Illus 1 *Location map. (Drawn by D. Munro. Courtesy of SUAT Ltd)*

Vitrified rocks from Dun Knock hillfort, Dunning, Perthshire

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Landscape setting

Dun Knock (NGR NO 023143) is a hillock 450m south-east of the centre of the village of Dunning, Strathearn, 13km south-west of Perth (see Illus 1). Its summit is approximately 150m above the village. The summit and the southern, eastern and western slopes are wooded, whereas a field occupies the northern slope. The southern boundary of the field lies just below the summit and is marked by a metre-high dry-stone wall. The northern boundary of the field is at the foot of the slope and borders the Forgandenny road. The field is c 200 m wide (north–south) and 400 m wide (west–east).

A number of aerial photographs taken by the RCAHMS in 1978 clearly show that the southern portion of this field is occupied by a crop-mark clearly identifiable as a small multi-vallate hillfort, suggestive of an early historic/medieval date. Aerial photography of the site has also been taken by the Cambridge University Committee for Aerial Photography and local flier Bill Fuller (see Illus 2). The area of the hillfort within the field amounts to around a third of the hillfort; the remainder is under trees and significantly eroded by quarry activity. This area was the subject of a pre-afforestation survey in 1998, which suggested that though there was significant damage, much of the fort enclosure and its interior may survive (Lowe and Dalland 1999, 8–10). The same field in which the crop-mark lies saw the discovery in 1981 of a Late Bronze Age cord-decorated socketed bronze axe head (now in Perth Museum, accession number 1983.336; Cowie and Reid 1987, 76–7, no. 5). The immediate environment of Dun Knock is replete with other evidence that helps to give a broad picture of human activity.

Less than a mile to the north lies the site of a Roman temporary camp (Dunwell and Keppie 1995, 51–62) and

Illus 2 *Photograph of the north side of Dun Knock, as seen from the north-east, showing concentric circle crop-marks. After harvesting nothing is visible and there is no topographic expression of the concentric structure. (Photo courtesy of Bill Fuller)*

Dunning itself was the site of an early medieval church as evidenced by the dedication to St Serf and a piece of probably 9th/10th century sculpture in the church (ECMS 319 and fig.33). The church was significant enough to be rebuilt with a fashionable Romanesque tower, possibly in the 11th century (Fernie 1987). Dunning was also the seat or *caput* of a thanage in the earldom of Strathearn and with no evidence known of any other form of lordly residence Dun Knock is the prime candidate to be identified with the *caput* (Driscoll 1991, 104–7; 1998, 41–2 and see also Rogers 1992, 300–06). Adjacent to the west of the Roman temporary camp is Duncrub, which has been suggested to be the site of the battle of *dorsum crup*, which took place in the early 960s AD, between rivals for the Scottish crown (Watson 1926, 56; Anderson 1990, 472–3). In his discussion Watson (ibid, fn. 2) notes a tradition recorded in 1723 that about half-a-mile south of Duncrub was a hill of sugar-loaf shape and garrisoned by the Picts. The hill in question is no doubt Dun Knock but it may be rather too fanciful to suggest that the hillfort was involved in the battle and that the conflict may account for the vitrification of its ramparts discussed below. The names Dunning (a contraction of *Edendunning*, meaning hillface/slope of Dunning, itself a reference to a fort, Watson 1995, 61) and Dun Knock ('fort of the small hill') are of Gaelic origin and accurately describe the nature of the place, presumably from the time of Gaelic incomers.

The Geological Survey map shows the near-surface geology of the area is late Glacial outwash sands and gravels lying on boulder clay that overlies sandstones of Middle Old Red Sandstone age (ie mid-Devonian age) that dip gently southwards. A half km to the south the sandstones are overlain by Upper Devonian age basalt and basaltic andesite lavas that also dip to the south, and form the northern slopes of the Ochils. Dun Knock lies on the glacial outwash sands and gravels.

The soil of the field is stony and the stones range from 1 to 25 cm across. We found that four-fifths are blocks of sandstone and almost all the remaining stones are 'basalt' (for brevity, we will use this word for rocks ranging in composition from basalt to andesite). Less than 1% of the stones have a smooth, very fine-grained or glossy external surface; these are the same as the potentially vitrified stones discussed in detail below.

Stones in the southern boundary dry-stone wall of the field also include both sandstone and basalt, no different to those in the soil from which presumably they were derived. Scarce very fine-grained and glossy stones are also present in the wall.

Methodology: fieldwalking and analysis

In 1997 the pasture field partially occupied by the hillfort crop-mark was ploughed for the first time in several years. Seizing the opportunity a fieldwalk was organised by the Dunning Parish Historical Society in partnership with the Tayside and Fife Archaeological Committee and Perth Museum and Art Gallery. It took place on 23 March 1997. Within the field a grid was laid out from the field corner at NGR NO 0228 1429, focusing on the crop-marked area and the land running away from it (approximately south to north) down to the Forgandenny road. The grid comprised six transects (labelled A to F and walked in that order), each divided into 11 squares (labelled 1 to 11) of 20x20m. On the day the most significant readily identifiable find was a Neolithic polished stone axe head (now in Perth Museum, accession no. 1997.605; Hall 1998, 75). Also found was a wide range of other material including a small sherd of Neolithic or Bronze Age pottery, several struck flint flakes, a sherd of medieval pottery and a fragment of a Victorian school slate (a sample of this material is now in Perth Museum, accession no. 1998.416.1–8). The material recovered also included what was provisionally identified as vitrified stone, (ie rocks that contain glass produced by the action of heat

	A	B	C	D	E	F
11						
10			5 1		1 1	
9				4 4		
8		5 4	2 2			
7						
6				2 0		
5			4 4	1 1	1 1	
4			2 2	5 1		
3				4 1		
2			3 2	5 4		4 2
1						1 1

Illus 3 *Fieldwalking grid with numbers of stones collected in each square (first number) and number judged to be vitrified (second number). Squares are of side 20 metres. A1 is located at the south-west corner of the field. Vertical lines are orientated approximately north–south.*

causing complete or partial fusion, followed by cooling that is sufficiently rapid to prevent crystallization). The stones collected came from just 16 of the 66 grid squares, with 1–5 stones collected from each (Illus 3). There is no obvious pattern to distribution of samples. The initial identifications were confirmed by the analysis described below (summarily reported in Hall 2003, 319, no.353).

The material was taken by Mike King (then St Andrews Museum, now County Down Museum) to colleagues in the School of Geography and Geological Science, where two of the authors (Donaldson and Allison) carried out a detailed analysis. This comprised an examination of 49 stones, each identified and those that contained glass investigated further. The methods used include macroscopic examination, hand lens examination, petrographic microscopic examination of thin sections, determination of mineral and glass compositions by electron probe microanalysis, and measurement of the composition of certain specimens by X-ray fluorescence analysis. A visit to Dun Knock was also made to examine more stones *in situ*, including stones that were vitreous. The findings confirm that some of the stones are partially glassy and so were incompletely molten at one time. However, we judge that some non-vitreous stones with fine-grained crystalline textures were entirely molten.

The vitrified stones

The stones range in size from 2g (1 x 1 x 0.5 cm) to 1.5 kg (12 x 9 x 9 cm), with most between 100–500g. Some are round, some are angular with one or more flat surfaces, however most are of irregular shape. None has any tool marks or a form that suggests artificial shaping.

Macroscopic and hand lens examination identified the rock types/materials listed in Table 1. These have been arranged in two groups; one in which the rocks show no evidence of having been heated, let alone melting, and the other in which there is clear or inferred evidence that they did. There is a predominance of vitrified samples indicating that the walkers were successful in identifying the unusual stones from the ordinary ones. The following descriptions concentrate on the latter group.

Sandstone

The non-vitrified samples are brown to red-brown to yellow-brown, coarse to fine sandstone. The features point to derivation from the Old Red Sandstone. The colours of the sandstones are characteristic of the environment in which the sand grains of quartz and feldspar accumulated—temporary rivers and lakes in an arid desert—and are due to iron oxide and hydrated iron oxide coating and cementing together the sand grains. In addition to quartz and feldspar, white mica and clay accumulated in many sandstones and in some of the finest rocks make up a significant proportion of the grains.

Illus 4 *Partially melted sandstone stone reflecting the water-clear shiny glaze on part of the surface. From grid square C8. Stone is 9cm across.*

Of the 31 stones that we have identified as vitrified, the biggest group (10) are formerly sandstone. These would have caught the walkers' attention because of a shiny, colourless or slightly yellow-green glaze that thinly coats the exterior to a depth of c 1–3mm. Walkers may also have noticed that this coating creates an unusually smooth surface to a stone (Illus 4). These stones feel light for their size, implying a low density rock.

Beneath the glaze these vitrified rocks are grey, with no trace of the red, brown or yellow colours of the original sandstone. They consist of 40–80 volume % white and grey-white crystals (0.5 – 1.4mm across) of quartz and scarce feldspar enclosed by shiny black glass (Illus 5). The glass usually contains round cavities from 0.1–2mm that can constitute up to 30 volume percent of a rock. These represent gas bubbles that grew in the former melt, now glass.

This mixture of crystals, glass and bubbles superficially resembles the igneous rock pitchstone (ie volcanic glass resembling pitch), however the abundances of crystals and bubbles are considerably greater in the stones. Furthermore, the microscopic features of these vitrified stones are not consistent with it being volcanic rock. *i* Whereas the crystals in a pitchstone normally would be surrounded by straight faces, recording their slow growth prior to quenching of the magma, the quartz and feldspar crystals in the stones are actually round or irregularly angular and indented by glass. These features indicate that the crystals partially dissolved when the glass was molten. *ii* There are clots of quartz and feldspar crystals in which crystals have curved contacts that are atypical of intergrown igneous

Illus 5 *Sectioned partially melted sandstone stone showing residual grains of quartz in dark glass. Note the fragment of finer grained partially melted sandstone at top right. From grid square C5. Stone is 7cm across.*

Illus 6 *Cindery sample of partially melted very fine-grained sandstone or mudstone. Note the abundance of cavities formed by expanding gas and that they form trains following the original bedding. From grid square B8. Stone is 5cm across.*

crystals. This points to such clots being residual unmelted material from the sandstone. *iii* Some of quartz crystals display optical evidence of strain (seen as uneven polarization of light). This cannot happen as crystals grow in magma; rather it shows that the quartz has been derived from a high-grade metamorphic rock such as gneiss or granite-gneiss, probably following their erosion from the Grampian mountain belt. In summary, there is unmistakable evidence that these vitrified rocks represent partially melted former sandstone.

The gas bubbles in the glass derive from H_2O originally contained in the structures of mica and clay grains and in the iron oxide mineral limonite. As these minerals decompose on heating, some of their H_2O initially dissolves in the melt before exsolving as bubbles of gas.

Table 1 *Summary of stones collected during fieldwalking*

rock type/material	**number of stones**
stones not considered to show evidence of melting	
sandstone	3
mudstone/shale	3
grey/pink/purple basalt/andesite	10
bone	1
cement/mortar	1
stones considered to have partially or wholly melted	
glazed/glassy sandstone	10
fresh, black basalt	4
andesite with tongue on surface	1
fresh, black basalt enclosing chunks of glassy sandstone	6
‘cinder’ of former very fine sandstone or mudstone	9
breccia of pink andesite fragments in grey-pink andesite	1

Among the stone collection are 9 small specimens of what resembles cinders from a coal fire (Table 1, Illus 6). These are highly porous, with abundant, interconnected cavities up to 5mm across, and a smooth dull-glazed, brown, surface. Given the other evidence at this site for vitrification, it is likely that they too are vitrified samples, of former mica- and/or clay-rich, very fine-grained sandstone (or mudstone) that almost completely melted and swelled up due to creation of a lot of gas. Bands in these stones picked out by differences in bubble size and abundance of bubbles probably reflect fine-scale bedding in the original sedimentary rock.

That all these vitrified sandstones are now grey, rather than red, brown or yellow, indicates that most of the iron that they contained was chemically reduced from Fe^{3+} to Fe^{2+} during heating and partial melting.

Basalt/andesite

Ten stones of basalt are included in the category of no melting (Table 1). As is typical of the Upper Devonian lavas of the Ochils, these stones are not the black to dark-grey colour of fresh basalt but show various shades of green, ochre and red, indicating that they are chemically changed, probably by weathering and hydrothermal alteration in the Devonian. Under the microscope the alteration shows as various degrees of replacement of the minerals olivine and pyroxene by green chlorite and brown clay, and of plagioclase feldspar by clay.

Four basalt stones are completely different. They are black, angular blocks of intermediate density and fine to medium crystal size. In a stone the grain size is uniform and there are no larger crystals such as are common in lavas. Empty gas bubbles are abundant in these stones but especially so on the external surface of a stone (Illus 7). These stones are completely fresh, ie there is no discolouration suggesting alteration, and the minerals are pristine. How a minority of basalt stones is not altered was initially problematic. Our original thought was that they had not been derived from the Ochils lavas but from a much younger source, such as a Tertiary basalt dyke. However, the true status of these stones emerges from the next category of sample.

Mixed sandstone and basalt stones

These are the most exciting 6 samples in the collection in that they combine both vitrified sandstone and fresh basalt in one stone. They include the biggest stones collected.

A stone from grid square E5 is representative of the group. It consists of several separate, angular, grey chunks of partially melted sandstone embedded in fresh black basalt (Illus 8). On the surface of the stone the basalt forms smooth and very fine-grained, but not glassy, tongue-like knobs. Lodged in the basalt are little fragments of partially melted sandstone up to 4mm across. The shapes of these knobs are reminiscent of the driblets of basalt that escape from the front of a very fluid basalt lava flow, forming smooth-surfaced, sack-like tongues of rock known as 'entrail pahoehoe' (Macdonald, 1967).

Illustration 9 shows an elongate example of this type of stone which demonstrates that the sandstone blocks are not necessarily surrounded by basalt, only parts are. Illustration 10 is of a mixed stone that has been sectioned to show the junction between basalt and sandstone is sharp and that the basalt is full of bubbles.

In thin slice under the microscope the two portions of these mixed stones resemble those stones made exclusively of partially melted sandstone or of basalt. Within 0.5mm of their contact the basalt is slightly finer grained than beyond, indicating that the basalt cooled against the sandstone blocks.

Illus 8 *Two views of a mixed stone sample showing several angular blocks of partially melted sandstone partly enclosed by driblets and tongues of smooth-surfaced basalt. From grid square E5. Stone is 12cm across.*

Illus 7 *Basalt stone showing abundance of burst gas bubbles of various sizes on one surface. From grid square C4. Stone is 8cm across.*

Illus 9 *Elongate stone consisting of several blocks of partially melted sandstone bound together by basalt but not completely enclosing the blocks. From grid square F1. Stone is 17cm long.*

It is clear from these relations that basalt melt flowed into the spaces between loose chunks of sandstone. Whether or not the sandstone blocks were partially melted at the time cannot be determined for the junction between basalt and sandstone is sharp in both hand specimen and thin section.

Returning to the origin of the fresh basalt/andesite stones, the unusually fresh condition of the basalt and the abundance of gas bubbles in both mixed and non-mixed stones is consistent with a common origin. Hence the mixed stones provide the evidence that the fresh basalt stones have also been vitrified. That they are different from basalt formed in a lava flow is indicated by a feint yellow colour to the pyroxene crystals as seen in thin section in both types of stone; pyroxene in 'natural' basalt is usually colourless or less commonly pale purplish brown. Bearing in mind that the unvitrified basalt samples are considerably altered to the hydrous minerals chlorite and clay, the abundance of gas bubbles in the vitrified basalt is expected.

Suggested origin of the vitrified stones

While 18 of the stones show no evidence of melting, 31 are evidently partially melted or are reasonably interpreted to have been entirely melted.

Glassy samples of sandstone are extremely unusual in nature, a lightning strike being the commonest cause. However, that would not cause either the extensive melting seen in some of the stones or account for the abundance of vitrified sandstone stones at this site. The possibility that the vitrified stones are related to metal working can be excluded on the grounds that no slag or ore or metal has been found at the site. In view of the concentric crop marks in the field a fortified, stone-walled enclosure is the logical assumed source of the vitrified stones. The stones themselves imply that one or more than one wall was intensely heated.

The builders of the walls would likely have used stones from as close to the site as possible and the stony soil would have been convenient. The stones in the soil would be dominated by rocks from the local geology, ie Devonian sandstones and lavas. If the present-day field existed at the time, conceivably some clearing of stones had already been undertaken to improve the soil, so that piles of stones may have been to hand for the construction.

Heating caused both sandstone and basalt blocks in the wall(s) to melt, the sandstone incompletely and the basalt completely. The melt produced in the sandstone was rich in SiO_2 (next section) which means it would be extremely viscous; the presence of residual crystals would have added to that viscosity. The melt + crystals would have been extremely stiff, possibly as stiff as a block of cold tar which is why the sandstone blocks are angular in shape (inherited from the unmelted blocks).

By contrast, basalt melt is comparatively fluid, like warm syrup. As an original basalt block melted, the melt would have dripped under gravity and flowed into the spaces between underlying stones, adhering to them and more or less filling up the space, bonding the stones together. It is also possible that the basalt was present as blocks between sandstone blocks and that these melted essentially *in situ*, spreading locally in the spaces. However, that would not completely fill the spaces, as is the case in some of the mixed sandstone + basalt stones (eg Illus 8); in such mixed stones it does seem necessary for 'extra' basalt melt to be introduced.

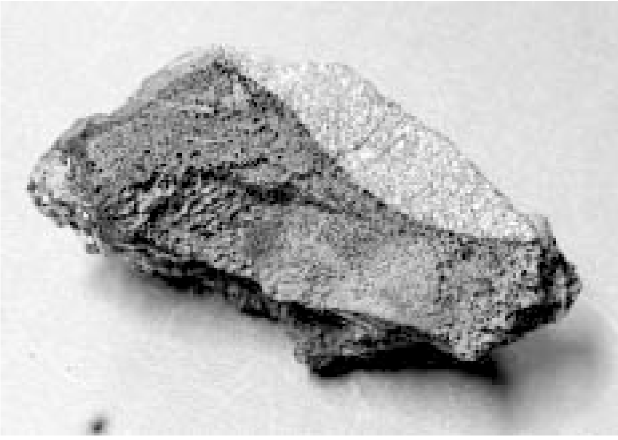
We note that there are no stones consisting of two or more blocks of partially melted sandstone adhering to one another. This isn't surprising given the evidence that the melt did not separate from the residual crystals, and so did not flow into the spaces between blocks. Hence the only opportunity for blocks to bond would be the 'points' where they touched. These would easily have broken during post-vitrification erosion (both natural and anthropogenic) of the wall and dispersal of stones through the field.

In this regard, we note that all but one of the grid squares in which stones were collected proved to contain at least one vitrified sample (Illus3),'implying that there has been no preferred pattern of dispersal of the vitrified stones.

Temperatures attained during melting

Sandstone would begin to melt at around 900°C (Huang and Wyllie, 1975) and depending on the proportion of quartz present might not completely melt until 1300 –1350°C (estimated from phase relations of the granite system (Schairer, 1950). Basalt would start to melt at c 1050°C and depending on its magnesium content might be completely molten at 1150 – 1250°C (Yoder and Tilley, 1962). This implies that during firing of the fort wall(s), it would have been sandstone blocks that began to melt first and would have continued to do so for an interval before basalt blocks began to melt. As temperature continued to rise both rock types would have melted further. In the absence of any blocks of partially melted basalt, we assume that temperature exceeded that of complete of melting. On the other hand, it did not exceed that of sandstone melting.

It is possible to further constrain the upper temperature attained from the composition of the basalt stones, which we have argued represent basalt melt, and from the composition of the black glass in the partially melted sandstone blocks. One basalt sample was analysed by X-ray fluorescence analysis and a number of glass analyses in sandstone were obtained by electron probe microanalysis in thin sections (Table 2). There are several methods that can be used to obtain the temperature (see for example Youngblood et al 1978). We have employed the widely used MELTS computer program of (Ghiorso, 1994). This compares the rock/glass composition to a database of compositions of samples of known melting point to estimate the melting point of the rock/glass. It is accurate to better than ± 15°C.



Illus 10 *Slice through mixed stone consisting of partially melted sandstone (above) and frothy basalt below. There is no sign of the basalt penetrating the sandstone or vice versa. From grid square D2. Stone is 8cm across.*

The results indicate that the basalt would have fully melted at 1180 °C and the glasses in sandstone at 1100–1160 °C. (These values are insensitive to the possible range of oxygen partial pressures that existed during melting.) Note that the former value does not preclude the possibility that temperature exceed the melting point of the basalt, ie this is a minimum estimate.

It is interesting that the basalt-derived temperature exceeds the glass-derived temperature. It is consistent with our suggestion that the basalt dripped down into spaces between sandstone blocks and so was derived from a hotter region of the fired wall.

These estimates are in line with those suggested 30 years ago by Nisbet (1975) and by Youngblood et al (1978) for the firing of vitrified forts built of a variety of rocks, elsewhere in Scotland. This is not surprising given that the firing would in all cases have featured one fuel—wood.

The temperature attained in a fire is very variable and difficult to measure; it depends critically on the access of air and whether it is mixed in with the fuel (turbulence) or not (diffusion) (eg Urbas and Parker, 1993; Babrauskas, 1997). Measurements of wood combustion in a conventional grate fire (diffusion) indicate a maximum temperature of 480–650°C between wood logs (and just 90–200°C at the tips of flames). On the other hand, artificially induced turbulence in the form of an air blast raises the maximum temperature to 870–1090°C (EcoFire website, 2003). As has previously been noted in investigations of vitrified walls the fire could either be set external to a wall (piling up of timber and brushwood), or it could be internal (as in the construction of a timber-laced wall [eg Ralston, 1995]). In the latter case restriction of air access during burning (eg if the wall is turfed) would be expected to reduce the temperature attained. On the other hand, it could produce gases that burn at higher temperatures than wood (cf Fredriksson et al 1983). Since experimental archaeologists have tried firing stone walls with the wood in both configurations (though never with both external and internal together) and achieved little, if any vitrification, (Childe and Thorneycroft, 1938; Ralston, 1987) there remains a fascinating unresolved problem about the circumstances of firing. The solution, we believe, will lie in persuading fire engineers to consider the context of fort firing. Until the problem is resolved, there can be no certainty that firing was a deliberate action by fort residents or enemies, as is commonly assumed.

Conclusion

This limited investigation of samples from Dun Knock shows that sandstone stones in the field are vitrified, that some are bonded together by fresh basalt, and that there are scarce stones of fresh basalt. Though the material is a surface sample not backed up by an excavated sample from a more closely defined context, there seems little doubt that the crop mark was a vitrified fort. The temperature of firing reached c 1160–1180°C. How a wood fire can produce and sustain these temperatures requires investigation. Such an investigation could form a critical component of an inter-disciplinary research project that sought to address the chronological horizon and cultural context of the vitrification. Further work at Dun Knock could make a significant contribution to such a project. The dating of a contextually secure sample of vitrification would be crucial and this work would readily build upon the thermoluminescence (TL) dating approach described by Sanderson, Placido and Tate (1988). There is scope for developing this work with a range of samples from a number of vitrified hillforts (pers. comm. Sanderson). A comprehensive approach including carbon-14 dating also recommends itself in the light of the C-14 dates of cal. AD 500–700 and cal. AD 590–730 from the vitrified hillfort of Caste Craig, Stirlingshire (Derek Hall, pers.comm.) The archaeological evidence from Dun Knock and its environs indicates a long-lived story of human occupation from at least the Neolithic. Of particular significance is the theory that the Dun Knock may have been an early medieval power centre, for it raises the question of when vitrification took place there either, as a cultural or natural phenomenon (the latter could still have serious human implications), in the latter part of the first millennium AD or significantly earlier.

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Abstract

31 out of 49 stones collected from a field on the slopes of Dun Knock have been identified as vitrified. This supports the previous inference of a former fort on the hill and indicates that its walls had experienced firing. Two rock types have been wholly melted (basalt) or partially melted (sandstone). The vitrified basalt stones are very finely crystallized, whereas the vitrified sandstone stones contain residual grains of quartz and feldspar embedded in a black glass that contains numerous gas bubbles. In a few stones blocks of partially melted sandstone are bound together by basalt that is assumed to have dripped down onto the blocks. The compositions of glasses in the vitrified stones and of the basalt indicate that temperatures of at least 1160–1180 °C were achieved. Further understanding of how the walls of vitrified forts fused requires application of knowledge about the physics and chemistry of wood fires in which wood is either placed outside the wall or is internal, as in timber-laced walls. Until then it remains possible that firing was not a deliberate act.

Keywords

andesite
basalt
crop-mark
Dun Knock
Dunning
hillfort
Iron Age
medieval
sandstone
vitrification