of the Conservation Center is to turn out not only professional conservators but also a new type of curator with a fundamental knowledge of materials and structures of works of art, with some experience in applying conservation techniques, and with a thorough grounding in history of art—all on the graduate level. Curators with this special background will eventually fill positions of responsibility in our larger museums, where the care and maintenance of collections is as important as their interpretation. Those who complete the four years of training and qualify for a diploma in Art Conservation will be in demand to head museum conservation laboratories, which are becoming more numerous and more important all over the country. Others may find private work in conservation more interesting and lucrative. Private conservators will have the task of caring for the vast cultural holdings still in private hands. Their work will be as important as that of workers in museum laboratories. Like university graduates in the established professions such as medicine, engineering, and the military services, graduates in art conservation may find that their specialized training qualifies them for varied careers. There is little doubt that the standards set by this university-level training program in art conservation will raise conservation standards all over the country. We may look forward to the establishment, on the basis of such foundations, of minimum professional requirements and even to state licensing for art conservators. Men trained in the Conservation Center of New York University will have an influence with museum administrators that artisans could never have achieved. They will help frame policies and introduce practices that will extend the life of cultural objects many hundreds of years.

References and Notes

1. H. J. Plenderleith, *Museum News* **38**, 26 (Nov. 1959).
2. W. Boustead, "The Conservation Department of the New South Wales Art Gallery, Australia," *Studies in Conservation No. 5* (1960), pp. 121–131.
3. P. Hendy, in "An Exhibition of Cleaned Pictures (1936–47)" (National Gallery, London, 1947).
4. Some idea of the interest in conservation of art in Europe is given in R. J. Gettens, *Museum News* **39**, 23 (Dec.–Jan. 1960–61).
5. *Endeavour* **9**, 163 (1950).
6. R. D. Buck, "An Experiment in Cooperative Conservation," *Studies in Conservation No. 2* (1956), pp. 101–109.
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Sarsen Stones of Stonehenge

How and by what route were the stones transported? What is the significance of their markings?

Patrick Arthur Hill

The concentric stone circles of Stonehenge, England, consist of two main types of stone, bluestone and sarsen. Both have been transported many miles from their original outcrop areas, the bluestones from the Prescelly Hills 140 miles to the west (*1*), the sarsens from the chalk Downs 21 miles to the north. To date, the bluestones, because of the greater distance transported, have received the greater attention, although the sarsens are larger and several times heavier.

Sarsens, in their natural state, consist of large blocks of silicified sandstone that lie at certain localities on the Downs. The nearest outcrops to Stonehenge are shown in Fig. 1, and there is no evidence to suggest that the stones—some weighing as much as 50 tons—were moved to Stonehenge by agencies other than human. The problem is, how and along what route were the stones transported? At the time of movement, in the early Bronze age (about 1500 B.C.), there were supposedly no wheels in Britain, no beasts of burden, and, other than rawhide, no rope (*2*).

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Route

In the only study of the transportation problem to date, Atkinson (*3*) suggested that the Stonehenge sarsens originated on the Marlborough Downs, because the largest outcrops occur there today. According to him, selected sarsens were dragged to Avebury, "blessed," then dragged one at a time on sledges over hardwood rollers to Stonehenge. To avoid the steep descent of the chalk escarpment, Atkinson swings his route westward to cross the Vale of Pewsey at its narrowest point (see Fig. 1) and, using this route (*3*, p. 115), calculates that the 81 sarsen stones were moved one at a time at an average speed of a half mile a day and that the task occupied 1500 men for 10 years. Later (*4*) he suggested that the *minimum* hauling party for the heaviest stone would have been 100 men most of the way and 450 up Redhorn Hill. These figures are for the haulers only and do not include the additional men required to shift the rollers and steer the sledge.

Despite the advantages, there are six objections to Atkinson's route. (i) The labor requirements are large. (ii) The route is 4 miles longer than necessary. (iii) A surprising number of sarsens outcrop south of the Kennet; many admittedly are smaller than those on the Marlborough Downs, but this may simply mean that the larger stones have been removed. (iv) Avebury does not lie on the direct route to Stonehenge. (v) It would be easier to have the stones blessed *in situ*. (vi) The ascent of Redhorn Hill is unnatural and unnecessary, and more than negates any advantage of the detour.

A possible alternative route (*5*), based on field work undertaken during 1958, is suggested in Fig. 1. It has the following advantages. It is shorter than Atkinson's route and is essentially downhill for 17 of its 21 miles. It would account for the pebbles of opalescent quartz found in some of the Stonehenge sarsens, because opalescent quartzes occur in sarsen outcrops at Lockeridge (*6*), which is on the route. It also connects with the Stonehenge avenue at Amesbury, and there is thus

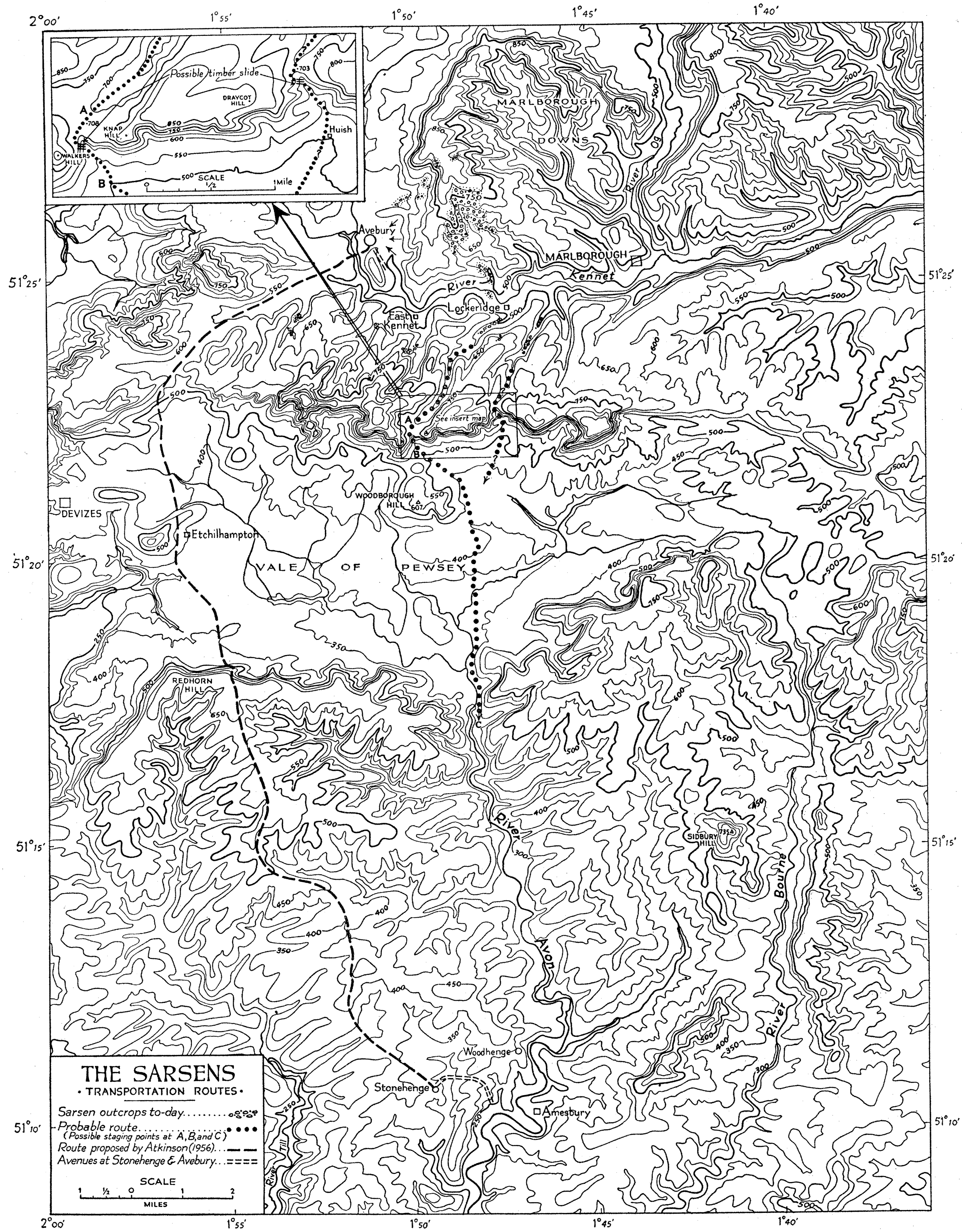

Fig. 1. Possible transportation routes to Stonehenge. [Contours from 1 in./mi. Ordinance Survey Sheets]

Fig. 2. The Avon at Upper Woodford, 4 miles south of Amesbury, looking south. (Width of river, 8 to 15 feet; average depth, 2 feet.)

no need to explain how the sarsens were dragged across the avenue.

This alternative route may be divided into five stages: (i) a steady but gentle climb for 3 miles from Lockeridge (500 feet) to the saddle (708 feet) between Walkers Hill and Knap Hill, with a possible subsidiary route at Huish; (ii) a slide or slides down the chalk escarpment; (iii) the crossing of the Vale of Pewsey; (iv) the journey down the Avon Valley; (v) the journey up the avenue from Amesbury. For the moment it may be assumed that the stones, except in stage (ii), were hauled in the "conventional" manner, on sledges over wooden rollers.

The free slide assumed for stage (ii) would have been the easiest, fastest, and safest way of lowering the sarsens the necessary 150 feet. The location of the slides is conjectural, but the locations shown are thought to be the most likely. Slides at these locations would have been the steepest and the shortest, and the nearest to the gaps through the Downs. The areas are sheltered from the westerly winds and are also partly sheltered from the sun. The slides may have been over snow, grass, or bare chalk. The sarsens may have been slid downhill on their sledges or tipped off and slid down on their own, to accumulate at the bottom to await the next stage of their journey. If this sliding-without-sledges was the method used, the stones might have been slid broadside over debarked tree trunks laid on (and pointing down) the hillside and fitted together end to end.

Along the Avon valley [stage (iv)] the route lies east of the river, to avoid the two tributaries. The stones, if the depth of water were the same as today (2 feet), could not have been floated; they must have been dragged, and in places, to avoid river bluffs, they may have been dragged through the water for some little distance (with the incidental gain of buoyancy). The number of river crossings is unknown: meanders may have changed position. To judge from the present position of meanders, however, only one or two crossings would have been necessary.

The idea that the stones might have been accumulated at staging points is logistically attractive. Each stage of the route presents its own problems, and each, for maximum efficiency, might have been the responsibility of one group of workers. Eating and sleeping arrangements would have been simplified, and the distance that each group would have had to travel would have been decreased.

Climate

So far it has been assumed that the climate and vegetation in 1500 B.C. were essentially the same as today. Climates, however, have changed repeatedly in the past and are changing today.

The changes since the last maximum of the Würm or Wisconsin glaciation are outlined by Brooks (*7*); according to him, "the sub-boreal climate (2500–500 B.C.) was peculiar. On the whole there was a gradual decrease of temperature and rainfall from the Climate Optimum [(*8*)], but this was interrupted by long droughts in which the surface of the peat dried up, followed by returns to more rainy conditions. This alternation occurred several times, the main dry periods falling about 2200–1900, 1200–1000, and 700–500 B.C."

Unfortunately, much of the evidence for climatic change "beyond the reach of the very short instrumental record is vague, and most of it is purely qualitative" (*9*). As for the local scene, Kennard and Woodward (*10*), from findings of nonmarine mollusks, concluded

Fig. 3. The heelstone, Stonehenge looking north. *A-B* older bollard marks; *D*, younger bollard marks; arrows spalling. (Scale: the book is 9 inches high.)

that the rainfall in Wiltshire was "much heavier," the downs "more wooded" (with beech), and the water table "much higher" than at present. On the other hand, Atkinson (*4*) thinks that the local climate was "distinctly drier," because wind-blown silt is found "not merely in the Y and Z holes of Stonehenge itself, but also in the ditches of broadly contemporary round barrows." Dimbleby (*11*), after preliminary pollen sampling from Windmill Hill, 1 mile northwest of Avebury, concluded that "the downs were more wooded, mainly with hazel" but hesitated "to translate such observations into terms of climate."

Willett (*12*), from data on sunspots for A.D. 1750 to 1950, derived a cycle of 80 to 90 years "consisting of alternating phases, each 40–50 years long, of maximum and minimum sunspot activity corresponding to nonglacial and glacial conditions respectively." Colder periods of longer duration are known to have existed before 1750, but it would be unwise to extrapolate sunspot information back to 1500 B.C. (*13*). On the other hand it is reasonable to assume that climatic fluctuations—duration and cause unknown—existed then as now. Accordingly, cautious speculations may be made about the effect of (i) a wetter climate and (ii) a colder climate on the transportation problem.

A wetter climate implies that the Avon was deeper and wider, and that the sarsens could have been floated downstream. Today, the average depth and width of the river are 2 and 10 feet, respectively (Fig. 2). A medium-sized sarsen block, 25 by 4 by 2½ feet, lying flat-side-down on a 25- by 12-foot wooden raft, would require a minimum depth of 5.6 feet (*14*). Whether the river was ever as deep as this would be difficult to determine; the whole river valley is artificially channeled.

The possibility that the Avon was dammed at, or below, Amesbury to obtain the required head of water has to be considered. Technically, the sarsen movers were quite capable of constructing a timber or earth dam; Silbury Hill (*15*), an earth mound 130 feet high, is a monument to their industry and skill. The evidence for such a dam, however, has yet to be found, and moreover, unless the regional water table were markedly higher than it is now, it would have been difficult to maintain the required level, for chalk makes a poor reservoir rock.

A colder climate does not imply that conditions were polar or subpolar—merely that winters were slightly colder than at present. In fact, as shown by Niven (*16*), subzero temperatures would have worked against the sarsen movers.

On ice, the sarsens could have been moved by a comparatively small number of men using sledges. One man properly shod can move a 2-ton Eskimo *komatik* (*17*), so 25 men could move the largest, 50-ton sarsen. Niven (*18*) believes that, once the sledge had been started, the number of men could have been reduced to 15, especially if, as believed, the sledge were moving down a gentle slope. The river, however, would have had to be frozen solid—a condition which presupposes severe continental winters.

Under less extreme climatic conditions there would have been packed snow, not ice. On average packed snow, one man can move a 1-ton *komatik*, and thus 50 men could move the heaviest sarsen. Unfortunately, "average" snow is difficult to define.

Snow deposits may be classified into five groups (*19*), of which, if the climate of prehistoric Britain did not differ too much from today's, the wet,

Fig. 4 (top). The lower half of the northeastern (inner) face of sarsen 16, Stonehenge. Three of the five grooves are indicated. The three crouching "figures" are in the center and at lower left (the figures are difficult to photograph; they show more clearly in color). (Scale: the book is 9 inches high.) Fig. 5 (bottom). A drawing made from Fig. 4 to show figures and tooling marks.

Fig. 6. The northwestern edge of sarsen 16—a close-up of the three grooves shown in Fig. 4. [Scale: the coin (at top, center) is 1.2 inches in diameter.]

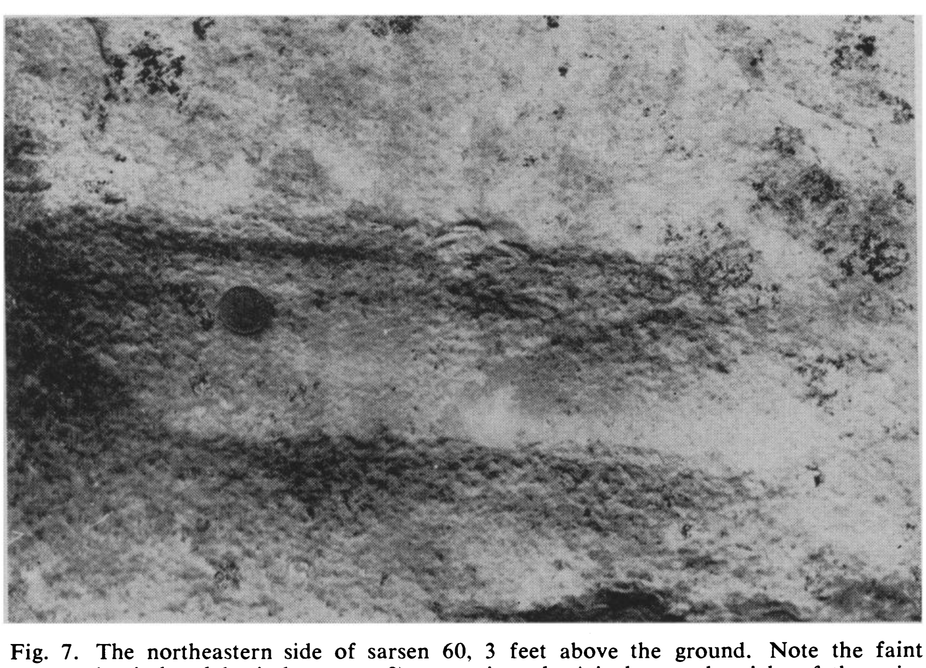

Fig. 7. The northeastern side of sarsen 60, 3 feet above the ground. Note the faint concentric circles (labyrinth pattern ?) approximately 4 inches to the right of the coin. In the photograph the circles appear to be younger than the main grooving but older than the whetstone mark which is superimposed on the southeastern perimeter of the circles. [Scale: the coin (left of center) is 1.2 inches in diameter.]

soft, fluffy snow of group 4 and the slush of group 5 would have been most common. When fresh, snow of the group-4 type offers considerable resistance to forward motion, although when packed its resistance decreases. Slush offers minimum resistance, "provided there is a solid foundation of snow or ice" (*19*). The best combination of snow and ice for heavy-duty transportation would be "ice roads" made from packed snow by the repeated passage of sledges or by the spraying or spilling of water. Although such roads have been used in northern Europe and North America for centuries, two interesting and related facts in this connection are not generally known.

First, insofar as the kinetic friction of ice is concerned, Amonton's law (*20*) does not always hold true. After a certain load is put on a sledge, "the drag increases but little by additional amounts" (*21*). Second, the best temperatures for moving very heavy loads are those just below 29°F, temperatures common in Britain in winter. Subzero temperatures on the other hand would increase frictional drag very markedly (*22*). Furthermore, to increase the longitudinal flexibility of the sledges and to improve handling and maneuverability, the stones were probably moved [except in stage (ii)] with their curved side downward and their flat side uppermost. This would also make it easier for the movers to re-start a frozen-in sledge.

The sarsens may have been moved along part of the route at night, particularly in the spring, when the best ice conditions obtained. With the Lockeridge-Avon Valley route and a prepared surface, each stone could have been moved in stages to Stonehenge at a slow walking pace, and its total time in transit could well have been less than a week. Green (*23*) believes that "If the blocks were dragged over grass during the summer months there would be the difficulty of providing labor at the time that labor was needed for agriculture. If however the blocks were transported during the winter, labor would be more readily available and the transportation of the stones would provide a social event to relieve the relative inactivity of the winter months."

If Newall (*24*) is correct in suggesting that the Stonehenge sarsens were laid out as they were to observe not the midsummer sunrise but the midwinter sunset, the main ceremonies would have been at dusk, and they might have been synchronized with those at Avebury by signal fires. The intersection in Sidbury Hill of the Stonehenge axis and the approximate axis of the Avebury avenue might not, therefore be coincidence (*25*).

To sum up, the suggestion that the accumulation of snow (or the amount of frost) was greater at the time the sarsens were moved cannot be proved, but it cannot be disproved. Since glacial times the climate has gradually become warmer, and as many as 13 minor oscillations of moisture and temperature are reported (*26*). In fact it might, even today, be possible to move the sarsens by sled to Stonehenge from one point to the next during selected winter periods.

Markings on the Stones

Although Stonehenge, the "most celebrated monument in Europe," has been the subject of numerous monographs, prehistoric carvings were discovered on the sarsens only in 1953 (*27*). Of the carvings the most important is a "Mycenaean" dagger—a finding which suggests that a Mycenaean architect may have supervised the erection of the stones. Of other man-made marks the only ones described before 1953 were tooling and dressing marks (*28*). Even today no marks indicative of quarrying, transportation, or erection are mentioned in the literature.

Current work has disclosed some undescribed markings on the heelstone and on sarsens 16, 28, and 60.

The heelstone is set approximately in the center of the avenue, outside the main sarsen structure. It rises 16 feet above the ground and is sunk an additional 4 feet in the ground. The stone leans noticeably toward the center of the avenue but, presumably, originally was upright. The naturally smooth east face has been polished and grooved. There are markings which appear to be bollard marks of two ages (Fig. 3). The earlier (*A-B*) is at right angles to the axis of the stone and was apparently made before the stone heeled over (*29*). It indicates that an object of some kind was dragged along the ground away from Stonehenge. The later bollard mark is higher and opens out at both ends.

As unpolished stone is highly abrasive, it is doubtful whether the polishing was done originally by rope. The stone might have been polished in preparation for use as a bollard. The polishing may not be prehistoric, but on the other hand sarsen 55, diametrically opposite the heelstone, has a bulbous protecting foot (*28*) above which material has been removed and the stone has been planed.

The most interesting marks are on sarsen 16, a wedge-shaped stone which like many Stonehenge sarsens has a curved outer face and a flat inner one. The marks are all on the inner face; there are three crouching figures and a series of grooves (Figs. 4 and 5). The figures are superimposed on the pocked "orange-peel" finish (*30*) of the stone and appear to be younger than the grooves on which the finish is superimposed.

The highest figure is the most prominent. It seems in part natural—a freak identified as "human," and accentuated —and may have served as inspiration for the other two figures (one steatopygous), which appear to be wholly man-made. These two figures, unlike the other carvings of Stonehenge, are not recessed but have been ground into the rock surface with a stone maul or an axe blade. The only other explanation for the figures is that sarsen 16, at one point on its journey to Stonehenge, was levered and swiveled side to side, flat face downwards, over hard round cobbles. It would, however, be difficult, if not impossible, to produce "figures" by this method.

The grooves on sarsen 16 are five in number and occur only along the one edge. Three of them are parallel. The grooves may date from historic times and may have been formed *after* the erection of the stones—that is, sarsen 16 may have been used as a whetstone for sharpening iron or steel implements.

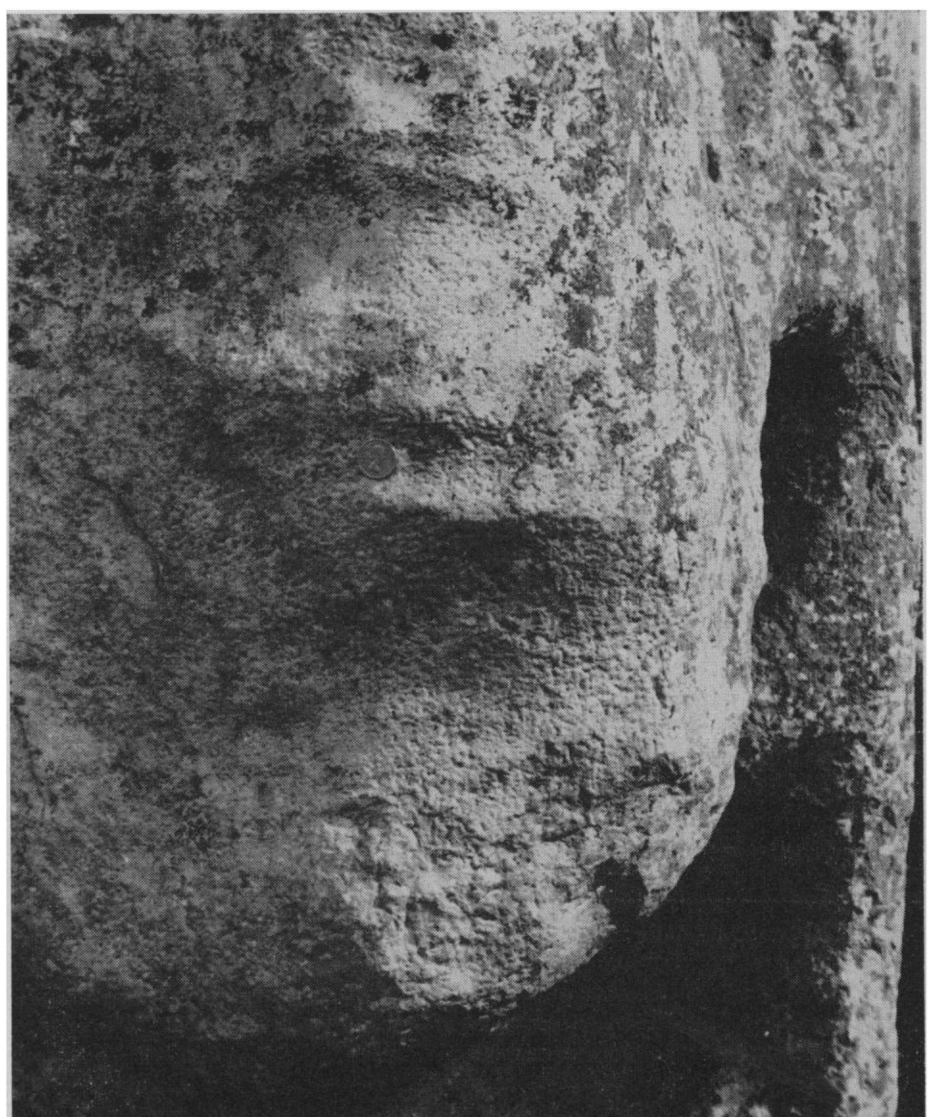

Fig. 8. The northwestern edge of sarsen 60. The prominent grooves underneath the orange-peel finish may be dressing marks. However, their position on the edge of the stone is unusual (?) for dressing marks, and other interpretations are possible. [Scale: the coin (center) is 1.2 inches in diameter.]

However, the upper two grooves are too high for this purpose; the orange-peel finish, assumed to date from the time of erection, is superimposed on the grooves, and the grooves are confined to one edge. On the other hand, if the grooves were made by the builders of Stonehenge, several interesting interpretations are open to consideration. These, in order of increasing probability (*31*), are as follows. (i) Sighting marks—unlikely (p, less than 0.1). The grooves are too wide. They aim upwards into the sky, and even if all sarsens were reerected, the grooves would sight open sky. (ii) Counterweight marks (that is, marks resulting from use of the stone as a moving counterweight in, or on, a crude balance or derrick)—unlikely (p, less than 0.1). The stone is not rectangular. It is wedge-shaped. Its center of gravity is so off-center that any engineering use is improbable. (iii) Dressing marks—unlikely (p, less than 0.2). The grooves are confined to one edge and do not resemble the tooling or dressing marks hitherto described. (iv) Rope scars made in erecting or demolishing the sarsen structure—unlikely (p, less than 0.2). The marks are underneath the orange-peel finish. They are too wide and too deep, and their longitudinal axes are not sufficiently convex. Moreover, the outer lips of the grooves are sharp, whereas if made by ropes they would be rounded. (v) Axe marks—possible (p, less than 0.5). However the grooves do not resemble other axe-sharpening marks; they are too long and too deep. Axe marks where only the blade has been sharpened are flat (*3*, plate 24a). Where the axe face has been repeatedly resurfaced, a groove does develop, but its longitudinal axis would appear to be concave upwards (*32*). (vi) Wedge marks—possible (p, near 0.5). But normally only iron wedges could cause such prominent marks, and usually wedges are driven in perpendicular to the working surface, not at an angle. If, however, the wedges were driven in by alternately lifting and dropping a heavy weight—that is, by gravity instead of by hammering—the grooves would be parallel because they would all originally have been vertical. In this case, the working surface must have been inclined. If wooden wedges were used, the grooves could be made by first filing a hole with a flint sand, water, and wood stakes and then increasing the diameter of the stakes until the hole was ready to take the final wedge (all of which seems unnecessary and laborious).

Finally (vii) we have the most controversial interpretation—that the grooves may represent slide or friction marks caused by the stone's sliding downhill over wooden logs. This is perhaps possible (p, ?) (*33*). The grooves, especially the longest, "fit" logs (Fig. 6). Their longitudinal axes are slightly convex, suggesting that the slide and the hillside on which it rested were correspondingly concave. If this interpretation is correct the angle between the grooves and the edge of the stone would indicate that the stone did not move downhill broadside on, but that the thicker, heavier end led slightly.

Although there are grooves on other sarsens, few appear to have been caused by sliding. Most appear to be dressing marks. Marks indicative of quarrying and transportation, if originally present, have apparently been obliterated. This is perhaps to be expected, because the flat inner faces, the ones which might be expected to show friction grooves, have been most carefully dressed. In addition, many stones are deeply weathered, and the edges of many others are chipped and destroyed.

Nevertheless, grooves are present on sarsens 60 and 28 (Figs. 7 and 8). Those on sarsen 60 were subsequently used for sharpening axes. The groove on sarsen 28 is high above the ground on the northwestern edge. It is prominent and horizontal, approximately 6 inches wide and 1 foot long, and appears to have a slightly convex longitudinal axis (?). Below it are three man-made grooves with concave longitudinal axes, made apparently to remove a protuberance.

Sarsen 16, with its prominent grooves and figures, might have been of special significance and might have been the first stone to have been slid downhill.

Summary

A route via Lockeridge and the Avon Valley, involving a slide down the chalk escarpment, is postulated for the sarsen stones of Stonehenge. The transportation problem would have been greatly simplified if the stones had been relayed from point to point over snow or slush during successive winters. Markings on the stones hitherto undescribed are interpreted.

References and Notes

1. H. H. Thomas, *Antiquaries J.* 3, 239 (1923).
2. This supposition is based on negative evidence. Conceivably oxen might have been available for draft purposes, and rope other than rawhide might have been in use. See N. Lockyer, *Stonehenge and Other British Stone Monuments Astronomically Considered* (Macmillan, London, 1909), p. 84; G. W. B. Huntingford, *Antiquity* 8, 456 (1934); J. G. D. Clark, *Prehistoric Europe, the Economic Basis* (Philosophical Library, New York, 1952), pp. 101, 122, 226.
3. R. J. C. Atkinson, *Stonehenge* (Hamilton, London, 1956).
4. ———, written communication.
5. The interest of R. J. C. Atkinson is gratefully acknowledged.
6. R. J. C. Atkinson, oral communication.
7. C. E. P. Brooks, in Malone, *Compendium of Meteorology* (Am. Meteorol. Soc., Boston, Mass., 1951).
8. W. C. Cooper [*Bull. Geol. Soc. Am.* 69, 941 (1958)] rightly objects to this misleading expression.
9. R. F. Flint, *Glacial and Pleistocene Geology* (Wiley, New York, 1957).
10. A. S. Kennard, *Wiltshire Archeol. Nat. Hist. Mag.* 45, 235 (1932); ——— and B. B. Woodward, *ibid.* 45, 334 (1932).
11. G. Dimbleby (University of Oxford), written communication.
12. H. C. Willett, *J. Meteorol.*, 8, 1 (1951).
13. Such an extrapolation would be unwise "especially as the problem of solar influences on weather is confused; some correlations seem to show in phase and others antiphase relationships," to quote from a letter from J. W. Locke, Dominion Observatory, Canada.
14. For this calculation a specific gravity of 2.4 for sarsen and of 0.60 for wood, and a 10-percent volume loss (void space) for the raft were assumed.
15. Silbury Hill, 1 mile south of Avebury, is not to be confused with Sidbury Hill.
16. C. D. Niven, *Eng. J. (Montreal)* 39, 226, 227, 230 (1956).
17. Information supplied by R. G. H. Williamson and P. Murdoch of the Arctic Division, Ottawa, and by W. E. Taylor of the National Museum, Ottawa, is gratefully acknowledged.
18. C. D. Niven (National Research Council, Ottawa), verbal communication.
19. W. E. Wakefield, *Publ. Forest Prods. Labs., Can., Div. Timber Mech., Project 107* (1938).
20. Amonton's law states that the frictional force acting between two bodies is proportional to the weight of the top body (or total pressure acting normal to the boundary).
21. C. D. Niven [*Eng. J. (Montreal)* 39, 226 (1956)], quoting W. E. Wakefield.
22. ———, *ibid.* 39, 226 (1956).
23. R. Green (University of Tasmania), written communication.
24. R. S. Newall, *Antiquity* 3, 75 (1929).
25. I introduce this idea with caution. Intersections have been unpopular ever since Lockyer [*Stonehenge and Other British Stone Monuments Astronomically Considered* (Macmillan, London, 1909)] used clock stars, May years, and intersections to "date" barrows, stone circles, and avenues. The Avebury avenue is, moreover, slightly sinous and of two different periods of construction.
26. L. von Post, *New Phytologist* 45, 192 (1946); J. Gordon Ogden, *Am. J. Sci.* 258, 341 (1960).
27. As most published photographs are not scaled, this oversight is, perhaps, not surprising.
28. E. H. Stone, *The Stones of Stonehenge* (Scott, London, 1924).
29. Alternatively, could the heelstone have stood in another position? Compare the outline of socket E with that of the heelstone in Atkinson (*3*).
30. This pock-marking or pitting is believed by both Stone (*28*) and Atkinson (*3*) to represent the final dressing of the sarsens. However, it is present on natural sarsens on the Marlborough Downs and may originate in more than one way.
31. See B. W. Brown, *Bull. Geol. Soc. Am.* 70, 561 (1959). Readers who object to the nonmathematical use of p should regard the numbers given as weighting factors indicative of my personal opinion as to the likelihood of the explanation's being the correct one.
32. See S. Piggott, *Antiquity* 32, 235 (1958), plate 25b.
33. The experimental work to date has been inconclusive.