7 to 40
Slake Durability Index	$I_{d2}$	%	13 to 96
Average SPT 'N' Value	$N$	-	8 to 36
Elastic Modulus	$E$	MN/m <sup>2</sup>	40 to 1,000

Notes to Table 2:

\* = calculated from dry density assuming  $G_s = 2.70$ .

+ = wet.

The Lower Chalk Formation in general has a higher content of clay impurities than the rest of the Chalk Group, which means that some of the geotechnical properties, especially plasticity, are different to those for the Middle and Upper Chalk formations. The degree of weathering will also affect the geotechnical properties of the chalk.

Case Histories within a number of the papers in the Proceedings of the International Chalk Symposium, e.g. Lake (1990) and Williams (1990) provide values for in-situ geotechnical properties for specifically the Lower Chalk and Middle Chalk Formations. Some parameters for the Middle Chalk Formation (at Hillington) are also provided in Bell (1981). Summaries of available geotechnical parameters for the Lower Chalk and Middle Chalk formations are provided in Tables 3 and 4 respectively.

Table 3. Typical Values of Geotechnical Properties for the Lower Chalk Formation.

Property		Units	Range
Unconfined Compressive Strength	$q_u$	MPa	2 – 9
Mass Permeability		m/s	$1 \times 10^{-8}$ to $5 \times 10^{-8}$

Table 4. Typical Values of Geotechnical Properties for the Middle Chalk Formation.

Property		Units	Range / Typical Value
Unconfined Compressive Strength	$q_u$	MPa	6 to 40
Cohesion	$c'$	kPa	0 to 35
Angle of Friction	$\phi'$	Degrees	$33^\circ$ to $40^\circ$
Moisture Content	$m$	%	Ave = 24
Liquid Limit	$w_L$	%	Approx. 24
Wet Density	$\gamma_d$	Mg/m <sup>3</sup>	Ave = 2.1
Point Load Index	$I_{s(50)}$	MPa	Ave = 0.36
Brazilian Index	-	MN/m <sup>3</sup>	Ave = 0.49
Young's Modulus	$E$	MPa	$3 \times 10^4$
Schmidt Hardness	-	-	30
Scleroscope Hardness	-	-	17
Coefficient of Consolidation	$C_v$	m <sup>2</sup> /yr	1135
Coefficient of Compressibility	$M_v$	m <sup>2</sup> /MN	0.019
Porosity	-	%	19.8
Permeability	-	m/s	$1.4 \times 10^{-9}$

A paper by Watson et. al. (2001) for the North Downs Tunnel of the new Channel Tunnel Rail Link in Kent contains design parameter values for a number of the Chalk Members including the Holywell Nodular Chalk Member (Middle Chalk Formation) and the Lower Chalk Formation (assumed to be the Zig Zag Chalk Member). Although these values are for the Chalk in Kent, they can be used as guideline values for the Chalk in the Marlborough Downs. Table 5 contains a summary of the Geotechnical Design Parameters for the Lower Chalk and Table 6 for the Holywell Nodular Chalk Member

*Table 5. Typical Values of Geotechnical Properties for the Lower Chalk Formation in Kent (From Watson et. al., 2000).*

Property		Units	Range
Bulk Density	$\gamma_d$	Mg/m <sup>3</sup>	2.1
Design Cohesion	$c'$	kPa	150 to 250
Angle of Friction	$\phi'$	Degrees	35°
Poisson's Ratio	$m$	-	0.25
Elastic Modulus	$E$	MPa	500 to 1,200
Design $K_o$	$K_o$	-	0.5 to 0.8

*Table 6. Typical Values of Geotechnical Properties for the Holywell Nodular Chalk Member (Middle Chalk Formation) in Kent (From Watson et. al., 2000).*

Property		Units	Range
Bulk Density	$\gamma_d$	Mg/m <sup>3</sup>	2.1
Design Cohesion	$c'$	kPa	150 to 300
Angle of Friction	$\phi'$	Degrees	38°
Poisson's Ratio	$m$	-	0.25
Elastic Modulus	$E$	MPa	1,500 to 2,250
Design $K_o$	$K_o$	-	0.8

During the excavation of the North Downs Tunnel, a back analysis was carried out to determining the actual stiffness and cohesion of the various Chalk Members. For the Holywell Nodular Chalk Member the actual stiffness was determined to be between 2,550 and 2,925 MP/m<sup>2</sup> and the actual cohesion between 200 and 300 kPa. For the Lower Chalk Formation, the actual stiffness was determined to be between 2,250 and 2,400 MP/m<sup>2</sup> and the actual cohesion between 100 and 250 kPa. The values varied depending on the amount of ground cover over the tunnel and the degree of weathering of the Chalk.

### 7.3 Properties for Chalk as a Fill Material

The geotechnical properties of chalk alter once it has been excavated for use as a fill material due to the breaking up of the chalk mass and crushing of the chalk into finer grain size. The crushing causes an increase in the silt and clay size fractions which in turn alters the geotechnical properties.

The natural moisture content of chalk remains at or very close to its saturation moisture content, the range of values for which can be between 8% and 36%. During earthwork operations, the excavation and compaction of the chalk fill partly breaks down the natural rock structure of the chalk, releasing some of the water it contains. As a result, chalk fill comprises a mixture of lumps and fines. At higher moisture contents the fines form a slurry or “putty chalk”. If the proportion of putty chalk is high enough to control the behaviour of the whole mass of fill, then the stability can be decreased. Therefore the stability of the freshly placed chalk fill depends on its moisture content and its fines content. When classifying chalk for its use as a fill material, these two parameters need to be determined. The percentage of fines can be predicted using an impact crushing test to determine the Chalk Crushing Value. For very soft chalk the crushing values range from 4.2 up to around 2.4 for a very hard chalk. Figure 2 in Ingoldby & Parsons (1977) shows that the Chalk crushing value is proportional to the saturation moisture content. It is also proportional to porosity, but in general is inversely proportional to strength.

Studies have been made on the geotechnical properties of chalk used for earthworks to determine the ranges of values such as strength and compressibility. The values of the remoulded geotechnical properties are linked to the properties of the source material and the type and amount of working the material had undergone during placement.

A number of the papers in the Proceedings of the International Chalk Symposium (1990), Ingoldby & Parsons (1977) and Lord et al. (2002) provide ranges of values for some geotechnical properties for the Chalk as a fill material. Other properties have graphs which are used to correlate some parameters from others (e.g., crushing test value and dry density). The values of the geotechnical parameters for chalk fill are linked to which member in the Chalk Group that the chalk material is sourced. Table 7 provides typical ranges of a number of geotechnical parameters for Chalk Fill.



*Table 7. Typical Ranges of Geotechnical Properties for Chalk Fill.*

<b>Property</b>		<b>Units</b>	<b>Range</b>
Effective Angle of Friction	$\phi'$	Degrees	29° to 33°
Cohesion (except soft chalks)	$c'$	kPa	0
Cohesion (soft chalks)	$c'$	kPa	0 to 10
Consolidation (white chalk fines)	$C_v$	m <sup>2</sup> /year	10 to 70 (Ave = 40)
Chalk Crushing Value (Lower Chalk)	-	-	2.6 to 2.7 (62 to 88 % CaCO <sub>3</sub> Content)
Chalk Crushing Value (Middle Chalk)	-	-	2.5 to 2.6 (95 % CaCO <sub>3</sub> Content)

## 8. CONCLUSIONS

- An extensive Desk Study was carried out to determine the geology of the Marlborough Downs and the area around Silbury Hill in Wiltshire. The literature review also aimed to provide a summary of the history of Silbury Hill during and after its construction around 4,500 years ago and the principal archaeological investigations which have been carried out.
- The geology of the Marlborough Downs in the vicinity of Silbury Hill comprises the Upper Cretaceous Chalk Group over which lie occasional patches of the Palaeogene Reading Formation of the Lambeth Group. Pleistocene and Recent deposits including Valley Gravel (re-worked Clay-with-Flints) and Alluvium overlie the Chalk in places.
- Silbury Hill lies on or close to the presumed boundary between the Middle Chalk and Lower Chalk Formations. The boundary itself is obscured by Valley Gravel and Alluvium below the topsoil and turf.
- Based on limited exposures of the Chalk in the former quarry face to the south-west of Silbury Hill and the logs of four boreholes sunk from the top of Silbury Hill in 2001 which penetrate into the underlying Chalk, Silbury Hill was constructed on a spur of the Holywell Nodular Chalk Member of the Middle Chalk Formation.
- Based on the literature review, Silbury Hill was constructed on a spur of the Middle Chalk Formation, with the chalk fill used to construct Silbury Hill being sourced from the Holywell Nodular Chalk Member of the Middle Chalk Formation and probably the Zig Zag Chalk Member of the Lower Chalk Formation.
- The Chalk Fill used for the conservation works should ideally come from the Holywell Nodular Chalk Member above the level of the Melbourn Rock, although chalk from the underlying Zig Zag Chalk Member may also be appropriate. The decision as to which Chalk Member will be used may well be made on engineering grounds.
- The Beggar's Knoll Quarry near Westbury in Wiltshire includes both the Holywell Nodular Chalk Member of the Middle Chalk Formation and the Zig Zag Chalk Member of the Lower Chalk Formation within the section of the Chalk Group exposed in the quarry. As such the quarry is considered to be an ideal source of chalk to match the original chalk used to build Silbury Hill.

## 9. REFERENCES

BARRON, R.S., 1976, "The Geology of Wiltshire – A Field Guide," Moonraker Press, Wiltshire, UK. ISBN 0-23900-165-6.

BBC, 2002, "The Hill with the Hole," Episode of the Southern Eye Television Series, Presented by Magnus Magnusson, BBC, London, UK.

BELL, F.G., 1981, "Engineering Properties of Soils and Rocks," Pub. Butterworth & Co (Publishers) Ltd., London, UK. ISBN. 0-408-00537-8.

BRISTOW, C.R., 1999, "The stratigraphy of the Chalk Group of the Wessex Basin," British Geological Survey Technical Report WA/99/08, British Geological Survey, Keyworth, Nottingham, UK.

BRISTOW, C.R., 1989, "Geology of the East Stour – Shaftesbury District (Dorset), 1:10,000 Sheets ST82SW and 82SE," British Geological Survey Technical Report WA/89/58, British Geological Survey, Keyworth, Nottingham, UK.

BRISTOW, C.R., MORTIMORE, R.N. & WOOD, C.J., 1997, "Lithostratigraphy for mapping the chalk of Southern England," Proceedings of the Geologists Association, Vol. 108, PP. 293 – 315.

BRITISH GEOLOGICAL SURVEY, 2000, "1 to 50,000 Sheet 281 – Frome (Solid & Drift Edition)," British Geological Survey, Keyworth, Nottingham, UK.

BRITISH GEOLOGICAL SURVEY, 1974, "1 to 50,000 Sheet 266 – Marlborough (Drift Edition)," British Geological Survey, Keyworth, Nottingham, UK.

BRITISH GEOLOGICAL SURVEY, 1926, "10,560 scale Sheet Wiltshire 28 SW (Original version 1895)," County Series of Maps, British Geological Survey, Keyworth, Nottingham, UK.

BROMLEY, R.G. & GALE, A.S., 1982, "The Lithostratigraphy of the English Chalk Rock," Cretaceous Research, Vol. 3, PP. 273 – 306.

CANTI, M.G., CAMPBELL, G., ROBINSON, D. & ROBINSON, M., 2004, "Site Formation, Preservation and Remedial Measures at Silbury Hill," CfA Report 61/2004, Centre for Archaeology, English Heritage, Fort Cumberland, Eastney, UK.

CLAYTON, C.R.I., 1990, "The Mechanical Properties of the Chalk," Proceeding of the International Chalk Symposium, Brighton Polytechnic, September 1989, PP. 213 – 232, Pub. Thomas Telford, London, UK. ISBN. 0-7277-1541-0.

GALE, A.S., 1996, "Turonian Correlation and Sequence Stratigraphy of the Chalk in Southern England," in HESSELBO, S.P. & PARKINSON, D.N. (eds.), 1996, "Sequence Stratigraphy in British Geology," Geological Society Special Publication No. 103, PP. 177 – 195, The Geological Society, London, UK. ISBN. 1-89799-49-7.

GEDDES, I., 2000, "Hidden Depths – Wiltshire's Geology & Landscapes," Ex Libris Press, Wiltshire, UK. ISBN-1-903341-05-1.

INGOLDBY, H.C. & PARSONS, A.W., 1977, "The Classification of Chalk for use as a Fill Material," TRRL Laboratory Report 806, Transport and Road Research Laboratory, Crowthorne, Berkshire, UK. ISSN. 0305-1293.

KENNEDY, W.J. & GARRISON, R.E., 1975, "Morphology and genesis of nodular chalks and hardgrounds in the Upper Cretaceous of Southern England," Sedimentology, Vol. 22, PP. 311 – 386.

LAKE, L.M., 1990, "Underground Excavations in Chalk," Proceeding of the International Chalk Symposium, Brighton Polytechnic, September 1989, PP. 461 – 467, Pub. Thomas Telford, London, UK. ISBN. 0-7277-1541-0.

LORD, J.A., CLAYTON, C.R.I. & MORTIMORE, R.N., 2002, "Engineering in Chalk," Report No. C574, Construction Industry Research and Information Association, London, UK. ISBN 0-86017-574-X.

MALONE, C., 1994 (2006 Reprint), "The Prehistoric Monuments of Avebury, Wiltshire – Second Edition," English Heritage & The National Trust, UK. ISBN. 1-84359-270-3.

MORTIMORE, R.N., WOOD, C.J. & GALLOIS, R.W., 2001, "British Upper Cretaceous Stratigraphy," Geological Conservation Review Series No. 23, Joint Nature Conservation Committee, Peterborough, UK. ISBN. 1-86107-488-3.

NATURAL HISTORY MUSEUM, 1993, "British Mesozoic Fossils (Sixth Edition)," The Natural History Museum, London, Pub. HMSO, UK. ISBN. 0-11-310025-6.

ORDNANCE SURVEY, 1985, "1 to 50,000 Landranger Sheet No. 173 – Swindon & Devizes," Ordnance Survey, Southampton, UK. ISBN 0-31922-173-3.

POWELL, J.H., 1998, "A guide to British Stratigraphical Nomenclature," Publication No. SP149, Construction Industry Research and Information Association, London, UK. ISBN 0-86017-489-1.

RAWSON, P.F., 1992, "The Cretaceous," Chapter 12 in DUFF, P. McL. D & SMITH, A.J. (Eds), "Geology of England and Wales," Pub. The Geological Society, London, UK, PP. 355 - 388. ISBN 0-903317-71-0.

SUMBLER, M.G., 1996, "British regional Geology – London and the Thames Valley," Fourth Edition, British Geological Survey, Keyworth, Nottingham, UK. ISBN 0-11-884522-5.

WATSON, P.C., WARREN, C., HURT, J.C. & EDDIE, C., 2001, "The Design of the North Downs Tunnel," Proceedings of Underground Construction 2001, PP. 63 – 77, Pub. Brintex Ltd., London UK. ISBN. 0-7079 7033-4.

WHITE, H.J., 1925, "The geology of the country around Marlborough: explanation of sheet 266," British Geological Survey, Keyworth, Nottingham, UK.

WHITTLE, A., 1997, "Sacred Mound, Holy Rings – Silbury Hill and the West Kennet palisade enclosures: a Later Neolithic complex in north Wiltshire," Cardiff Studies in Archaeology, Oxbow Monograph No. 74, Pub. Oxbow Books, Oxford, UK. ISBN 1-900188-26-0.

# Figures



*Figure 1. Silbury Hill looking South-East (Image CIMG0351, 20/11/06).*



*Figure 2. Aerial View of Silbury Hill in 1934 showing a hole in the top  
(© English Heritage).*





*Figure 3. Annotated aerial view showing the Four Exposures of Chalk near to Silbury Hill (Original photograph © English Heritage).*



*Figure 4. View of the Steep Face showing the Four Exposures of Chalk near to Silbury Hill (Image CIMG0348, 20/11/06).*





*Figure 5. Silbury Hill looking NE from Exposure 3 (CIMG0342, 20/11/06).*



*Figure 6. Silbury Hill Exposure 1 looking SE (Image CIMG0334, 20/11/06).*





*Figure 7. Centre Section of Silbury Hill Exposure 1 showing white chalk weathered blue-grey in the upper part of the exposure (Image CIMG0336, 20/11/06).*





*Figure 8. Centre Section of Silbury Hill Exposure 1 showing white chalk weathered creamy-buff in the lower part of the exposure (Image CIMG0337, 20/11/06).*





*Figure 9. Centre Section of Silbury Hill Exposure 1 showing white chalk with spotted blue-grey weathering at the top of the exposure (Image CIMG0339, 20/11/06).*





*Figure 10. Silbury Hill Exposure 2 looking South showing white chalk weathered creamy-buff with A5 sized note book for scale (Image CIMG0340, 20/11/06).*



*Figure 11. Silbury Hill Exposure 3 looking South showing white chalk generally weathered creamy-buff. A5 sized note book for scale (Image CIMG0341, 20/11/06).*





*Figure 12. Left hand part of Silbury Hill Exposure 4 showing white chalk weathered creamy-buff. Note the light brown coloured 0.05m thick block band of chalk just below the topsoil. A5 sized note book for scale (Image CIMG0343, 20/11/06).*





*Figure 13. Right hand part of Silbury Hill Exposure 4 showing white chalk with spotted blue-grey weathering at the top of the exposure. A5 sized note book for scale (Image CIMG0344, 20/11/06).*





*Figure 14. Beggar's Knoll Quarry Exposure A showing the New Pit Chalk Member of the Middle Chalk Formation (Image CIMG0356, 13/12/06).*





*Figure 15. Beggar's Knoll Quarry Exposure B showing the Holywell Nodular Chalk Member of the Middle Chalk Formation. Note the difference in colour between the brownish-grey coloured weathered chalk in the top right of the view compared to the off-white of the fresh chalk (Image CIMG0357, 13/12/06).*



*Figure 16. Beggar's Knoll Quarry showing a view of the Middle and Upper Chalk Formations. Part of the Melbourn Rock at the base of the Middle Chalk Formation can be seen overhanging the underlying Plenus Marls at the top of the Lower Chalk Formation (Image CIMG0358, 13/12/06).*





*Figure 17. Pile of Chalk Nodules from the Melbourn Rock at the base of the Middle Chalk Formation in one of the access roads at Beggar's Knoll Quarry (Image CIMG0359, 12/12/06).*



*Figure 18. Beggar's Knoll Quarry Exposure C showing the boundary between the Melbourn Rock (Middle Chalk Formation) and the underlying Plenus Marls (Lower Chalk Formation) with a geological hammer for scale (Image CIMG0360, 13/12/06).*





*Figure 19. Beggar's Knoll Quarry looking along the quarry face from Exposure C (Image CIMG0361, 13/12/06).*





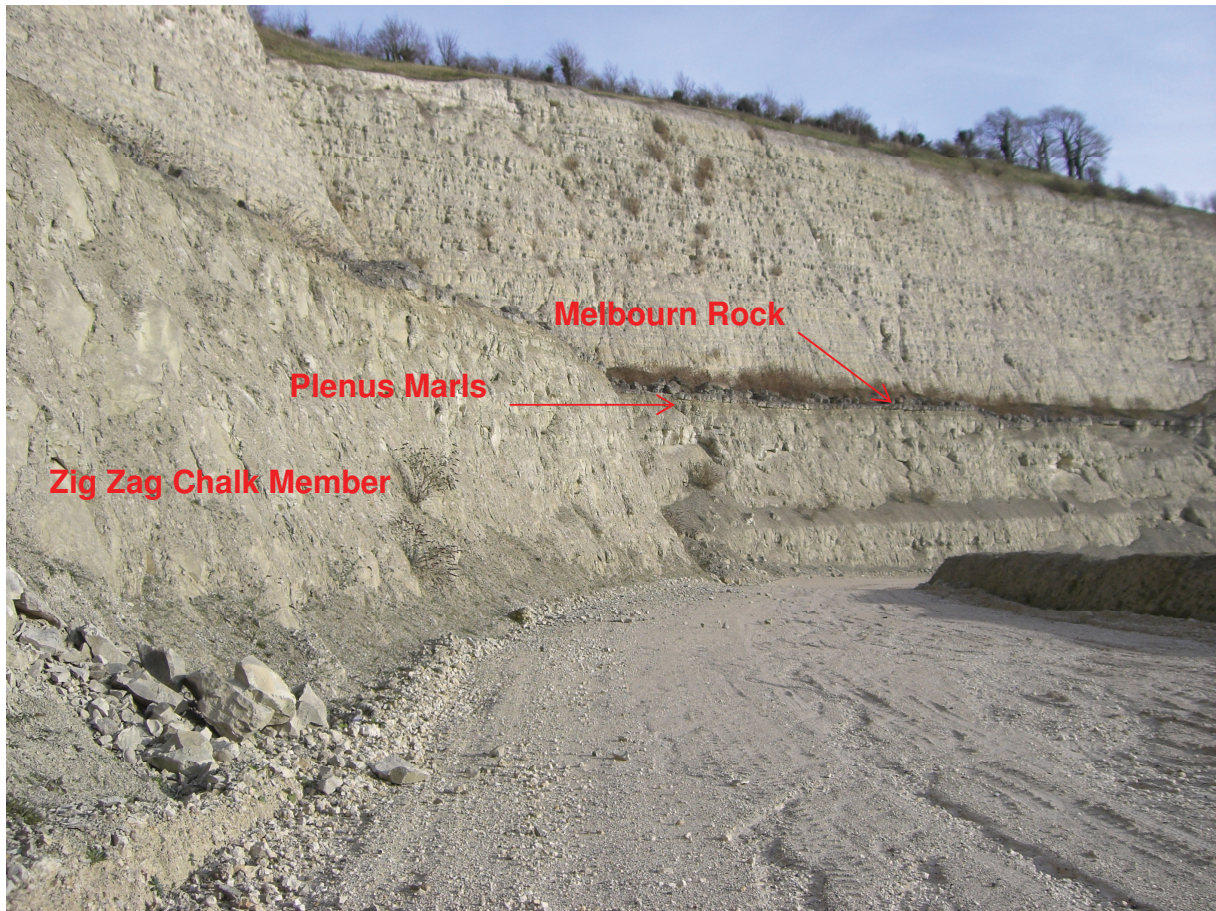
*Figure 20. Beggar's Knoll Quarry Exposure C showing a view of the Plenus Marls (Image CIMG0362, 13/12/06).*





*Figure 21. Beggar's Knoll Quarry Exposure D showing a view of the grey chalk in the Zig Zag Chalk Member of the Lower Chalk Formation (Image CIMG0363, 13/12/06).*





*Figure 22. Beggar's Knoll Quarry looking along the quarry face from Exposure D (Image CIMG0364, 13/12/06).*



**Skanska Technology Limited**

Maple Cross House

Denham Way

Maple Cross

Rickmansworth

Hertfordshire

WD3 9SW

Phone: +44 (0) 1923 776666

Fax: +44 (0) 1923 423940

Web: [www.skanska.co.uk/technology](http://www.skanska.co.uk/technology)

**Skanska Technology Limited**

Kenfig Industrial Estate

Margam

Port Talbot

West Glamorgan

SA13 2PR

Phone: +44 (0) 1656 742 000

Fax: +44 (0) 1656 745 014

Web: [www.skanska.co.uk/technology](http://www.skanska.co.uk/technology)

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