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The Provenance of Rocks used in the Construction of Stonehenge

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Introduction

THE FACT THAT THE WIZARD MERLIN was invoked to explain the construction of Stonehenge and the supposed carriage of its stones from Ireland suggests that already in the mediaeval period visitors to the site had realised that there is no obvious local geological source for any of the building materials used in its construction. Certainly, as soon as we have the written accounts of enquiring visitors, a striking feature of their observations is their recognition that the provenance of the stones is problematic. Perhaps the earliest written reflection on this point is that of Hermann Folkerzheimer, a Swiss visitor to England in the mid sixteenth century. Writing home in 1562 after riding out from Salisbury to look at Stonehenge he reports that the stones '. . . are of an uncommon size almost every one of which, if you should weigh it would be heavier even than your whole house'. Yet they stand, he says '. . . in a very extensive plain at a great distance from the sea, in a soil which appears to have nothing in common with the nature of stones or rocks' (Chippindale 1983).

The geology of Stonehenge

The Monument

There are two groups of rock types represented in the visible monument at Stonehenge. The principal building material is sarsen stone, of which 53 specimens remain at Stonehenge today though it seems likely that there were originally at least 85 sarsens in the structure. Sarsen stone is a silicified sandstone which is found not as a continuous geological stratum but as scattered blocks resting on the Chalk in southern England. Sarsen stone is the product of silicification affecting beds of sand in the Lower Tertiary geological formations that overlie the Chalk and are now mainly preserved in the Hampshire and London Basins (Curry 1992). An important subsidiary building material at Stonehenge is a group of predominantly volcanic rocks, collectively known as the bluestones. In many cases these can be matched in specific geological outcrops in South Wales (Thorpe *et al.* 1991). There are 43 recorded bluestones at Stonehenge. Thirty three of these remain above ground level today and a further ten have been identified as stumps below the ground surface. The configurations in which the bluestones were originally used suggest that there may once have been a further 36 bluestones present at Stonehenge.

Foundations and tools

In addition to the stones forming the visible monument at Stonehenge, rock was used in its construction to wedge the upright stones firmly in their holes. Numerous sarsen blocks were employed for this purpose, but also blocks of Chilmark ragstone of Portlandian age and glauconitic sandstone derived from the Upper Greensand of Albian age. These rock types have their nearest outcrop at a distance of some 20 km to the south of Stonehenge, in the Upper Jurassic and Lower Cretaceous formations of the Vale of Wardour (Fig. 1). Stone was also the material used by the builders of Stonehenge to prepare and dress the monoliths. Large numbers of mauls or hammerstones have been found in excavations at Stonehenge. In 22 separate excavations, mainly those of Gowland (1902) and Hawley (1921–1928), at Stonehenge, for which detailed records of the stone debris are published, 447 stone mauls and hammerstones, or fragments, are recorded. Almost all the mauls and hammerstones are made from sarsen. Many are made from the same type of sarsen as the monoliths, but there are also substantial numbers made from a distinctive type of sarsen which is very densely cemented by microcrystalline silica and in consequence of exceptional toughness. This type of sarsen occurs as cobbles and small boulders in the river gravels of Wessex and occasionally as isolated blocks lying on the ground surface. A few possible mauls and hammerstones of exotic rock types have been recorded, including a small boulder of ignimbritic tuff-lava described by Kellaway (1991) and of probable Welsh origin. It seems unlikely that such a stone would have been brought from such a distant source simply to be used as a maul, so it may originally have had some other function before being tried, probably unsuccessfully, as a maul and then finally discarded. Other stone artefacts that have been recovered in excavations at Stonehenge are mainly flint tools but also include objects made of chalk and tools made from rocks entirely foreign to the Wessex region.

Waste

As well as the stones and stone tools used in the construction of Stonehenge, there are in the immediate vicinity of the monument huge quantities of stone waste. This consists of chips and fragments of almost all the rock types that can be identified in the structure or have been found in use as hammerstones and mauls. In the 22 excavations referred

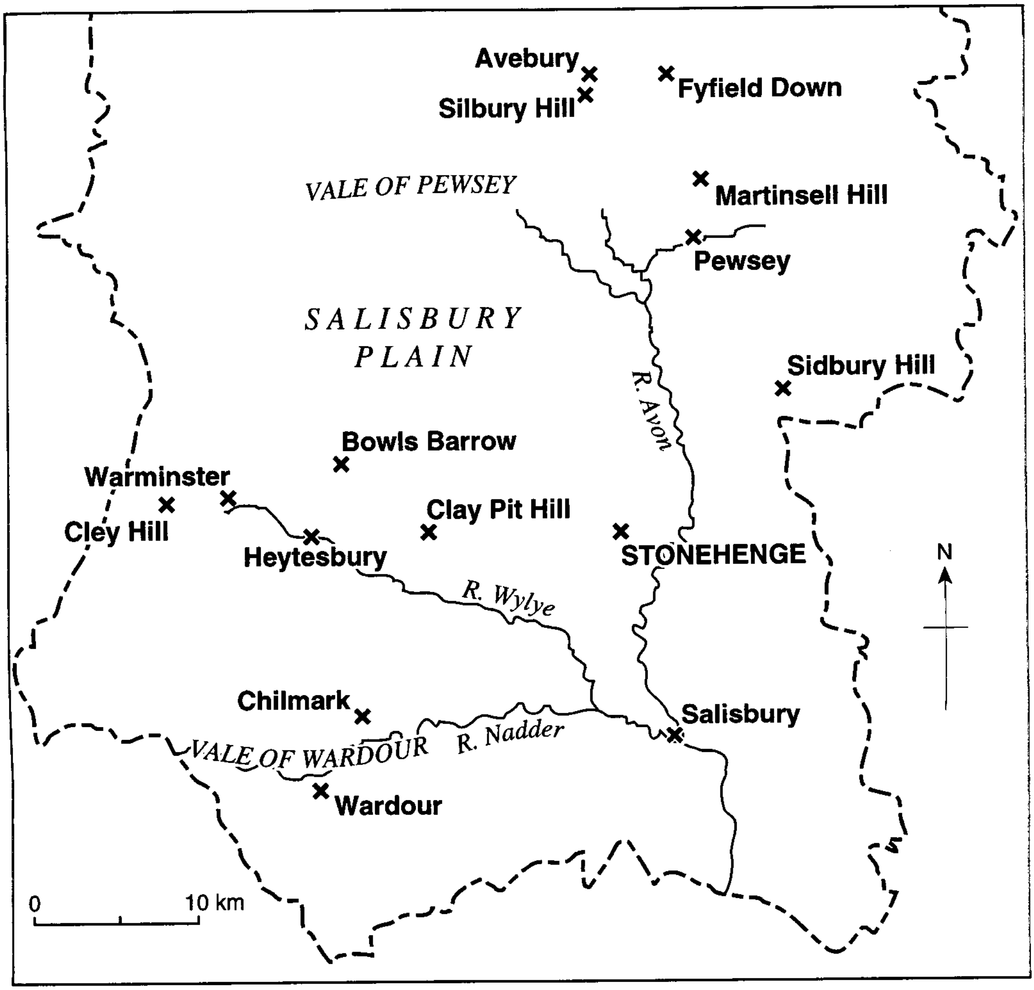

Figure 1. South Wiltshire – location map.

to above, over 11,500 stone fragments were recorded, including nearly 4,000 pieces of sarsen from a single location in the Avenue between the Heel Stone and the Slaughter Stone (Hawley 1925). Some of this material was probably produced during the several stages of construction and rearrangement affecting the stones during a period of some 1500 years in Late Neolithic and Bronze Age times (Pitts 1982). However, bearing in mind the possible disappearance from the site of perhaps sixty or seventy stones from the total number originally used, some of the waste undoubtedly relates to the robbing of material at various times since the monument fell into disuse in the prehistoric period.

Source areas

The geological problems, which have been a subject of debate for more than 250 years, concern the provenance and history of the geological materials that are found at Stonehenge. When the site of Stonehenge was first chosen in the prehistoric period, was all or some of this material already present close to the site, brought there in the more remote past by natural agencies? Or was it brought to Salisbury Plain from a variety of distant sources by the people who built Stonehenge?

Minor rock types

The large number of sarsen hammerstones found at Stonehenge, particularly the tougher variety, can only be explained convincingly in terms of systematic search along river beds and at natural exposures over a large area. The use of Chilmark ragstone and Upper Greensand sandstones also argues for the exploitation of a recognised and accessible local resource, albeit 20 km away. There is certainly no natural process in the history of landform development in south Wiltshire that could have transported blocks of Jurassic and Lower Cretaceous rock from the low ground within the Vale of Wardour northward, and upward, onto Salisbury Plain. Thus it can be shown that some of the smaller pieces of rock used in the construction of Stonehenge had been selected on the basis of particular qualities and had been systematically collected and brought to the site from an area having a radius of at least 20 km. This is an important observation, because it establishes a pattern of social organisation and resource use which has implications for an understanding of the stones forming the monument itself. These present two separate problems —the provenance of the sarsens and the provenance of the bluestones.

Sarsens

The sediments in Wessex and elsewhere in southern England, affected by the silicification process that produced the sarsen stone are all of Lower Tertiary age. Both the sediments themselves and the silicification process appear to be no later than the earliest Eocene and thus mainly Palaeocene. There has been very little modern work on the petrology or the original stratigraphic position of the sands forming sarsen stone. Their assignment to the Palaeocene Reading Formation is based largely on the fact that sands regarded as having suitable characteristics of composition and texture have occasionally been recognised in that formation (Whalley and Chartres 1977). Work on the diagenetic fabric of sarsen (Summerfield and Goudie 1980) suggests that the process of silicification was identical with that observed in modern silcretes forming in semi-arid sub-tropical environments. This finding is consistent with what is known about the depositional environment and palaeoclimatic conditions of the Reading Formation.

Palaeocene sediments, represented by the Reading Formation, are present both in the

Hampshire Basin, extending northward almost as far as Salisbury, and in the London Basin, extending westward to the north of the Vale of Pewsey (Fig. 2). In the intervening area, which includes the whole of Salisbury Plain and the site of Stonehenge, Palaeocene sediments *in situ* are absent except for a possible outlier on the summit of Sidbury Hill, some 20 km north and east of Salisbury and consisting of a shingle of well-rounded flint pebbles.

The Reading Beds probably once extended across the whole of this region. There is however good evidence (Green 1985) that in the area occupied by Salisbury Plain they had already been removed prior to the Middle Eocene and been replaced by sediments of Middle Eocene age. Small remnants of these Middle Eocene sediments are preserved on the summits of the Chalk on the western edge of Salisbury Plain, and in a large solution pipe in the Chalk at Clay Pit Hill, near Chitterne, about 12 km to the west of Stonehenge. Similar sediments are also present on the Chalk at Martinsell Hill, to the north of the Vale of Pewsey. The Middle Eocene age of these sediments is demonstrated by the composition of the pebble beds which matches closely the highly distinctive composition of the Agglestone Grit in the Middle Eocene of Dorset (Green 1985). The composition and sedimentology of the Middle Eocene outlier at Cley Hill, near Warminster on the western edge of Salisbury Plain, also suggest that the summit there, and neighbouring summits at a similar altitude are remnants of a Middle Eocene erosional surface (Green 1969). These summits rise above the general level of the Chalk summits in south Wiltshire, which themselves represent a polycyclic erosional surface of low relief that formed in the later part of the Tertiary period (Green 1974). The present river valleys cut deeply into this surface and are the product of dissection during the Quaternary. This history shows that the relief of Salisbury Plain has been reshaped repeatedly since the Palaeocene and that in consequence there is little likelihood that any sarsen stone will have survived in the immediate vicinity of Stonehenge at the time that its construction was undertaken.

The present-day distribution of sarsen stones in Wiltshire fully supports this interpretation of Tertiary landform development. The survey of sarsen stones in Wessex as a whole, initiated by the Society of Antiquaries (Bowen and Smith 1977), showed that in Wiltshire to the south of the Vale of Pewsey, sarsen stones in whatever condition of preservation are few in number and small in size. There is no record from south Wiltshire, apart from the stones at Stonehenge, of a sarsen with a long dimension greater than 5.0 m, and most of the recorded stones are very much smaller. In addition, apart from cobbles noted in river gravels, no numerous scatters of sarsen stone occur in south Wiltshire, and at only 11 sites were groups of even as many as two or three sarsens found together in circumstances adjudged to be undisturbed. At a further 28 sites single sarsens were recorded in apparently undisturbed situations. In south Wiltshire, sarsen is also rarely found incorporated in prehistoric structures (18 cases recorded), or used as a building material in the historic period (17 cases recorded). Where it has been put to use, in almost all cases only a few small stones are present.

The scarcity and meagre dimensions of the sarsen stones in south Wiltshire give no

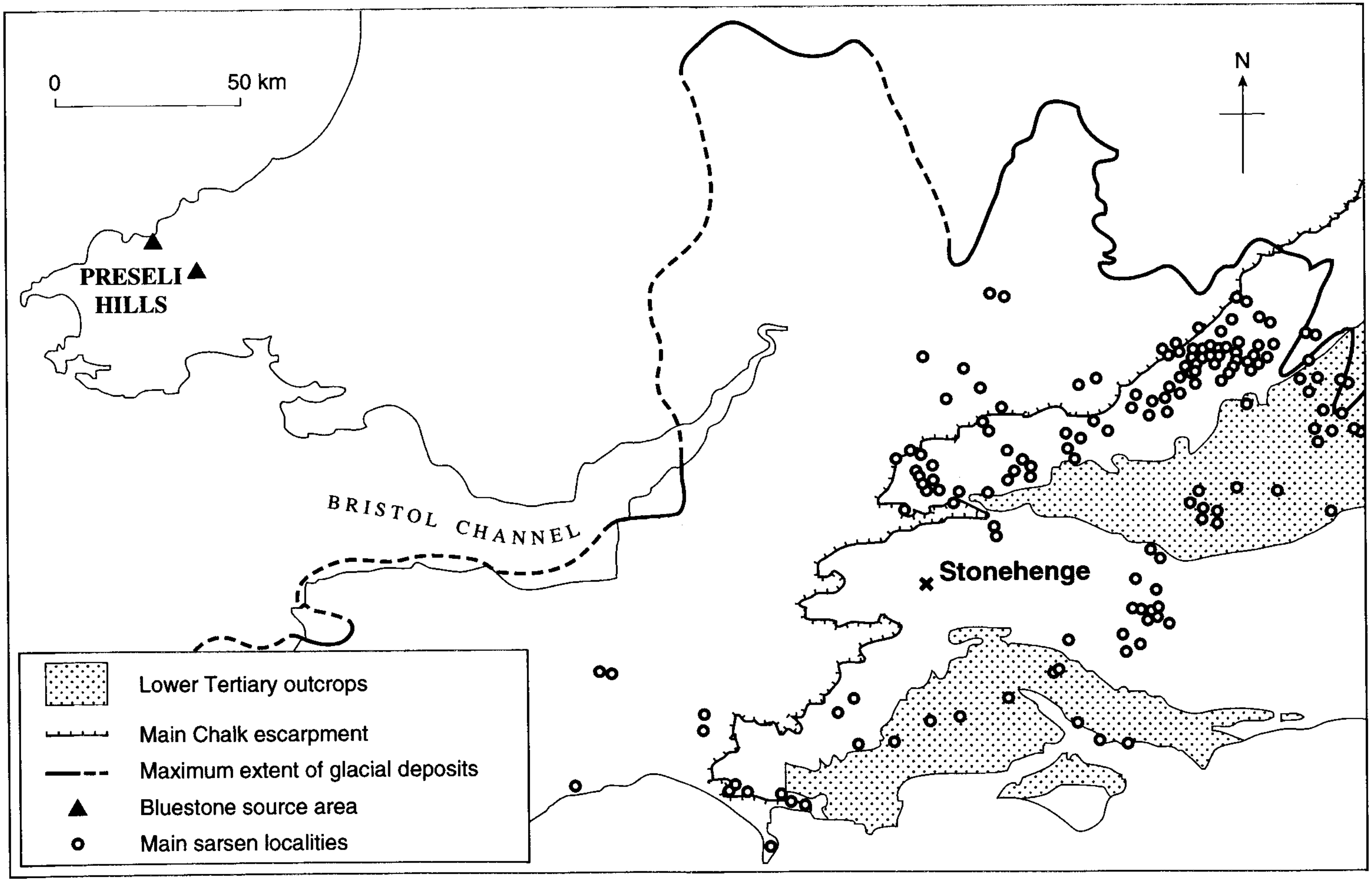

Figure 2. Stonehenge – the geological setting. Main sarsen localities based on Summerfield and Goudie (1980); extent of glacial deposits based on IGS Quaternary Map of the UK (1977) and Gilbertson and Hawkins (1978); bluestone source areas based on specific identifications in Thorpe *et al.* (1991).

indication of a likely source for the stones used in the construction of Stonehenge. The sarsen stones at Stonehenge are exceptional even in the context of areas where sarsens are numerous and large. Summerfield and Goudie (1980) indicate that in general the upper end of the size range for sarsens in southern England is represented by 'boulders with long axes of 4 to 5m'. Clark *et al.* (1967) found that 77 per cent of the boulders at Fyfield Down, near Marlborough, one of the best known and most extensive sarsen spreads, had long dimensions of less than 1.5 m. The largest stones at Stonehenge are those used in the central trilithon of the inner horseshoe. The surviving upright, stone 56, is over 9.0 m in total length and is estimated to weigh about 50 tonnes. The other sarsens in the horseshoe and circle are from 6.0 m to 7.0 m in length and each weigh approximately 25 tonnes. Sarsens of this size are nowhere common, and it seems probable that the Stonehenge examples were carefully selected in an area where sarsens were plentiful. The most likely source area is the Marlborough Downs, where many thousands of sarsens remain today, despite prolonged commercial exploitation in the nineteenth and early twentieth centuries. It is interesting to note however that in an exploratory study of the heavy mineralogy of sarsen fragments from Stonehenge, Howard (1982) found that the Stonehenge material differed from sarsen collected in the Marlborough area. A fuller investigation of sarsen mineralogy seems very desirable as a possible means of pin-pointing the source area of the Stonehenge sarsens. If, as still seems most likely, the Stonehenge sarsens came from the Marlborough area, it follows that the builders who incorporated these very large stones into Stonehenge had the social organisation and technical facilities to move them over a distance of approximately 40 km.

Bluestones

Thirty-three bluestones remain visible at Stonehenge today. There are 28 examples of dolerite, all but three of these being the so-called spotted dolerite, four examples of rhyolite and one example of sandstone, namely the Altar Stone. A further ten bluestones are known to survive as stumps below the ground surface. Two of these are spotted dolerites, five are volcanic ashes, two are sandstones and one is a rhyolite. It has long been understood that all these stones are totally foreign to the Stonehenge area. Successive petrological investigations (Maskelyne 1878; Thomas 1923; Thorpe *et al.* 1991) have had the effect of narrowing down the source area from which these rocks can be shown to have come. The most recent work (Thorpe *et al.* 1991) involved the sampling of 15 of the dolerite monoliths and all four of the visible rhyolite monoliths. Thorpe *et al.* also analysed nine dolerite fragments, 13 rhyolite fragments and one sandstone fragment, all derived from previous excavations at Stonehenge.

All the dolerite samples were shown by Thorpe *et al.* (1991) to come from a small area in the eastern Preseli Hills, within a radius of not more than 1.5 km and possibly of as little as 0.5 km. The rhyolites were shown to have a rather more scattered provenance. Ten of the samples could be referred to an area lying within the same 1.5 km radius as the dolerite samples, two were referred to outcrops lying about 8 km from the edge of the dolerite distribution, and three were tentatively referred to outcrops further afield on the north coast of Pembrokeshire. One of the rhyolites remained unidentified and the last was referred in general terms to '? Pembrokeshire'. The sandstone sample was identified as a Palaeozoic sandstone from South Wales. It might be a fragment from a former sandstone monolith, now present only as a buried stump. It could not be matched with the Altar Stone, also a sandstone and the largest of the bluestones. The Altar Stone was not sampled by Thorpe *et al.* but a careful visual examination led them to suggest that it also comes from the Palaeozoic outcrop in South Wales, possibly from the Senni Beds in the Old Red Sandstone.

Transport of the bluestones

The problem that remains to be discussed is whether these rocks from south-west Wales were brought to Stonehenge by the people who used them there, or were they found in prehistoric times on Salisbury Plain having reached there in the remoter past through some natural agency. The long distance transport of stone during the Neolithic period has long been recognised and the ritual or ceremonial significance of selected rock types in Neolithic society is now generally appreciated (Clarke, Cowie and Foxon 1985; Edmonds 1995). The widespread dispersal of stone artefacts from highly specific source outcrops is well attested. The use of stone brought from a distance in the fabric of ceremonial structures is relatively uncommon, but where it does occur it seems to be associated with particularly ambitious structures such as the elaborate passage tombs at Newgrange and Knowth in Ireland (Mitchell 1992) and the great menhir and ornamented dolmen at Locmariaquer in Brittany (Thomas 1923).

In relation to the bluestones of Stonehenge, the only plausible natural agency capable of transporting them from South Wales to Salisbury Plain would seem to be glacial ice, as proposed originally in connection with the Stonehenge stones by Judd (1902) and more recently claimed by Kellaway (1971, 1991) and Thorpe *et al.* (1991). In general, where ice has penetrated into an area, it brings with it rock debris from the outcrops over which it has passed, and this debris is left behind when the ice disappears. This rock debris commonly comprises material of all sizes up to and including substantial boulders. It may occur where it was left by the ice, as a spread or scatter of glacial material, or it may subsequently suffer erosion and be found incorporated into later sediments. The case for a glacial origin of any of the Welsh rocks on Salisbury Plain is totally unsupported either by the character of the bluestones themselves or by the Quaternary geology of the area. In the following paragraphs, the evidence on Salisbury Plain is reviewed and certain key problems are re-examined.

Limited diversity of bluestone rock types

An ice sheet advancing from the Irish Sea basin, across South Wales and into southern England would cross the outcrop of a great variety of durable rock types, which ought therefore to be represented in any glacial deposit on Salisbury Plain. The Stonehenge bluestones display no such variety. Their detailed petrology shows that they come from a small area in south-west Wales.

Absence of glacial deposits on Salisbury Plain

No one has ever claimed to recognise glacial deposits *in situ* on Salisbury Plain, and no boulder, petrologically similar to any of the bluestones of Stonehenge has ever been recorded in a natural context anywhere south or east of the Bristol Channel. It has been suggested however (Bartenstein and Fletcher 1987; Thorpe *et al.* 1991) that the present-day absence of rocks on Salisbury Plain reflects the clearance of agricultural land in the late eighteenth and early nineteenth centuries and that before this clearance not only sarsen but also volcanic rocks were present as boulders scattered over the surface of the Plain. The sole basis for this suggestion appears to be an account of Salisbury Plain written by the French geologist De Luc (1811) following visits to the area between 1777 and 1809. The suggestion that volcanic rocks were to be seen on Salisbury Plain in the late eighteenth century is obviously highly significant. However in a careful reading of De Luc it is clear that the reference to volcanic rocks in the passage describing Salisbury Plain (De Luc 1811, vol. III, 461) relates not to field observations on Salisbury Plain but is a reference to superficial geological deposits described by Playfair in the Midland counties of England 'beginning from about Worcester and Birmingham and proceeding north-east through Warwickshire, Leicestershire, Nottinghamshire, as far as the south of Yorkshire' (De Luc 1811, vol. III, 463). The absence of volcanic rocks from Salisbury Plain in the eighteenth century is in fact perfectly evident from the records of those who were best acquainted with Stonehenge and Salisbury Plain at that time. Both Stukeley and Cunnington recognised that the bluestones at Stonehenge had come from distant source areas. Had volcanic rocks been present in any sort of natural context on Salisbury Plain in the eighteenth century, such careful observers would undoubtedly have recognised the possibility of a local source for the volcanic material.

The Bowls Barrow bluestone

In an archaeological context and away from the source area in South Wales, the only example of a substantial bluestone outside the Stonehenge setting is a large boulder of spotted dolerite, now in Salisbury Museum, which is currently regarded (Cunnington 1924) as having been found by William Cunnington, together with a quantity of sarsen boulders, during an excavation of Bowls Barrow near Heytesbury on Salisbury Plain in 1801.

Bowls Barrow is a long barrow and appears therefore to represent a cultural tradition that flourished several hundred years before the earliest recognised appearance of the bluestones at Stonehenge. If the accepted provenance of this stone is correct, then the Bowls Barrow spotted dolerite is either of glacial origin, or it indicates a cultural link between South Wales and Wiltshire that pre-dates the incorporation of the bluestones into Stonehenge. However, there is an element of doubt regarding the provenance of the dolerite boulder now in Salisbury Museum. The documentary record is less than completely satisfactory.

The stone in Salisbury Museum came to light in the 1920s in the grounds of Heytesbury House as the result of enquiries being made at that time by B.H. Cunnington (1924), the great-grandson of William Cunnington. These enquiries, which included correspondence with the Hon. Mrs Hamersley who had lived at Heytesbury House for many years during the nineteenth century, demonstrated two significant facts about the stone. Firstly, the stone had been in the grounds of Heytesbury House since before 1860; and secondly, the stone was known to the household at Heytesbury House as 'The Stonehenge Stone'.

That the stone discovered in the grounds of Heytesbury House in the 1920s might be a stone found by William Cunnington in Bowls Barrow in 1801 has been inferred on the basis of two pieces of evidence. Firstly, William Cunnington lived in Heytesbury in a house only a few hundred yards from the place where the stone was found in the grounds of Heytesbury House. Secondly, there is Cunnington family correspondence which has a bearing on the facts (Cunnington 1924). On 18th July 1801, William Cunnington wrote to his patron H.P. Wyndham of Salisbury. The letter comes down to us in the form of a copy made at the time of writing by Cunnington's daughter Elizabeth. Cunnington describes the excavation at Bowls Barrow. He reports that the core of the barrow consisted of 'a ridge of large sarcen (*sic*) stones'. There is a note at this point written on this copy of the letter, in Cunnington's own hand, 'the stones are about 28lbs to 200lbs weight'. The letter continues, 'The stones that composed so large a part of this ridge over the bodies are of the same species as the very large stones at Stonehenge.' At this point there is a further footnote to the manuscript in Cunnington's own hand, 'Since writing the above I discovered amongst them the Blue hard stone ye same as the upright stones in ye inner Circle at Stonehenge.' The letter then goes on to describe sarsen stones in general, 'They are often found just under the turf in the vallies in our Downs. They have the appearance of very old landmarks. I have brought away ten to my house.'

There are several points of particular interest in this copy of Cunnington's letter. Firstly, this letter contains the only reference in Cunnington's papers and publications to the discovery of bluestone at Bowls Barrow, despite the obvious potential significance in terms of linking the construction of Stonehenge to the people whose burial rites included inhumation in long barrows. Secondly, Cunnington's note about the discovery of bluestone at Bowls Barrow is related within the letter to his account of discovering a core of large stones within the barrow. It is not related to his record of bringing ten stones to his house in Heytesbury. It seems unlikely that he should have selected stones to bring away to his house and not noticed that one of them was a bluestone. His note says nothing about the size or form of the bluestone he discovered at Bowls Barrow. Thirdly, Cunnington's note on the weights of individual stones forming the core of Bowls Barrow indicates a range from 28 lb. to 200 lb. (12.7–90.8 kg). The bluestone in Salisbury Museum, on the basis of its dimensions and the specific gravity of the minerals comprising dolerite, must weigh at least 300 kg and possibly as much as 400 kg. Is it likely that Cunnington would not have noted either on his letter to Wyndham, or elsewhere, the exceptionally large size of the bluestone had it come from Bowls Barrow?

Thus we have no record from Cunnington's own time that a boulder of bluestone weighing over 500 lb. was found in Bowls Barrow, let alone brought away to Heytesbury. While all we know about the bluestone now in Salisbury Museum is that it was in the grounds of Heytesbury House before 1860, and that it was known there as 'The Stonehenge Stone'. There must therefore be at least some doubt about the provenance of the bluestone in Salisbury Museum. Is it in fact a stone from Stonehenge brought to Heytesbury House at some unknown time in the past, prior to 1860? B.H. Cunnington (1924) believed that 'it has certainly been dressed on its faces and is not a rough block as quarried'. Its dimensions and shape are consistent with it having been part of a stone in the bluestone horseshoe at Stonehenge and this is a possibility that could be explóred more fully.

William Cunnington's tantalising record of finding bluestone in Bowls Barrow cannot be dismissed but is less problematic if his find was of a relatively small piece or pieces. His account does not indicate an exact rock type, which may therefore have been either dolerite or rhyolite. In either case, implements using these materials are known from the Early Neolithic onward and finds of such material in Early Neolithic contexts either as artefacts or even as raw material (Edmonds 1995) are therefore possible.

One further item of documentary interest is a letter written by William Cunnington's grand-daughter, Elizabeth, in 1864, in which she describes the garden of her grandfather's house in Heytesbury and recalls that 'a circle of blocks of stone from Boles Barrow near Imber was placed round a weeping ash at the end of the lawn'. Thus there is confirmation of the record in her grandfather's correspondence that stones were indeed brought from Bowls Barrow to Heytesbury. A search in the 1920s by B.H. Cunnington in the garden of William Cunnington's house at Heytesbury produced only three sarsen stones.

Quaternary terrace gravels

Not only is there no evidence of glacial deposits *in situ* on Salisbury Plain, there is no trace of glacially-derived material in the Quaternary deposits of the rivers draining the area. Around Salisbury and in the valley of the river Avon to the south, there are river terraces representing stages of valley development from the earliest Quaternary to the present day (Clarke and Green 1987). If glacial ice brought far-travelled rocks into the catchments of these rivers at any time during the Quaternary, it seems certain that examples of those rocks will be present in the terrace sediments.

In a study (Green 1973) of over 50,000 pebbles from 28 sites, representing at least seven separate stages within the terrace succession, not one pebble was found that could not have come from existing pre-Quaternary outcrops within the present-day catchments of the rivers. The bulk of the material is either flint from the Chalk or chert from the Upper Greensand. The small suite of other durable rock types, mainly quartz, can be matched in the Middle Eocene sediments, described above, that survive as small outliers on Salisbury Plain.

This situation is very different from the one that prevails in the terrace sediments of rivers where the catchment is known to have been glaciated. It is now widely accepted that the catchment of the river Thames was glaciated in the pre-Anglian Pleistocene and that rock types in pre-Anglian terrace gravels which are foreign to the present-day catchment of the river are of glacial derivation. Such rock types may form as much as 50 per cent of the 11.2 mm to 16.0 mm fraction of pre-Anglian gravels of the Thames, and in general form between 30 and 45 per cent of the total in this size fraction (Green *et al.* 1982).

Conclusion

The geological and geomorphological arguments outlined in this paper show as conclusively as the present evidence permits that the bluestones found at Stonehenge were not brought to Salisbury Plain by glacial ice. It follows that they were carried there by the people who incorporated them into Stonehenge. In some respects this appears a less challenging undertaking than the transport of the sarsens from the Marlborough Downs. Although the distance is greater and a sea voyage has been deemed likely (Atkinson 1979), the bluestones are substantially smaller than the sarsens and their transportation would seem to be well within the capabilities of societies that could contemplate the technical and organisational achievements represented by such monuments as Silbury Hill and Avebury.

References

ATKINSON, R.J.C. 1979: *Stonehenge: archaeology and interpretation* (Harmondsworth).

BARTENSTEIN, H. and FLETCHER, B.N. 1987: The stones of Stonehenge – An ancient observation on their geological and archaeological history. *Zeitschrift fur deutsche geologische Gesellschaft* 138, 23–32.

BOWEN, H.C. and SMITH, I.F. 1977: Sarsen stones in Wessex: the Society's first investigations in the Evolution of the Landscape Project. *Antiq. J.* 57, 185–96.

CHIPPINDALE, C. 1983: *Stonehenge complete* (London).

CLARK, M.J., LEWIN, J. and SMALL, R.J. 1967: The sarsen stones of the Marlborough Downs and their geomorphological implications. *Southampton Res. Ser. Geogr.* 4, 3–40.

CLARKE, D.V., COWIE, T.G. and FOXON, A. 1985: *Symbols of power at the time of Stonehenge* (Edinburgh).

CLARKE, M.R. and GREEN, C.P. 1987: The Pleistocene terraces of the Bournemouth-Fordingbridge area. In Barber, K.E. (ed.), *Wessex and the Isle of Wight, Field Guide* (Cambridge, Quaternary Research Association).

CUNNINGTON, B.H. 1924: The 'Blue Stone' from Boles Barrow. *Wiltshire Archaeol. Natur. Hist. Mag.* 42, 431–7.

CURRY, D. 1992: Tertiary. In Duff, P.McL.D. and Smith, A.J. (eds), *Geology of England and Wales* (London, The Geological Society).

DE LUC, J.A. 1811: *Geological Travels. Volume III. Travels in England* (London).

EDMONDS, M. 1995: *Stone tools and society* (London).

GILBERTSON, D.D. and HAWKINS, A.B. 1978: The Pleistocene succession at Kenn, Somerset. *Bull. Geol. Survey Great Britain* No. 66, 1–41.

GOWLAND, W. 1902: Recent excavations at Stonehenge. *Archaeologia* 58, 37–105.

GREEN, C.P. 1969: An Early Tertiary surface in Wiltshire. *Trans. Inst. Brit. Geogr.* 47, 61–72.

GREEN, C.P. 1973: Pleistocene river gravels and the Stonehenge problem. *Nature* 243, 214–16.

GREEN, C.P. 1974: The summit surface on the Wessex Chalk. In Brown, E.H. and Waters, R.S. (eds), Progress in Geomorphology. *Inst. Brit. Geogr. Spec. Publ.* 7, 127–38.

GREEN, C.P. 1985: Pre-Quaternary weathering residues, sediments and landform development: examples from southern Britain. In Richards, K.S., Arnett, R.R. and Ellis, S. (eds), *Geomorphology and soils* (London).

GREEN, C.P., MCGREGOR, D.F.M. and EVANS, A.H. 1982: Development of the Thames drainage system in Early and Middle Pleistocene times. *Geol. Mag.* 119, 281–90.

HAWLEY, W. 1921: The excavations at Stonehenge. *Antiq. J.* 1, 19–39.

HAWLEY, W. 1922: Second report on the excavations at Stonehenge. *Antiq. J.* 2, 36–51.

HAWLEY, W. 1923: Third report on the excavations at Stonehenge. *Antiq. J.* 3, 13–20.

HAWLEY, W. 1924: Fourth report on the excavations at Stonehenge. *Antiq. J.* 4, 30–9.

HAWLEY, W. 1925: Report on the excavations at Stonehenge during the season of 1923. *Antiq. J.* 5, 21–50.

HAWLEY, W. 1926: Report on the excavations at Stonehenge during the season of 1924. *Antiq. J.* 6, 1–25.

HAWLEY, W. 1928: Report on the excavations at Stonehenge during 1925 and 1926. *Antiq. J.* 8, 149–76.

HOWARD, H. 1982: A petrological study of the rock specimens from excavations at Stonehenge, 1979–1980. In Pitts, M.W. 1982, 104–24.

JENKINS, G. and JENKINS, J. 1993: The Stonehenge 'bluestones' enigma: how to test the glacial hypothesis. *Geol. Today* 9(3), 87.

JENKINS, G., JENKINS, J. and WILLIAMS-THORPE, O. 1994: de Luc's Salisbury Plain in 1780 and 1810, and the rocks of Stonehenge. *Geol. Today* 10(3), 95–6.

JUDD, J.W. 1902: Note on the nature and origin of the rock fragments found in the excavations made at Stonehenge by Mr Gowland in 1901. In Gowland, W. 1902, 106–18.

KELLAWAY, G.A. 1971: Glaciation and the stones of Stonehenge. *Nature* 232, 30–5.

KELLAWAY, G.A. (ed.) 1991: *The Hot Springs of Bath* (Bath).

MASKELYNE, N.S. 1878: Stonehenge: the petrology of its stones. *Wiltshire Archaeol. Natur. Hist. Mag.* 17, 147–60.

MITCHELL, F. 1992: Notes on some non-local cobbles at the entrance to the passage-graves at Newgrange and Knowth, county Meath. *J. Roy. Soc. Antiq.* 122, 128–45.

PITTS, M.W. 1982: On the road to Stonehenge: report on investigations beside the A344 in 1968, 1979 and 1980. *Proc. Prehist. Soc.* 48, 75–132.

SUMMERFIELD, M.A. and GOUDIE, A.S. 1980: The sarsens of southern England: their palaeoenvironmental interpretation with reference to other silcretes. In Jones, D.K.C. (ed.), *The shaping of southern England* (London).

THOMAS, H.H. 1923: The source of the stones of Stonehenge. *Antiq. J.* 3, 239–60.

THORPE, R.S., WILLIAMS-THORPE, O., JENKINS, D.G. and WATSON, J.S. 1991: The geological sources and transport of the bluestones of Stonehenge. *Proc. Prehist. Soc.* 57, 103–57.

WHALLEY, W.B. and CHARTRES, C.J. 1977: Preliminary observations on the origin and sedimentological nature of sarsen stones. *Geologie en Mijnbouw* 55, 68–72.

some elements of the physical record of Stonehenge are offered and suggestions are made for the future direction of experimentation.

C. P. GREEN

The provenance of rocks used in the construction of Stonehenge

The geological evidence in Wiltshire gives no support to the view that the stones forming Stonehenge were found by its builders close to the site of construction. The presence of suitable sarsen stones near Stonehenge in the Early Bronze Age is indicated neither by the geological history of the area nor by the present-day distribution of sarsens. The absence of glacial or glacially-derived material on Salisbury Plain makes it unlikely that glacial ice carried the bluestones of Stonehenge from the Preseli Hills to Wessex. The history of the bluestone supposedly found in Bowls Barrow is reviewed.

J. D. SCOURSE

Transport of the Stonehenge bluestones: testing the glacial hypothesis

Two principal mechanisms have been invoked to explain the transport of the far-travelled bluestones used in the Stonehenge monument from their source region in Pembrokeshire: by glacier or by man. Glaciers have been thought to represent the only natural agency capable of transporting boulders of the size of the bluestones over the distances required, and this mechanism has periodically received serious attention since it was first proposed by Judd in 1902. There are two current propositions invoking transport of the bluestones by ice; Thorpe *et al.* (1991) envisage Anglian ice flowing eastwards from Pembrokeshire across South Wales and into central southern England, whilst Kellaway (1991a, 1991b) suggests deposition from the north in association with a Pliocene glaciation at 2.47Ma. The glacial hypothesis is critically tested by addressing four issues: the physical principles underlying the entrainment and transport of large boulders by glaciers; the occurrence/absence and implications of diagnostic surface microwear and particle shape characteristics of the bluestones; the Pleistocene stratigraphy and geomorphology of southern England and adjacent shelves; and the glaciological plausibility of a source trajectory from Pembrokeshire. It is demonstrated that though glaciers are capable of transporting erratic boulders many thousands of kilometres irrespective of bed topography, the particular case posed by the Stonehenge problem is not compatible either with the mechanics of ice flow or with the geological evidence. The weight of the current available evidence strongly indicates that the Stonehenge bluestones were not transported by ice from Preseli to Salisbury Plain.