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DEMYSTIFYING SARSEN: BREAKING THE UNBREAKABLE

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This small project was initiated to create a broader understanding of the working properties of sarsen and its challenges. This notoriously durable coarse-grained sandstone is most familiarly associated with the Phase 3 monument at Stonehenge, Wiltshire, although its exploitation persisted into the twentieth century. Discussion has focused on the probable methods employed in prehistory to work the stone: splitting, flaking and pecking. These techniques have rarely been applied in practice, but have been considered broadly in this project. The preliminary results, obtained from a single block of saccharoidal sarsen, have reawakened understanding and appreciation of the potential provided by shock waves to split and shape this intractable silicate successfully and repeatedly using direct percussion, techniques that were familiar to Neolithic communities to work flint. The flaking properties of the stone are considered together with attributes of hammer mode in comparison with data from prehistoric stone assemblages at Stonehenge. The discussion questions to what extent flaking could be controlled repeatedly to form a major part of monolith production. Results derived from the laborious nature of pecking supplement previous attempts to recreate dressed surfaces at Stonehenge. Efficiency was not improved by applying heat to the surface of the stone; indeed, it confirmed that uncontrolled, excessive heat shatters the structure of sarsen, rendering it unworkable.

Keywords: experimental archaeology; flint; sarsen; Stonehenge

INTRODUCTION

Sarsen is synonymous with Wiltshire. Although it occurs across other parts of southern England,[1] nowhere does it exist as plentifully as on the Marlborough Downs of north Wiltshire. Its abundance enabled it to be exploited extensively in the prehistoric monuments of the county either in an unaltered state, as at Avebury, or reaching its apotheosis in the structure involving complex stone working at Stonehenge. Sarsen working was not restricted to Stonehenge but also featured extensively throughout prehistory for smaller, more utilitarian purposes, including hammer stones, rubbing stones, quern stones and hearth stones.[2] Some of these divergent aspects to sarsen use required no surface modification, while others, with abrasive functions, undoubtedly

1. Bowen and Smith 1977: Summerfield and Goudie 1980; Whitaker 2020a.
2. Whitaker 2022.

benefitted from repeated surface dressing to maintain their effectiveness. Activity of a more unsystematic nature[3] may have been linked to acts of ritual destruction.[4]

Despite this broad range of uses from the area, consideration of the working properties of the stone throughout prehistory has remained largely theoretical and focused on Stonehenge. Some of these sarsen related studies have benefitted from contributions funded by the Society of Antiquaries of London.[5] This small project has adopted a practical approach to sarsen working to provide some preliminary observations that may be relevant to future studies.

GEOLOGY

Sarsen is a hard silcrete formed by surface sand that is cemented in a silica matrix,[6] a component that accounts for more than ninety per cent of the fabric and enables some forms to be flaked in a similar way to flint. It has been classified into four silcrete fabric types: conglomeritic, matrix, floating and grain-supported.[7] Most of the sarsen boulders from the downs of north Wiltshire are probably of the grain-supported fabric type, which is sugary in texture leading it to be classified by archaeologists as saccharoidal.[8] These forms are relatively softer and break sub-conchoidally with varying degrees of consistency, according to variable silica content. It occurs as blocks up to 1m thick where sandy geological conditions existed for the formation of this variety of sarsen.[9] Sedimentary conditions across the central parts of Salisbury Plain differed and led to the creation of quartzitic varieties, which are proportionally harder and denser. These finer-grained varieties occur in the coombe bases and contain less well-defined characteristics of percussion; however, the differences in the two types can be poorly separated.

Howard recognised that some saccharoidal sarsen,[10] which formed the principal components of the Stonehenge monoliths,[11] crumbled easily, while other examples were less friable. She considered that quartzitic varieties were ‘virtually impossible to break’.[12] The coarse differential grain size and distribution within sarsen creates a dense stone that is challenging to work. It can be sawn using specially prepared diamond tipped blades, but its silicate structure fractures most effectively by passing shock waves through the material by direct or indirect percussion. Stone age communities, as with anyone familiar with flint working, were undoubtedly aware of the conchoidal flaking qualities of sarsen,[13] but also appreciated the limitations and techniques needed to work it.

3. Pollard 2013.
4. Barclay and Bradley 2017.
5. Gowland 1902; Bowen and Smith 1977; Whitaker 2020a.
6. BGS 1996; Summerfield 1983a.
7. Summerfield 1983b; Nash and Ullyott 2007, tab 4.4.
8. Howard 1982; Chan and Richards 2020a; Harding *et al* 2024.
9. Harding *et al* 2024.
10. Howard 1982.
11. Nash *et al* 2020.
12. Howard 1982, 121.
13. Pitts 2022.

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SARSEN USE

Sarsen-working in Wiltshire can be traced from the Early Neolithic period. Smith reconstructed a process whereby blocks of stone were split and trimmed to create rectangular or circular querns at Windmill Hill.[14] Fracture may have been undertaken using a maul, similar to that weighing 3.56kg and made from a massive flake of saccharoidal sarsen, that was found in a pit at Barrow Clump, Netheravon.[15] Nine flakes with dressed surfaces, of which two refitted, from an Early Neolithic pit at Bulford[16] were probably derived from a quern or rubbing stone, objects that were frequently trimmed by flaking around the circumference.[17] The study of Late Neolithic material has frequently focused on collections from Stonehenge;[18] however, large flakes, including one weighing 790g, and debris have also been found from contemporary activity in the surrounding landscape at the Tor Stone, Bulford,[19] Woodhenge[20] and Durrington Walls.[21] Unsystematic flaking strategies are also represented by a sub-angular block of saccharoidal sarsen, weighing 15kg, that had been reduced by rudimentary flaking from a Late Neolithic posthole at MOD Durrington.[22] Sarsen remained a vital material for the production of quern stones throughout prehistory; large collections of Late Bronze Age manufacturing debris have been recorded from the Marlborough Downs, demonstrating continued output on an industrial scale into this period.[23] These utilitarian objects were made on large flakes, the modification of which also created numerous trimming flakes. Extensive exploitation of sarsen continued in this area for building blocks, gateposts and kerb stones through the nineteenth and twentieth centuries. This activity decimated large spreads of sarsen boulders, generating quantities of waste material.[24]

Heat has also been associated with sarsen, most notably to facilitate breaking large saccharoidal blocks. However, like other silicates, this form of sarsen reacts badly when subjected to excessive heat, becoming sugary and unresponsive to controlled fracture.[25] Debris of this type frequently occurs on archaeological excavations,[26] where it can be difficult to attribute it to intentional stone working or use in domestic hearths. Aubrey[27] and Stukeley[28] observed and described an apparently unsystematic quartering process of sarsen breaking involving thermal shock using fire pits at Avebury. This activity, which Aubrey indicated could be achieved 'without any great trouble',[29] was fuelled with straw and wood to envelop the stone with fire and break it by direct percussion. The description made no reference to how much this provided control over the fracture;

14. Smith 1965, 123.
15. Andrews *et al* 2019.
16. Wessex Archaeology 2020, 73.
17. Barclay and Bradley 2017; Cruse 2017.
18. Gowland 1902; Howard 1982; Montague 1995; Harding 2010; Chan and Richards 2020a.
19. Chan and Richards 2020b.
20. Cunnington 1929.
21. Chan and Richards 2020b, 311.
22. Thompson and Powell 2018.
23. Gingell 1992.
24. King 1968; Whitaker 2023.
25. Willies 2002.
26. Richards 1990, fig 82, MF F3.
27. Fowles and Legg 1980, 38.
28. Stukeley 1743; Piggott 1950, 94.
29. Fowles and Legge 1980, 38.

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indeed, Gillings *et al*,[30] commenting on a print of 1724,[31] provided a scenario depicting a dynamic process that offered little prospect of providing a controlled linear fracture. This view was supplemented by archaeological results indicating that the process produced large fragments that could be flaked for subsequent use in buildings,[32] but that heat control was indeed variable, with excessive temperature invariably also creating heavily burnt, sugary debris.

PROJECT BACKGROUND

Gowland, following excavations at Stonehenge,[33] proposed a tripartite model for working saccharoidal sarsen at the monument involving splitting, flaking and pecking. These phases were probably founded on theories drawn from ethnographic observations and descriptions by Aubrey[34] and Stukeley,[35] with supplementary knowledge obtained from contemporary stone workers,[36] although Whitaker questioned the appropriateness of applying this approach to prehistoric methods.[37] Gowland regarded the primary stage, splitting, as 'not a matter of great difficulty' and proposed that this could be achieved by igniting strips of wood along a preplanned line and cooling the stone with water before using direct percussion.[38] Apparent confirmation of the splitting process has been revealed by laser scanning on three stones at Stonehenge;[39] the authors conceded that it was difficult to demonstrate that heat had been used to achieve this. The survey also noted traces of flaking, most notably a large scar on the outer surface of Stone 3 and other similar traces that were exposed during excavations around the base of Stone 30.[40]

Gowland also gave consideration to the range of tools used to prepare each monolith. He recognised five classes of stone 'implements' from excavations at Stonehenge,[41] including those with traces of percussion, which he classified as hammers and mauls. Hammers were identified by traces of battering that were frequently extensive. Damage of this type can result from any routine percussive activity, including flint working, but was regarded in the context of Stonehenge as having been created in the construction of the monument. Hammers of flint were placed in Classes II and III, with those of sarsen into Class IV. Large sarsen mauls, which were up to 29kg in weight, were placed in Class V and were frequently formed from rounded quarzitic boulders that were obtained from gravel that is present in the coombes around Stonehenge. Gowland's classification has been widely adopted,[42] although Whitaker, in a comprehensive study focusing on the way in

30. Gillings et al 2008, 294.
31. Bodleian Library MS Gough Maps 231, fol 5.
32. Gillings *et al* 2008, 319.
33. Gowland 1902.
34. Fowles and Legge 1980.
35. Stukeley 1743.
36. Gowland 1902; Stone 1924; Atkinson 1956.
37. Whitaker 2020b.
38. Gowland 1902, 75.
39. Abbott and Anderson-Whymark 2012, 13.
40. Pitts 2001, 216.
41. Gowland 1902, 57.
42. Montague 1995; Harding 2010.

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which they might have been selected and worked, has questioned the complex division, preferring to classify them collectively as hammers.[43]

The fundamental techniques to split and flake sarsen using direct percussion have remained largely untested in archaeological study despite current widespread interest in experimental archaeology. Embryonic attempts to dress sarsen were undertaken by Gowland, who commissioned Mr Stallybrass, a stone mason, to replicate peck dressing using a quartzite hammer stone.[44] The results matched those on stones at Stonehenge, although Gowland remained sceptical that flint could be used to dress anything but the softer sarsen and volcanic rocks at the monument. The process was subsequently repeated by a professional stone mason, who produced six cubic inches of sarsen dust in an hour using a stone maul.[45] Zaminski similarly used mauls weighing 4.5kg and 2.2kg to peck dress a flat sarsen surface covering approximately 0.09sq m in a day.[46]

METHODOLOGY

Study of sarsen debris from Stonehenge was hampered until the late twentieth century by the lack of large, well documented assemblages. Montague noted that, apart from material collected by Pitts, the largest concentration of material was that collected by Gowland.[47] This situation has been improved by subsequent excavations at the monument,[48] which have produced large quantities of sarsen flaking debris with associated detailed specialist reports.[49] Informal discussions of these assemblages and the results led to consideration regarding hammer mode to produce sarsen flakes and mirror similar studies undertaken in flint technology.[50] The interest focused on whether sarsen flakes removed by a stone hammer, which might relate to monument construction at Stonehenge, differed from those detached using metal hammers during Romano-British and post medieval destruction. Debate extended to what processes or hammers might be employed to produce flakes of similar size to trimming flakes found on the site.

Hammers used in the initial parts of this study to consider these issues related to flaking. They comprised a sub-spherical cobble of Bunter quartz, weighing 454g, and a standard ball pein hammer, weighing 794g. A 7lb (3kg) sledgehammer was added subsequently as the project was widened to include sarsen splitting. These hammers, despite being predominantly of metal, were all of comparable weight to Gowland's Class IV sarsen 'hammer stones, more or less rounded'.[51]

The final process, peck dressing, was replicated using five separate flint hammers and the Bunter quartzite cobble. These objects most closely approximate to Gowland's Type III and IV hammer stones, which are frequently characterised by battered, chamfered edges. The flint examples were produced using bifacial/alternate flaking to create a 'chopper core'

43. Whitaker 2020b.
44. Gowland 1902.
45. Stone 1924.
46. Zaminski 2020.
47. Montague 1995, 386.
48. Pitts 1982; Darvill and Wainwright 2009; Parker Pearson et al 2020.
49. Howard 1982; Harding 2010; Chan and Richards 2020a.
50. Ohnuma and Bergman 1982.
51. Gowland 1902, 65.

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type tool with an irregular, acute edge that was sufficient to degrade or peck the sarsen. These hammers were used to peck the surface of the saccharoidal sarsen block by hand for periods lasting fifteen minutes. Debris from the process, comprising flint and sarsen flakes with miscellaneous micro-debitage, was collected and sieved through 9.5mm, 4.0mm, 2.0mm and 1.0mm mesh at the conclusion of each stage.

In use, the hand-held stone hammers proved to be the least attractive options for both flaking and peck dressing. These tools were both tiring and jarring to use for anything other than simple trimming. The sledgehammer was swung in a forceful but controlled manner to maintain a precise point of impact. The addition of a handle inevitably increased the inertia upon impact, possibly raising it to something approximating to Gowland's larger mauls. Indeed Gowland speculated that some of these cumbersome pieces may have required teams of workers to swing and maximise their accuracy and effectiveness.[52] It is possible that some of the smaller hammers were also fitted with a handle to improve their efficiency.

Heating the sarsen as part of the production process has similarly received limited attention in practice to consider whether its application may be beneficial or detrimental.[53] Application of heat, up to 400 degrees C, has been shown to improve the working properties of some silicates by releasing water from the stone and reordering the crystalline structure, producing a glassy surface texture on unpatinated knapped flint.[54] Higher temperatures impair the internal structure of flint, rendering it unworkable and creating grey, heavily crazed material that is instantly recognised as 'burnt flint'. Sarsen similarly becomes sugary when heat is excessive.

This small project confined its study to peck dressing to identify whether efficiency might be improved when the stone was heated. A small bag of lumpwood (hard wood) barbeque charcoal, weighing 1.25kg, was fired directly on top of the sarsen block and allowed to burn for approximately two hours before the sarsen was exposed, allowed to cool naturally and pecked with a flint hammer. The exercise was repeated using two similar sized bags of charcoal. No attempt was made to record temperatures accurately; however, two flint flakes and two of sarsen were inserted as 'controls' to evaluate the extent to which the stone was burnt and visually assess temperature levels.

The entire project was undertaken using an unprovenanced boulder of saccharoidal sarsen with a plano-convex cross section, weighing 54kg and measuring 0.37m long, 0.32m wide and 0.2m thick. One end was snapped with two negative flake scars, 0.14m and 0.18m long, but the block was otherwise unworked.

RESULTS

The results presented here follow Gowland's tripartite model reflecting technological order: splitting, flaking and peck dressing.[55]

52. Ibid, 70.
53. Ibid, 75.
54. Griffiths *et al* 1987.
55. Gowland 1902.

Splitting

This process formed the principal component for Gowland's reconstruction of monolith formation at Stonehenge. The fracture mechanics were not described in detail but were based on methods for working sarsen in the nineteenth and twentieth centuries when the tool kit comprised wedges and hammers of varying sizes,[56] techniques that followed traditional patterns of stone working.[57] Former sarsen extraction sites in Buckinghamshire and Wiltshire contain industrial waste,[58] which shows clearly that the process involved chiselling out a row of sockets into which iron wedges were inserted. These were used individually or with sleeves, the wedge and feather technique, to split the stone using indirect percussion. Improved control over the fracture may be made by carving a guideline, tracing a line or by placing a support beneath the stone.[59] This technique, known as point loading, provides a linear pivot against which to snap the stone by blows delivered from above. Adaptations of these traditional techniques may have been used by prehistoric communities who relied on direct percussion, employing a tool kit comprising hammers of varying sizes.

The realisation of how direct percussion might be used to split the sarsen, in the sense of cleaving as distinct from flaking, arose during the production of flakes using a ball pein hammer. These removals were frequently detached by delivering a single blow; however, in more than one case repeated blows to the same impact point were required before a flake was eventually detached. The process was repeated using a hand-held stone hammer, when blows delivered to a single impact location produced a flake that was larger than other removals created using the same stone hammer.

This unexpected observation was confirmed on a larger scale using a sledgehammer (fig 1.1) and was replicated successfully to confirm the process (fig 1.2–4). In each case, repeated strikes to the same point of percussion widened an incipient fracture that had formed in the stone, effectively using the proximal end of the partially detached block as a punch to split the stone. It demonstrated a previously unappreciated progressive development of the fracture line in the sarsen in contrast to the spontaneous response that is more familiar in flint.

The results produced by this simple repeated demonstration focused attention on the conchoidal properties of the stone and the way in which these attributes might be employed to use direct percussion to split sarsen in a more controlled fashion. Subsequent adaptations successfully divided a small fragment of sarsen to create an angular block using point loading by resting the stone on a row of sarsen boulders to provide a pivot point (fig 2). This modification mirrors the use of an anvil (*sur enclume*) in flint working, a technique that was known to Palaeolithic knappers[60] and modern gun flint knappers,[61] although its use through the Neolithic period is less certain.[62] The process produced little or no diagnostic waste products and required limited secondary trimming. Further improvement within the available Neolithic technology may theoretically have resulted by pecking a groove, 'tracing a line', to weaken the stone along a predetermined fracture line.

56. Whitaker 2023.
57. Warland 1929.
58. Whitaker 2023.
59. Warland 1929.
60. Bergman *et al* 1987.
61. de Lotbiniere 1977.
62. Anderson-Whymark 2011.

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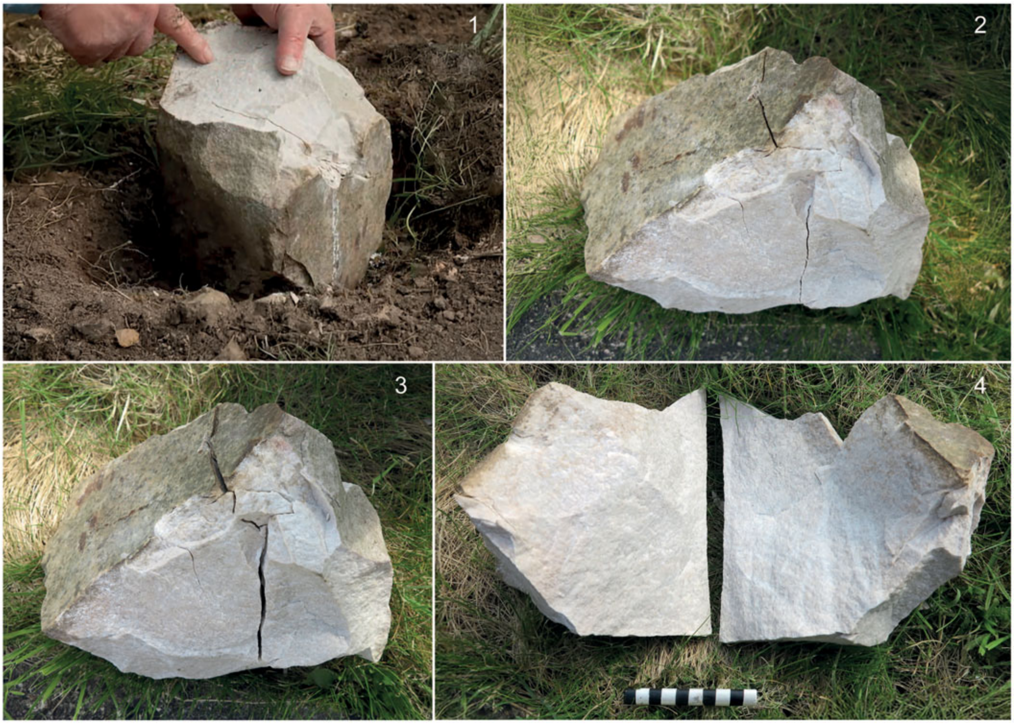

Fig 1. Splitting sarsen: 1) incipient fracture in the sarsen block after one blow using a sledge hammer; 2) a subsequent fracture created by one blow; 3) crack opened by a repeat blow; 4) the split block. *Photographs*: author.

Flaking

The direct percussion process inevitably produced quantities of debris including waste flakes.[63] However, these removals are often technologically undiagnostic and, apart from impact removals from hammer stones, may relate to construction or subsequent destruction of monoliths at Stonehenge.

Previous studies have failed to note characteristics of hammer mode or consider to what extent flaking could be undertaken in a controlled systematic way to create large blanks for other purposes, including quern stones. Table 1 catalogues hammers used and dimensions of flakes that were removed in this project with supplementary details of the largest flakes from Stonehenge, MOD Durrington and Barrow Clump. 'Shatter' comprises miscellaneous fragments that formed around the point of percussion that retained distinct flake-like characteristics. Micro-debitage was assessed as material measuring less than 15mm long.

Twenty-five flakes were generated using the three different hammers. All flakes were characterised by relatively broad plain butts where the point of impact was securely seated behind the edge of the striking platform. Bulbs of percussion were generally diffuse, as noted by Gillings *et al*,[64] with cones of percussion predominantly absent and conchoidal rings indistinct, which collectively provided no identifiable differences between stone or metal

63. Pitts 1982; Montague 1995; Harding 2010; Pollard 2013; Chan and Richards 2020a.
64. Gillings *et al* 2008, tab 10.4.

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Fig 2. Point loading: 1) showing block resting on sarsen supports; 2) the blow delivered; 3) the resulting squared fracture. *Photographs*: author.

Table 1. Flake removals shown by hammer, length (mm), breadth (mm), thickness (mm) and weight (g) with relevant comment.

	Hammer	Length	Breadth	Thickness	Weight	Comment
Flake	Quartzite	32	70	12	21	
Flake	Quartzite	34	60	16	38	
Flake	Quartzite	51	71	16	43	
Flake	Quartzite	60	83	22	102	
Flake	Quartzite	90	69	34	131	
Flake	Quartzite	70	120	18	173	
Mean		56	79	20	85	
Flake	Ball pein	45	67	17	34	
Flake	Ball pein	55	76	15	51	
Flake	Ball pein	81	135	25	193	
Flake	Ball pein	113	157	49	758	Siret
Flake	Ball pein	145	119	64	1018	
Mean		88	111	34	411	
Shatter					37	7 pieces
Micro-debitage					19	17 pieces <15mm
'Dust'					9	
Flake	7lb sledge	103	115	24	330	
Flake	7lb sledge	143	143	35	759	
Flake	7lb sledge	147	154	53	1110	
Flake	7lb sledge	190	233	42	1839	
Flake	7lb sledge	181	234	47	1933	
Flake	7lb sledge	240	230	92	4180	
Flake	7lb sledge	112	88	20	148	Broken; Siret
Flake	7lb sledge	97	102	25	227	Broken
Flake	7lb sledge	112	93	29	249	Broken; Siret
Flake	7lb sledge	50	60	17	55	Broken: Siret
Flake	7lb sledge	21	58	15	22	Broken; step fracture
Flake	7lb sledge	68	76	23	129	Broken; step fracture
Flake	7lb sledge	62	49	8	23	Broken; Siret
Mean		117	126	33	846	
Shatter	7lb sledge				485	29 pieces
Micro-debitage	7lb sledge				62	61 pieces <15mm

(*Continued*)

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Table 1. (*Continued*)

	Hammer	Length	Breadth	Thickness	Weight	Comment
'Dust'	7lb sledge				9	
Stonehenge flake[65]		350	220	40	–	Salisbury Museum
Stonehenge flake		242	172	35	1806	Atkinson backfill
MOD Durrington flake[66]		155	175	82	2178	Broken
Barrow Clump flake[67]		140	230	79	3559	

hammers (fig 3). These undifferentiated characteristics may also be attributed to the coarse-grained texture of the stone. Five flakes were broken by Siret fractures, an accidental breakage that is more prevalent in worked flint industries with the use of hard hammers. Flake production could be maintained, provided the angle of percussion, as in flint, remained acute. A number of flakes terminated with hinge or snapped distal ends, terminations that became more prevalent when the angle of percussion at the edge of the block increased.

Flake dimensions show that only four flakes measured less than 50mm long, figures that are comparable with saccharoidal sarsen flakes from Trench 44 at Stonehenge.[68] Flake size resulting from the use of each hammer shows some overlapping of dimensions between removals produced by individual percussors; however, a heavier hammer, especially when connected to a handle, not surprisingly created larger flakes than a small hand stone hammer. The removal of a flake with dimensions approaching the largest recorded examples from Stonehenge, using only a 7lb (3kg) sledgehammer, suggests that mauls of Gowland's Class V, weighing up to 29kg, were undoubtedly capable of removing flakes of similar size. The rarity of such large flakes at the site may endorse the idea that mauls of extreme weight functioned primarily for splitting and were not intended as flaking hammers.

The most distinctive flakes were those with traces of percussion at the proximal end of the dorsal surface that were detached from the base of the flint hammers during peck dressing. These pieces were extracted from sieved debris and included ninety-four examples in the 9.5mm residues, of which forty-four were heavily fractured. Unbroken flakes were consistently less than 30mm in length and breadth and 6mm thick, measurements that replicate flake size dimensions for flint and quartzitic sarsen[69] removals from hammer stones at Stonehenge. Butts on these flakes were consistently crushed, broken or linear, which resulted from the point of percussion on the hammer having been initiated by a glancing blow against the sarsen and not seated intentionally on the striking platform as might result from controlled flaking.

Pecking

The flint hammers used in this activity showed a rapid rate of attrition that probably necessitated regular replacement, as indicated by the relatively large numbers recovered

65. Whitaker 2020b.
66. Thompson and Powell 2018.
67. Andrews *et al* 2019.
68. Chan and Richards 2020a, tab 6.2.
69. Montague 1995; Harding 2010; Chan and Richards 2020a, tab 6.2.

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Fig 3. Flake removals showing mode characteristics: 1–2) quartzite hammer; 3–5) ball pein hammer; 6–7) sledge hammer. *Photographs*: author.

from excavations at Stonehenge.[70] The individual episodes of pecking produced variable quantities of debris (table 2) that were influenced by factors including the structure of the hammer or area of working on the stone. Hammer 1 retained a relatively sharp edge after fifteen minutes work; however, hammer 2 became severely flattened with an apparent corresponding loss of efficiency.

No perceptible positive or negative alterations were detected in the working properties of the stone when the material was heated using of a single bag of charcoal. The surface of the sarsen block was reddened by the heat but produced no other visible changes. The flint flakes inserted as controls when two bags of charcoal were used became crazed, indicating that the temperature had apparently exceeded 400 degrees C. One of the sarsen flakes could be snapped relatively easily, confirming modification to the matrix at this temperature. Apart from these clear changes to the structure of the flakes, heat penetration within the internal fabric of the block appeared to be insignificant, as demonstrated by quantities of 'dust' that showed slight reductions when the surface was processed using an unmodified quartzite pebble and flint hammers 3 and 1 (table 2).

Hammers 4 and 5 were both used twice for periods of fifteen minutes. These episodes made it possible to note how the pecked surface of the block changed visually in an hour

70. Chan and Richards 2020a.

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Table 2. Sarsen peck dressing by hammer and process listing flint and sarsen flakes with miscellaneous micro-debitage by weight, and sieved mesh residues. Debris from flint hammers 4 and 5 is shown in fig 4 and the resulting surface in fig 5.

	Wg (g)	9.5mm	4.0mm	2.0mm	1.0mm	Dust
Flint hammer 1	585	26 flint (89g)	59 flint (19g) 2 sarsen (<1g)	*c* 500 flint (26g)	(13g)	(26g)
Flint hammer 2	368	24 flint (80g)	45 flint (12g) 5 sarsen (<1g)	(19g)	(10g)	(24g)
Dressing heated sarsen: Flint hammer 3	550	22 flint (52g) 5 sarsen (10g)	53 flint (14g) 6 sarsen (2g)	(22g)	(10g)	(21g)
Dressing heated sarsen: Quartzite hammer	454	2 sarsen (4g)	12 sarsen (5g)	(4g)	(2g)	(15g)
Dressing heated sarsen: Flint hammer 1		1 flint (1g) 1 sarsen (<1g)	5 flint (2g) 2 sarsen (<1g)	(4g)	(3g)	(13g)
Flint hammer 4 0–15 minutes	477	9 flint (45g) 2 sarsen (5g)	118 flint (23g) 12 sarsen (4g)	462 flint (9g) 27 sarsen (1g)	(8g)	(23g)
Flint hammer 4 15–30 minutes		5 flint (73g) Include broken hammer frag	20 flint (5g) 10 sarsen (2g)	103 flint (3g) Sarsen 25 (1g)	(3g)	(16g)
Flint hammer 5 30–45 minutes	453	2 flint (2g) 5 sarsen 6g)	25 flint (3g) 10 sarsen (2g)	110 flint (3g) 24 sarsen (1g)	(4g)	(19g)
Flint hammer 5 45–60 minutes		5 flint (16g)	44 flint (9g)	165 flint (5g) 6 sarsen (<1g)	(4g)	(25g)

(fig 4), variations in the debris produced (fig 5) and changes to the hammers (fig 6). Observations could be made at the end of each stage that highlighted the progress in this laborious process using similar hammers to those found at Stonehenge. Attrition of arêtes in the initial fifteen minutes was relatively rapid but slowed as the surface areas to be worked across the block increased.

Removals from the flint hammers used in this activity (fig 5) produced individual idiosyncrasies in the composition of the debris. Sarsen flakes over 10mm long also increased when pecking was undertaken near the edge of the block, as in hammer 5 after thirty to forty-five minutes. Removals from the flint hammers were easily distinguishable by colour and texture in 9mm, 4mm and 2mm residues from those of sarsen. Sandy, white 'dust', which colour indicates is composed largely of crushed sarsen, represented the most diagnostic confirmation of stone dressing by pecking. This component passed through the finest mesh size, rendering it archaeologically irrecoverable and unrepresented in excavated residues. It was produced in more consistent quantities, averaging 20g in each fifteen-minute phase, totals that equate to approximately 16.38cu cm, slightly lower than the 1.5cu inch obtained by Stone.[71] Hammers with an acute edge angle were especially prone to shatter, creating more flakes or broken fragments, when they were freshly used, as seen in the initial use of hammer 4. This hammer subsequently broke during the second period of use, reducing its efficiency (fig 6), and rapidly acquired a more rounded, battered surface that is characteristic of hammers from the site.

71. Stone 1924.

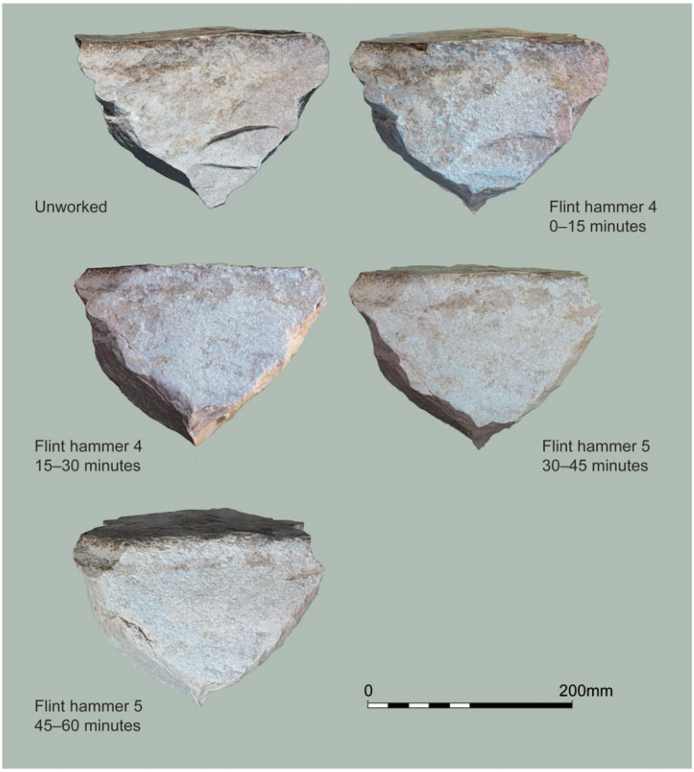

Fig 4. Changes to the visual appearance to the surface of the sarsen block by peck dressing using flint hammers 4 and 5 over periods of fifteen minutes. *Photographs*: author.

DISCUSSION

This small project was initiated to investigate hammer mode characteristics of both stone and metal hammers in sarsen working. The scheme widened to observe the broad working qualities of sarsen from a practical point of view, noting associated challenges and limitations and studying the effects of heating the stone. The principal achievement has been to consider the mechanics of direct percussion involved in this stone. These properties have rarely been observed or replicated in studies of prehistoric sarsen working to support any discussion on the subject despite forming proposed stages of monolith manufacture at Stonehenge.

The theories surrounding sarsen working have largely drawn on models conceived by Gowland,[72] which have remained virtually unchallenged. Using his training as an engineer and observer of Japanese stone workers, he proposed that monoliths might have been manufactured by percussion using massive mauls. When these were used in sequence, he suggested that the technique could be used to split large, naturally tabular blocks along a preconceived fracture line. This 'sledgehammering'[73] process could be improved by the prior use of fire to heat the stone. It is unclear to what extent his experiences extended to a

72. Gowland 1902.
73. Ibid, 75.

https://doi.org/10.1017/S0003581525100309 Published online by Cambridge University Press

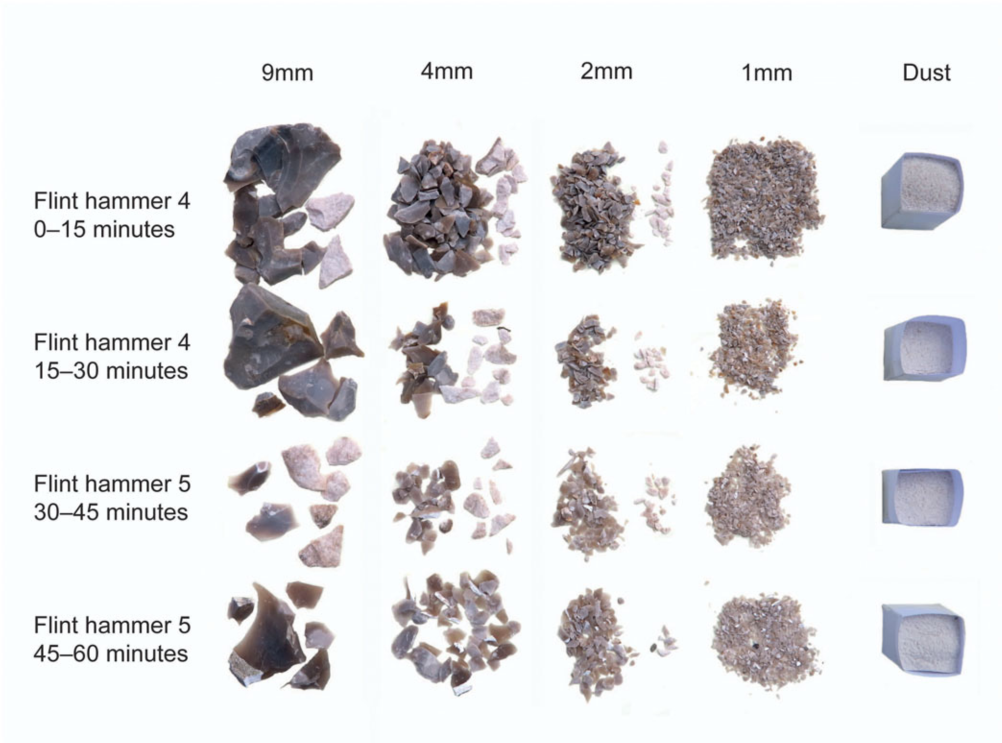

Fig 5. Variations in residues by sieve mesh size and time using flint hammers 4 and 5 to peck dress one surface of the block in a period lasting sixty minutes. The blue boxes represent 1cu inch (16.38cu cm). *Photograph*: author.

clear understanding of the flaking properties of silicates as a geologist or engineer or whether he was aware of them in practice as a craft worker with supplementary personal knowledge derived from the local sarsen industry.

Gowland's model was endorsed by Atkinson,[74] who, invoking techniques employed by sarsen workers and related quarrying industries, suggested that wedges might be used, replacing metal examples with wooden ones. This tenuous suggestion relied on conveniently located natural cracks in the sarsen to be successful. Its use remains entirely speculative, untested or confirmed in practice, and largely inappropriate for prehistoric sarsen shaping at Stonehenge.[75]

The results presented here have indicated that direct percussion does provide a plausible technique for working this silicate using techniques and materials available to prehistoric communities. In the process it has confirmed that sarsen remains fiendishly difficult to work, especially where controlled reduction strategies are intended. Many boulders that were selected for the construction of Stonehenge from the proposed source at West Woods[76] may well have included rounded or sub-rounded surfaces in their natural

74. Atkinson 1956.
75. Whitaker 2020b.
76. Nash *et al* 2020.

https://doi.org/10.1017/S0003581525100309 Published online by Cambridge University Press

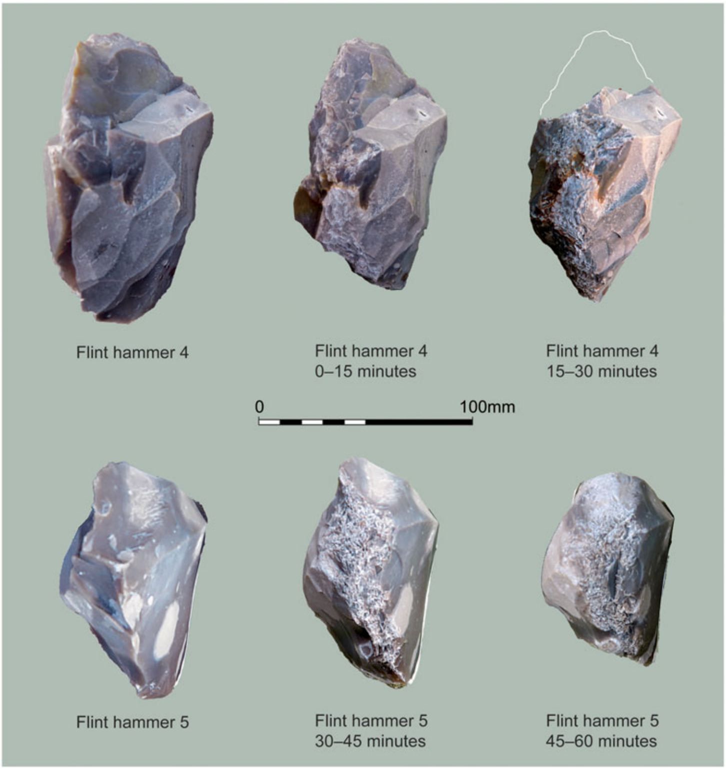

Fig 6. Flint hammers 4 and 5 used for peck dressing. Images show condition as made with subsequent changes in edge damage resulting from use for periods of fifteen minutes. *Photographs*: author.

state, making them poorly suited for preliminary flaking and thereby increasing the value of splitting. This process utilises the conchoidal properties of a durable silicate that responds to shock waves. The attribute can be ably demonstrated at Stonehenge by Stone 55, part of the central trilithon, which toppled over and 'broke its back' when it fell, a process that may have been increased by impact against the recumbent Altar Stone. Neolithic communities would unquestionably have been familiar with these conchoidal properties through the manufacture of flint tools, although they may have developed specialist stone workers with specific skills to undertake the task when working sarsen.

The practical experience afforded by the project has made it possible to witness the development of cracks from shock waves created by repeated, accurate blows. These fractures can be enlarged by further impact or by inserting wooden wedges, as proposed by Atkinson. It is possible that the coarse, granular structure of saccharoidal sarsen helps the progressive fracture process by creating an element of elasticity in the stone. This attribute may help reduce flexion breakage or shatter, as may occur in brittle, microcrystalline flint especially around the point of impact. The observed results add detail to Gowland's 'sledgehammering' technique.[77] The repeated demonstration that a block of saccharoidal sarsen, approximately 0.2m thick, can be split in this way, using a 7lb (3kg) sledgehammer,

77. Gowland 1902, 75.

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suggests that the technique may be scaled up and applied effectively to fracture blocks approaching 1m thick, as represented by the Stonehenge monoliths, and using mauls averaging 20kg in weight. Gowland recognised that persistent use of these giant mauls would have benefitted from some form of developed handle,[78] or elementary drop hammer using a tripod or A frame to maximise the efficiency and use of such heavy weights. The increased impact imparted by dropping a heavy spherical object made from dense quarzitic sarsen from height, and the resulting concentrated force to a focal point of aim, may have enhanced the successful fracture of the stone. Efficiency might also have been improved by dropping several weights repeatedly from a given height along a predetermined line of impact points. The effective use of these fundamental principles of conchoidal fracture may have been further improved by point loading or tracing a line to create relatively angular blocks.

The sub-conchoidal properties of the sarsen also allowed flake production by following basic technological principles adopted from flint working. Maintaining an operational flaking angle of percussion formed a vitally important consideration, especially when attempting to develop a systematic reduction strategy. Understandably, the weight of the sarsen made it impossible to rotate this relatively small block with ease to modify and control the flaking angle as it is when flaking a relatively small hand-held flint nodule or core. An inevitable increase in the angle of percussion at the edge of the stone limited or eliminated the potential for further flake removals and, as with flint, often resulted in the sarsen shattering at the point of impact or terminating in a step fracture. The trial piece invariably developed into a block with multiple striking platforms, using a rotating core reduction strategy, similar to that excavated at MOD Durrington.[79]

The proposition that flaking may have been a significant part of monolith shaping can be questioned. To be effective, it would have required the creation of a removal of sufficient length to cross the mid line to thin and shape the stone. This principle forms a crucial function in the production of flint and stone axes, implements with a lenticular cross section.[80] The process of removing flakes with comparable attributes becomes more problematic if percussion is envisaged to shape a large block of coarse-grained raw material with a rectangular cross section of comparable size to the monoliths at Stonehenge. Significantly, none of the recorded flakes from Stonehenge or from this flaking exercise were of sufficient length to have crossed the mid line of even the thinnest part, the width, of monoliths at Stonehenge. These technological limitations indicate that, although individual flakes of comparable dimensions to the largest examples found at Stonehenge and Barrow Clump have been found, flaking was unsuited for thinning or shaping monoliths as applies in the manufacture of bifacial core tools. It suggests that the role of flaking in monolith production may have been restricted to one of supplementary trimming and dressing of split blocks.

Despite the relative ease with which flakes could be produced from a single block of sarsen when the basic principles of knapping were followed, removals remain relatively rare at Stonehenge. Chan and Richards recorded only 693 sarsen flakes over 50mm long from the stone working area in Trench 44,[81] of which 538 (78 per cent) were of quartzitic sarsen and probably derived from hammer stones. Small numbers of sarsen flakes, which were

78. Ibid, fig 23.
79. Thompson and Powell 2018.
80. Newcomer 1971.
81. Chan and Richards 2020a, tab 6.2.

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rarely more than 20mm long, have also been noted from the Stonehenge layer inside the monument,[82] where only twelve per cent of the assemblage comprised flakes that may have resulted from the removal of minor overhang at the edge of a split sarsen block. Atkinson considered that the shortfall of flakes at the monument endorsed the idea that stones were shaped and dressed at the extraction site.[83] Alternatively, flaking may have formed a relatively insignificant part of monolith manufacture. Deep remnant flake scars of the type that could not be obliterated by extensive stone dressing are relatively rare on monoliths at Stonehenge, although they frequently survive on polished flint and stone axes as areas that resisted grinding and polishing.

The laborious task of pecking is likely to have formed a familiar task from its use to dress quern stones. The process may also have borrowed from techniques used in many Neolithic stone axe factories, where raw material with no conchoidal properties was pecked into shape. The process influenced not only the construction of Stonehenge but also the final appearance of the monument as one characterised by the unoxidised light grey of freshly worked sarsen. Replication, using flint hammers similar to those from the monument, has produced comparable surface finishes and quantities of dust to those produced by Gowland and Stone,[84] challenging the former's assertion that flint hammers were unsuited for stone dressing. Mauls, possibly linked to some form of mechanical device, may also have provided improved efficiency.

The final issue involved considering to what extent heat may alter the surface composition of the stone and make peck dressing more efficient. Studies have indicated that controlled heat can help improve the working qualities of flint.[85] However, projects that have isolated individual chemical, crystallographic and water-related properties,[86] knapping force,[87] and chronological,[88] geographical[89] and experimental[90] variables have recognised that not all modifications resulting from heat to the silicate structure are beneficial. These experimental studies have primarily focused on tool manufacture where heat can be transferred evenly through the internal structure of relatively small masses. Reproducing the process with large saccharoidal sarsen boulders, as advocated by Gowland and Atkinson,[91] is unachievable where differential degrees of heating are likely to arise between the surface exterior of the block through to the inner core of the stone, producing mixed results when the material is worked. Willies confirmed that,[92] when breaking a boulder of saccharoidal sarsen using this technique, temperatures varied dramatically between 750 degrees and 800 degrees C, yet some areas, away from the flames, reached only 150 degrees C. This published source apart, Gillings *et al*,[93] in detailed analysis of eighteenth-century stone breaking debris, noted the lack of comparable data or observations on appearance, structure or penetration by which to assess the results produced by heat on the workability of the stone when classifying heat-treated sarsen. They

82. Harding 2010.
83. Atkinson 1956.
84. Gowland 1902; Stone 1924.
85. Griffiths *et al* 1987.
86. Schmidt *et al* 2017.
87. Mraz *et al* 2019; Nickel and Schmidt 2022.
88. Schmidt *et al* 2013.
89. Zhou *et al* 2014.
90. Crabtree and Gould 1970; Wurz 2013.
91. Gowland 1902; Atkinson 1956.
92. Willies 2002.
93. Gillings *et al* 2008.

adopted a five-fold subdivision of debris types when analysing a collection from excavated fire pits related to sarsen breaking at Avebury:[94] spalls, defined as thermal pot-lids created on the outer surface of the stone where the heat was greatest, crested pieces and flakes that resulted from mechanical fracture, with lumps and miscellaneous debris. They were unable to identify any visible changes to the structure of the stone, apart from noting reddening of the surface or smoke blackening at presumed lower temperatures with unworkable, sugary, angular material resulting where the stone had been exposed to excessive heat.

This body of data provides no clear support to show that the application of heat produces clear benefits to improve the working qualities of the stone. The evidence is endorsed by the lack of any evidence for the general use of heat to modify silicates in British prehistory. Flint, which formed the primary raw material for prehistoric tool manufacture, is sufficiently even textured to work well without heat treatment, and this may also have applied to sarsen. Boulders were also routinely broken using direct and indirect percussion by nineteenth- and twentieth-century stone workers,[95] who split the stone without recourse to heat.

CONCLUSIONS

This small project was undertaken primarily by someone who is more familiar with flint technology than sarsen working, but expanded to consult practising stone workers, geologists, academics and engineers. The multi-disciplinary approach has attempted to demystify sarsen and reawaken understanding and appreciation of the potential provided by direct percussion to split and shape this notoriously intractable coarse-grained silicate successfully and repeatedly without using wedges. The hardness of sarsen creates a unique set of challenges. Using the limited tool kit available to Neolithic communities, the project has drawn on the sledgehammering technique as theorised by Gowland, but who offered nothing to explain how it might have worked in practice to split sarsen. The brief discussion, using only a single block of saccharoidal stone, has suggested control may have been improved using techniques common to modern stone masons.

Flaking appears to offer no benefits to the primary shaping of the stone. There is similarly nothing to indicate that heating may have been used to control its fracture. The laborious nature of peck dressing remains unquestionable, but produced comparable results to previous attempts using similar methods to replicate the process. These conclusions in no way claim to have comprehensively resolved the complex technological challenges linked to this stone or explain how it was done. They hope to document some fundamental thoughts on previously unexamined fracture mechanics of sarsen that may be of interest to future workers who choose to pursue the process in more controlled experiments. They will unquestionably acquire admiration for the skill and persistence of the prehistoric workers in the process.

94. Ibid, tab 10.4.
95. Ibid, 331.

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