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Source: *Science*, New Series, Vol. 184, No. 4141 (Jun. 7, 1974), pp. 1035-1043
Published by: American Association for the Advancement of Science
Stable URL: http://www.jstor.org/stable/1738395
Accessed: 02/08/2010 18:23

7 June 1974, Volume 184, Number 4141 SCIENCE

Astronomical Alignment of the Big Horn Medicine Wheel

Cairns of an unexplained Amerindian rock pattern appear to have been aligned to the summer solstice.

John A. Eddy

The stone Medicine Wheel in the Big Horn Mountains of northern Wyoming is a well-known archeological structure whose origin and purpose have long remained unexplained. It lies on an exposed shoulder of Medicine Mountain (44°49.6′N, 107°55.3′W) at an altitude of about 9640 feet (2940 meters), just above the timberline in the Big Horn National Forest. The "wheel" is a pattern on the surface of the ground, made up of an imperfect circle of stones, about 25 meters in diameter, with a central cairn about 4 meters in diameter. From this inner cairn or hub radiate 28 unevenly spaced spokes which connect to the rim. Five smaller cairns, each an open circle 1 to 1.5 meters in diameter and several courses high, are placed at irregular intervals along the periphery of the wheel. A sixth cairn, of similar construction, lies about 4 meters beyond the rim on an extended, southwestern spoke. Figure 1 is an early photograph (about 1926) of the site; Fig. 2 is a plan view made as part of a recent archeological survey (*1*).

Background

The Medicine Wheel is generally believed to be of considerable antiquity and is commonly attributed to early Plains Indians, which might include Crow, Sioux, Arapahoe, Shoshone, or Cheyenne, all of whom lived nomadically in the region and for whom the Big Horn Mountains had especial significance. This association is based principally on the circumstances of its discovery, on its location—near a well-worn travois trail—and its yield of a few Amerindian artifacts. At the time of its discovery by whites in the late 19th century and in subsequent archeological investigation (*2, 3*), local Indians were found to be aware of the wheel but none interviewed knew its precise location or its purpose. They reported that it was there when they came, or that it had been made "by people who had no iron."

Less is known about the date of construction, although several factors indicate that it has been there for possibly 200 years. These include depositions taken at the time of its discovery, the weathered and partially sunken appearance of the stones in the pattern, and a tree-ring analysis (earliest date, A.D. 1760) of a piece of wood found in one of the cairns in 1958 by Grey (*4*). In the 1958 study the interiors of all the cairns and the sectors between about one-third of the spokes were excavated. A few potsherds, beads, and points were found which were generally consistent with the dendrochronological date, although these could represent a later use of the wheel. Beneath the central cairn was found a filled, conical hole in the bedrock about 1 meter deep, of the sort that could have served to step a vertical pole in the center of the cairn.

Perhaps the most interesting feature of the Big Horn Medicine Wheel is its unique nature, for the early inhabitants of the northern Great Plains were not known as builders or monument makers. The most common stone artifacts of the region are tipi rings, but these apparently utilitarian structures are simpler and much smaller than the spoked Medicine Wheel and are most probably unrelated to it (*5*). Other stone structures are rare. They include surface effigy monuments (*6*), linear stone alignments [see, for example, (*7*)], and a few other spoked wheels (*8*), all found along the Rocky Mountains from northern Alberta to southern Wyoming. Of the spoked wheels found thus far, the Big Horn Wheel is clearly the largest and most elaborately constructed, and it is the only one with a rim and outlying cairns.

The word "medicine" was used by Indians to mean "magic" or "supernatural," and the Medicine Wheel is associated in most accounts with religious use. Its general similarity to the floor plan of a ceremonial Medicine Lodge (*9*) led Grinnell in 1922 (*3*) to suggest that this may have been its pattern or original use (see Fig. 3). In this analogy, the central cairn (labeled O in Fig. 2) represents the center lodge pole and the 28 spokes represent the 28 rafters. Cairn F, which opens to the center on the west side, portrays an altar which was by tradition located there; cairn B, on the east and opening east, represents the entry which opened to the rising sun. Other cairns could mark traditional stations of worship; in particular, outlying cairn E marked the "lonely lodge" of the Cheyenne Medicine Lodge ceremony. This association was restated in similar terms by Robert Yellowtail, chairman of the Crow Tribal Council (*10*). Yellowtail believed that the outlying cairns marked the (cardinal) directions of the four winds which were customary stations of fasting or worship. Based on his

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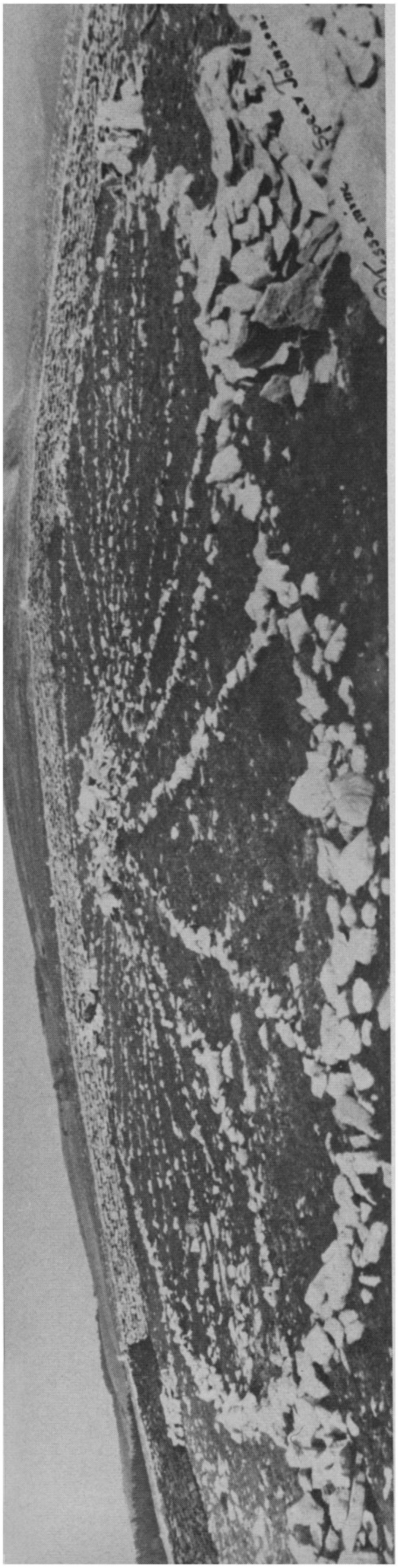

Fig. 1. Photograph of the Medicine Wheel, about 1926, by Jessamine Spear Johnson, Sheridan, Wyoming, made when a stone wall protected the site. [Source: Western History Research Center, University of Wyoming]

own knowledge of Indian ceremonial customs, he felt that the Medicine Wheel was most likely a two-dimensional replica of the Medicine Lodge (or Sun Dance Lodge) which had been built at one time to allow the observance of the Sun Dance ceremony at a place where timber was not easily available.

The association of the Medicine Wheel with the floor plan of a ceremonial lodge is not perfect. There are too many cairns, and they do not lie at or even very near the cardinal directions. The crucial cairns B and F are distinctly not diametrically opposite as are their counterparts in the Cheyenne Lodge. The ceremonial use of the site by large groups is also subject to doubt. There is little evidence that the site was ever occupied by any number of people for any length of time (*1*), and indeed it marks a most inhospitable location—wind- and snowswept and far from water and plentiful wood. The site seems better suited as a place of personal spiritual quest, in the custom of the Plains Indian, or, by virtue of its altitude and clear horizons, as a primitive astronomical observatory.

Astronomical Use

Stone alignments such as the Medicine Wheel could have been used as horizon markers, to identify the directions of rise or set of selected celestial bodies. A pole stepped vertically in the central cairn could serve as a gnomon or foresight, which, in conjunction with a backsight point at a peripheral cairn, would define the azimuth of rising or setting of some important object (*11*). We might first suspect the sun, because of its religious importance in Amerindian culture and its frequent association with the Big Horn Wheel in form, name, and legend. The spoked pattern resembles a common sun symbol. A Crow name for the Big Horn Wheel was "the Sun's Tipi," and in one Crow legend "the Sun built it to show us how to build a teepee" (*12*). "It was built before the light came," according to another reported Crow explanation (*13*) which was interpreted, perhaps mistakenly, as indicating that the wheel was of ancient age. A more illuminating translation could well have been "before the sunlight came," or "to mark the sunrise."

The horizon points of sunrise and sunset shift daily; their paths go through reversals of directions at the times of summer and winter solstice, when the sun rises and sets at its most northern and most southern positions, respectively. These singularities were commonly noted by many primitive peoples for calendar, ritual, or agricultural purposes. The solstitial alignments of Stonehenge and other European megalithic monuments, of Egyptian pyramids and temples, and of Mayan temples are by now generally recognized [see, for example, (*14, 15*)]. Recently, solstitial alignments have been proposed to explain architectural structures of the Anasazi in New Mexico and southern Colorado (*16*), posthole patterns at the Cahokia mounds in Illinois (*17*), and the alignment of ceremonial circles on the central Kansas plain (*18*). Contemporary Pueblo ritual has required the identification of the solstices by specific tribal officers who have used horizon markers for this purpose (*19*).

Of the two solstices only during the summer solstice is there practical access to the Big Horn Wheel. Even then the trail up Medicine Mountain leads through frequent deep snow, and, if the experience of the last two summers is typical, much of the wheel itself can be covered at the time of solstice. On 19 June 1972, a boot-deep snow fell on the mountain; on 18 June 1973 a blowing snowstorm halted traffic on the nearby highway. In both cases, although drifts were deep at lower points, the barren shoulder on which the wheel is built was swept clean by wind soon after the storm. For at least 3 days around the 1972 solstice almost the entire wheel was clear of snow; in 1973 several inches of snow covered the spokes on the eastern half although the cairns were clear. Frequent snow cover may explain the unique use of built-up cairns at the Big Horn Wheel, as opposed to more common surface alignments, and the selection of this windswept shoulder, since these would seem to ensure the visibility of the reference marks in summer snowfalls. Thus the fundaments of the Big Horn Wheel are probably the cairns; the spokes and rim, which for so long have captured the attention of observers and interfered with serious explanation, are

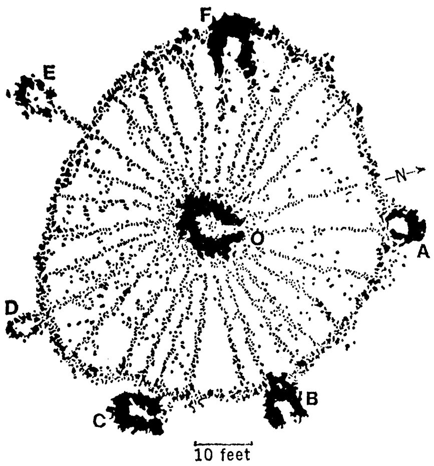

Fig. 2. Plan of the Medicine Wheel with cairn letters added, from a 1958 survey by Grey (*1*).

likely of secondary importance and may well have been added later as a day counter or simply as a decoration.

How useful, meteorologically, is the Big Horn site for observing the sun at solstice? The chances of a clear horizon at sunrise or sunset are probably worse for a mountain location at high latitude than for known sites of solstice markers in the American Southwest, Mexico, or Egypt, but probably as good as Stonehenge, for example, which lies at higher northern latitude. At the time of summer solstice in 1972, one morning out of three at the Big Horn Wheel was clear at sunrise; in 1973, three mornings out of four were clear. The solar declination changes very slowly through the solstice—no more than 2′ arc per day in the week before and after—and to the accuracy of stone-and-post alignments the solstice is not a sharply defined reversal but a pause of several days in the place of sunrise or sunset. One clear sunrise per week would probably suffice, particularly if the trend of shift in preceding and subsequent days were noted. These considerations would seem to establish the site as a practical one for watching for the summer solstice. But the choice of a cold and arduously reached mountaintop in preference to the equally usable nearby plains must be justified on other grounds—possibly mystical or purely aesthetic.

Solstice Cairns

To test for possible astronomical alignment it is necessary first to establish the positions of the cairns and then to check for coincidences with important azimuths of rise and set. This test had apparently not been made at this site in the past; most earlier workers have concentrated on establishing the general pattern and history of the wheel, and on searching for surface or buried artifacts. The early maps by Simms (*2*) and Grinnell (*3*) were only approximate sketches, with no accurate compass reference. A transit survey of spoke angles was made in October 1917 by Stockwell, although never published (*20*). The first comprehensive map was published in 1963 by Grey (*1*), as a result of a 1958 survey of the site by the (amateur) Wyoming Archaeological Society. This map (Fig. 2) faithfully portrays the general plan and shows accurate relative bearings of spokes and cairns, although it contains an unfortunate error in scale (the distances shown are 15 percent too small) and the direction reference is approximate.

In the summer of 1972, using a surveyor's transit and steel tape, I made a new survey of the cairns at the Big Horn Wheel to establish their positions and directional alignments. The true compass reference was determined by observation of solar azimuths and checked by triangulation with landmarks from the U.S. Geological Survey chart. In addition, the solstice sunrise was observed on the morning of 20 June in line with cairns E and O, for which solstitial sunrise alignment was indicated. In the summer of 1973 I rechecked the true compass reference on the site, again with solar azimuths, and observed sunrise on 20, 21, and 22 June and sunset on 20 June.

The 1972–1973 survey is summarized in the first six lines of Table 1, which lists the position of the center of each peripheral cairn with reference to the center of the hub cairn O. Table 1 also gives the celestial declination circle which corresponds to the measured azimuth alignment, taking into account the effects of measured horizon dip angle and calculated refraction. In this procedure I have taken cairn O as a common foresight for each peripheral backsight cairn. The survey indicates that the line EO intersects the horizon where an object of declination $+23.6°$ rises, as compared to $+23.4°$ for the solstice sun. This is illustrated in Fig. 4. The other likely solstice sun alignment, line CO, corresponds to the setting point of declination $+25.5°$. This is about 2° from the expected value; however, the solstice sunset line from foresight O passes easily through the central part of the widely spread cairn C. In Table 1 I have given for the solstice lines EO and CO the difference between the measured alignment azimuth and that calculated for a declination of 23°26′, which measures the fit of these lines to the present position of the solstice. These alignments are convincingly confirmed by observation of the rising and setting solstice sun (Figs. 5 and 6). From backsight E one sees the flash of the dawn sun at the center of foresight O; from cairn C one sees the last of the setting sun very nearly in line with O. One should keep in mind that the original reference point in each cairn is not precisely known and has here been presumed to be the center of the present clear area in the middle of each cairn. For these rough, unstabilized cairns this reference point may not be precisely valid and in any case cannot be determined to better than ± 15 centimeters, or about ± 1.5° in alignment. Moreover, we are ignorant of the diameter of post used for a gnomon and its manner of use, if indeed one was stepped in the central cairn as was suggested by Grey's excavation.

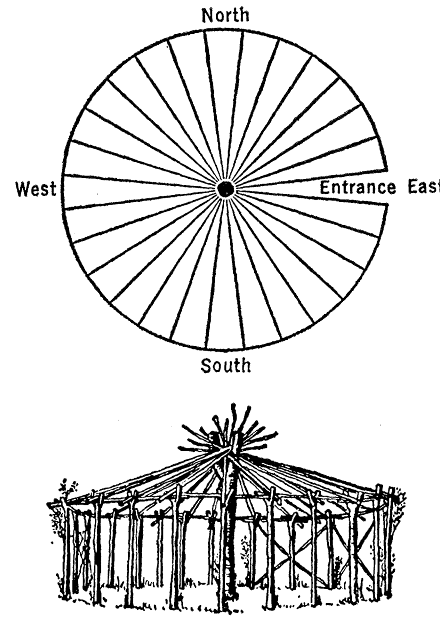

Fig. 3. The Sun Dance Lodge (Medicine Lodge). [From *The Sacred Pipe: Black Elk's Account of the Seven Rites of the Oglala Sioux*, Joseph Epes Brown, Ed. Copyright 1953 by the University of Oklahoma Press]

The centers (defined above) of the distinctive cairn E and the central cairn are aligned to the solstice sunrise to

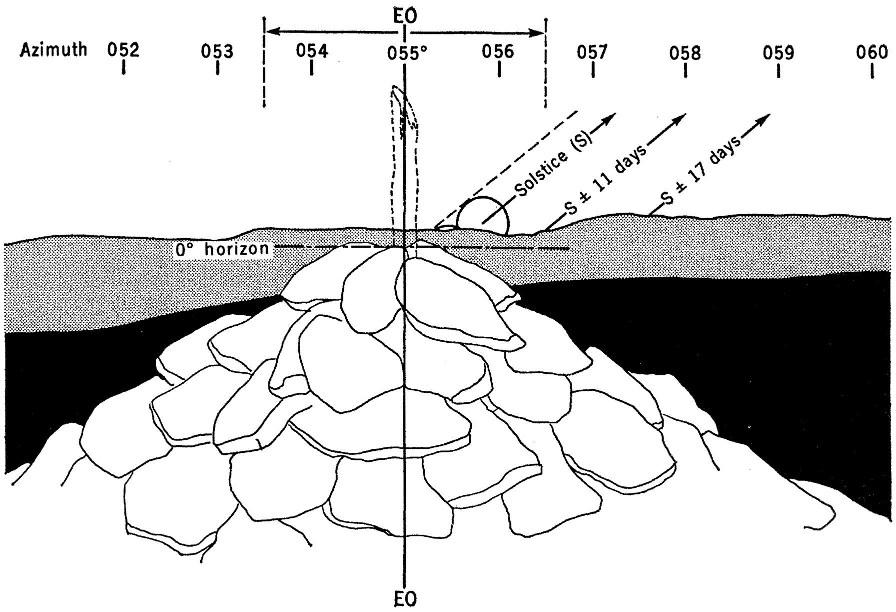

Fig. 4. View of the Medicine Wheel horizon in the EO direction, showing calculated lines of rise for the center (solid line) and upper limb (dashed line) of the sun. The present position of the EO alignment is shown, with an hypothesized foresight pole in cairn O. Limits of certainty of the survey are ± 1.5° (vertical dashed bars).

a tolerance which is much less than my measurement uncertainty. The statistical probability of a chance coincidence of one of six arbitrary lines to a predetermined direction to within a small angular tolerance $\Delta°$ is 1: $(360/6\Delta)$ or, with $\Delta = 0.3°$, 1 in 200. The center of the more amorphous cairn C is aligned to the central cairn in agreement with the solstice sunset to within an error that is about twice my estimated accuracy of fixing the cairn reference points. If the lines of sunrise and sunset at summer solstice are the most likely candidates for possible astronomical alignment of the Medicine Wheel, then the probability that by chance alone two or six peripheral cairns would be aligned to these directions to within the measured tolerances $\Delta_1 = 0.3°$ and $\Delta_2 = 3.4°$ is 1: $(360/6\Delta_1)(360/5\Delta_2)$, or less than 1 in 4000. Moreover, as will be demonstrated below, the coincidences of the other cairn alignments with other logical celestial risings further decreases the probability of chance placement of the cairns. When we allow for the unstabilized nature of the cairns and the present uncertainty in their original reference centers, the statistical argument for solstitial placement seems even more compelling. The case seems strong that these cairns of the Big Horn Medicine Wheel were built for the specific purpose of marking the summer solstice. Cairns E, O, and C, with but little additional specification of their real reference points, would have permitted their builders to identify the time of the solstice with a precision of several days. Such refinement would have followed quite naturally from repeated annual observation and use.

Other Cairns

This leaves unexplained the four remaining peripheral cairns, of which cairns A, B, and F appear to equal the size, and presumably the significance, of the solstice pair, cairns E and C. We might suspect that the central cairn served as a foresight for each of these other cairns, to mark directions of rise or set of other prominent celestial features, such as the nodal points of the paths of the moon or planets, or the fixed points of rise or set of bright stars or asterisms. When the declinations derived in this way (lines 3 through 6 in Table 1) are compared with the declinations of known prominent celestial features, we find only one likely coincidence: backsight F with cairn O points to the rising point of the brightest star, Sirius. Cairns A, B, and D show no convincing alignments with the center cairn.

It is conceivable that cairn O, the center of the spoked, sun-symbol wheel, was chiefly used for solar marking, and that for other objects combinations of the peripheral cairns were used. In testing for astronomical coincidences in this way some logic or restraint should be used, since a large number of lines can be defined by pair-

Table 1. Summary of 1972 survey of cairn positions.

Cairns		1972 survey		Azimuth (deg)	Celestial declination of rise (R) or set (S) (deg)	Indicated alignment (epoch 1972)		Declination difference (deg)	Azimuth difference (deg)
Backsight	Foresight	Separation (m)	Horizontal dip angle (deg)			Declination (deg)	Object		
E	O	13.4	+0.18	055.0	+23.6 (R)	+23.4	Solstice sunrise	0.2	0.3
C	O	12.5	−0.25	308.6	+25.5 (S)	+23.4	Solstice sunset	2.1	3.4
A	O	12.4	−0.5	196.5	−43.8 (S)		?		
B	O	12.3	−1.0	263.6	− 5.7 (S)		?		
D	O	12.9	−0.2	348.5	+43.4 (S)		?		
F	O	12.1	+1.9	114.5	−15.7 (R)	−16.7	Sirius rise	1.0	1.6
F	A		−0.6	065	+16.6 (R)	+16.5	Aldebaran rise	0.1	0.1
F	B		0	099	− 6.7 (R)	− 8.2	Rigel rise	1.5	2.1
E	B		−0.4	069	+14.1 (R)	+16.5	Aldebaran rise	2.4	3.8

ing all possible cairns. A convincing case might be that in which one cairn is a common fore- or backsight for more than one other cairn, to mark a set of significant celestial objects. Of all combinations, only when cairn F is taken as a backsight is this criterion met. An observer at cairn F, the largest peripheral cairn, sees Aldebaran (magnitude 0.8) rise over cairn A, Rigel (magnitude 0.11) rise near cairn B, and Sirius (magnitude −1.44) rise over cairn O (see Fig. 7 and lines 6, 7, and 8 of Table 1).

These three stars are the brightest in a compact region of the sky which is near the path of the sun in summer. Thus they rise near dawn at the only season of practical occupancy of the Big Horn Wheel (Fig. 8). The nearest stars of comparable brightness are Betelgeuse (variable magnitude 0.1 to 1.2, labeled point B in Fig. 8) and Capella (magnitude 0.2, labeled point C in Fig. 8). Although Capella is brighter than Aldebaran, it is circumpolar at the latitude of the Big Horn Mountains and hence cannot be marked at the horizon. Atmospheric extinction will limit the number of stars which can be observed near the horizon and will restrict the altitude angle at which even the brightest can be seen. This effect, which has been discussed by Thom (*15*), will, for the elevation of the Big Horn Mountains, shift azimuths of apparent rise southward, about 0.5° for Aldebaran and negligibly for brighter Rigel and Sirius. For crude cairns these are insignificant changes. It is more to the point to recognize the effect as probably limiting likely summer dawn-marked stars to the five cited here, thus strengthening the significance of the apparent marking of Aldebaran, Rigel, and Sirius.

Aldebaran is the brightest star in the well-known Hyades asterism in Taurus. On 21 June it now rises, unseen in predawn light, about 1 hour before the sun. At the summer solstice in earlier epochs it rose earlier, in a darker sky, and at one time it rose just as the predawn sky brightened to extinguish it. This momentary appearance at rising defines the heliacal rising of a star, which, because of the significant daily motion of the sun in right ascension, is a fairly well-defined point in time. The heliacal rising of the brightest stars was used for calendar reference by other early peoples. Perhaps the most commonly acknowledged use was in early Egypt, where at one time the heliacal rising of Sirius occurred at the summer solstice, which was also the season of the annual rise of the Nile (*21*). Hipparchus reportedly made use of the changes in the heliacal rising times of certain stars to determine the difference between the lengths of the solar year and the sidereal year (*22*).

At the Medicine Wheel the heliacal rising of Aldebaran—the only bright star to rise heliacally near the time of summer solstice—would have provided the only other celestial signal for the summer solstice (*23*); moreover, with experience the observer, using the heliacal method, might increase the precision of the sunrise-azimuth method, since the daily solar motion in right ascension is greater than in declination. The heliacal method requires horizon pointers such as the cairns but not precise placements, since all that is needed is a rough indication of the place of rise to identify the star.

The FA cairn alignment could thus serve to point out the approximate place of rise of the one star whose momentary appearance near dawn would signal the solstice. Later in the

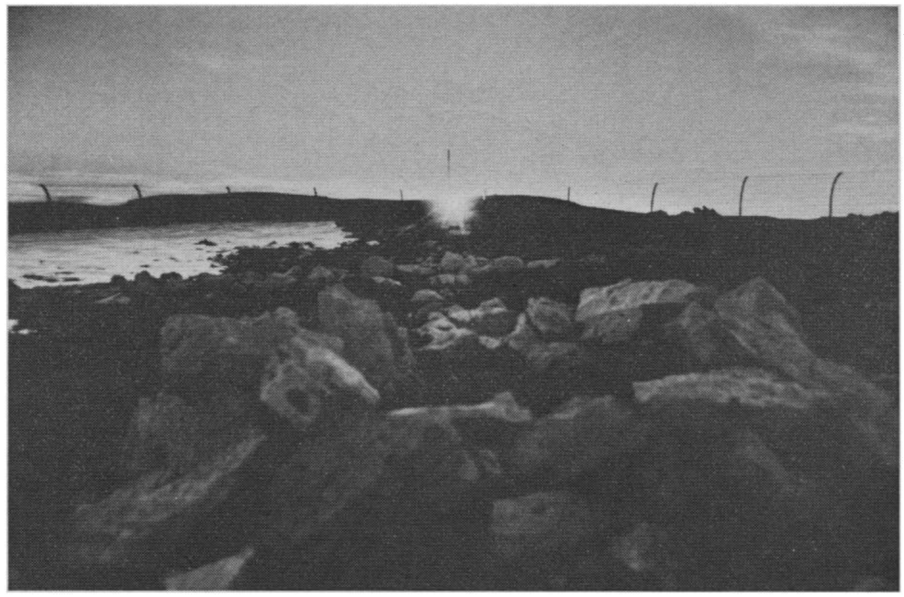

Fig. 5. Solstice sunrise at Big Horn Medicine Wheel, 22 June 1973, with cairn E (backsight) in the foreground and cairn O (with tall vertical survey pole) a distant foresight. Curved steel fenceposts enclosed the wheel. [Photograph by author]

Fig. 6. Solstice sunset at the Big Horn Medicine Wheel, 20 June 1973, with cairn C in the foreground and cairn O (with tall survey pole) a distant foresight. The U.S. Forest Service signpost to the left of the survey pole stands outside the enclosure. [Photograph by author]

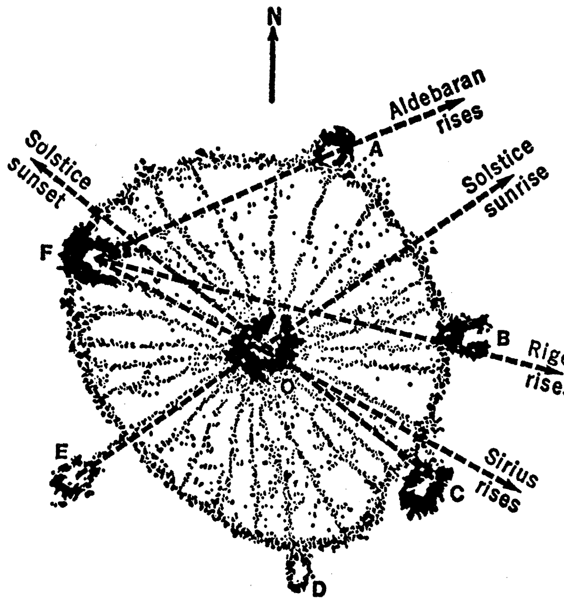

Fig. 7. Summary of adopted cairn alignments, superposed as direction vectors on the diagram by Grey (*1*). The direction of north has been rectified about 2° to agree with the present survey. Indicated direction vectors accurately depict the true differences between presumed alignments and measured cairn positions.

summer, from the same backsight cairn, alignments FB and FO would point in similar fashion to the rising points of brighter Rigel and Sirius. Rigel, in familiar Orion, is the brightest object to rise heliacally after Aldebaran. It did so, at the latitude of the Big Horn Mountains, almost exactly one lunar month after Aldebaran's heliacal rise at solstice. Bright Sirius then rose heliacally about another lunar month later. It may be significant that there are 28 spokes in the Medicine Wheel, which could be used as day counters for these lunar-month intervals. It is at first surprising that stars were marked whose heliacal rising occurred after the solstice. Indeed, logical use might suggest instead the marking of presolstice events, to serve as warnings from which solstice countdowns could proceed. No such objects are marked, but there are two reasons why we should not expect them. One is the particular absence of bright stars in the region of the sky west of Aldebaran where presolstice heliacal rising would occur (Fig. 8). The other is the normally severe weather on the mountain in late spring, which would surely discourage use of the Medicine Wheel much before mid-June.

Why should Rigel and Sirius be marked? Perhaps simply because they were the brightest stars that rose in the summer dawn. Or, more logically, because their dates of heliacal rising would mark off the warmest moons of the year, the 2-month period after the solstice when the weather on the mountain was least severe. The heliacal rising of Sirius would be a good warning to leave the Medicine Wheel. We should also consider whether the Sirius, Rigel, and Aldebaran markers could have been laid down at different times by a sequence of different users, as the aspect of the sky changed with the precession of the equinoxes. Each of these stars at one time in the past rose heliacally at the solstice there—first Sirius, then Rigel, and, last of all, Aldebaran—but the periods between are measured in millennia and this is not consistent with the generally homogeneous construction of the Medicine Wheel or with reasonable estimates of its age.

An alternate interpretation of the peripheral cairn alignments does not require alignments on other than the sun and Aldebaran. It may be that cairn F was used only for the FA Aldebaran line, and that cairn B was sighted from cairn E, the solstice sunrise station, as another line to the same heliacal solstice star (Fig. 7). The line along EB is not as good an Aldebaran marker as the line along FA, but it is within 4°, close enough to permit identification (line 9 of Table 1). In this case, on days before the solstice, an observer at cairn E would note the daily shift of the sunrise point toward the EO line. From the same station, in the period before dawn, he could watch for the momentary appearance of a bright star (Aldebaran) along line EB. On the day of the solstice he would see both phenomena, about 1½ hours apart, in what would have been an impressive reaffirmation of the temporal coincidence of these two singularities of daybreak. At each subsequent dawn the ever-increasing persistence of Aldebaran in the predawn sky would confirm that the solstice was past, as would the slow shift of the sunrise point away from the line EO.

Cairn D remains the unused piece of the puzzle, for its relation to the other cairns seems to fit no plausible sky alignment. It could be a crude attempt (11.5° error) to mark the celestial pole—a feat more difficult than the marking of objects that rise and set. In size and orientation this cairn appears anomalous, and it may have been a later addition, perhaps unrelated in purpose or of nonauthentic origin. The general appearance of the rest of the Medicine Wheel suggested to Grey (*1*) that at least some of the cairns may have been built before the rest of the structure. The uses proposed here make that seem likely, with phases of construction reflecting stages of refinement in its astronomical use. Cairns O, E, and C may once have stood alone, laid out by a first user to mark the rising and setting of the solstice sun, possibly on a lone pilgrimage or vision quest to the mountaintop. Cairns B, A, and F could have been added later by the same or different users for the added precision of Aldebaran's heliacal rise, and possibly for the mystical marking of Rigel and Sirius. The reported affinity of Amerindians for round objects (*24*) may explain the rim and spokes, which were likely added last. The 28 spokes were probably chosen to equal the days of the moon, for day counting or simply numerology. It should not surprise us that the wheel is not round (Fig. 2) (if it was built after the cairns), or that it meanders and flattens as though to lend significance to the more important cairns.

Probable Date of Construction

The declination of the sun at solstice is a measure of the obliquity of the ecliptic, which changes with time. Since this is a well-known function, one might presume to establish the date of construction of a presumed solstitial alignment such as the Medicine Wheel by making a sufficiently accurate measurement of alignment directions. An indicated azimuth of rise or set corresponds to a unique celestial declination, or obliquity, which in turn corresponds to a unique date in the terrestrial precession cycle. A number of workers (*25*) have cautioned against using such a procedure for sunrise or sunset markers. The change in the obliquity is so slow—about 1° in 8000 years—that the uncertainty in refraction and in the user's definition of sunrise introduces a chronological uncertainty of literally thousands of years, even for the most precise alignment determination. The situation is further degraded in the case of the Big Horn Medicine Wheel alignments by the crude nature of the cairns and our ignorance of their exact points of reference.

However, the implied use of Aldebaran as a heliacally rising star at summer solstice gives us a dating device which is not subject to these faults. This is a potentially powerful dating tool, since the change in Aldebaran's position with time is appreciable; moreover, the method is insensitive to the positional accuracy or stability of the cairns, once we are convinced that Aldebaran was so used. The absence of other bright candidate stars for the FA cairn alignment and the unique position of Aldebaran relative to that of the solstice sun leave little doubt that this was indeed the case.

In this dating method one uses the long-term change in the position of Aldebaran with respect to the solstice point, which comes about chiefly through precession of the equinoxes. Precession is such that at present the elongation angle between Aldebaran and the sun at solstice is decreasing at the rate of about 1.4° per century. Currently the separation is about 22°, such that, at the latitude of the Big Horn Mountains, Aldebaran rises about 9° before the sun on 21 June. As mentioned earlier, this is too close to permit one to observe the rising of a first-magnitude object, and Aldebaran at solstice now rises unseen in the predawn glow. Some time ago, when it rose approximately 11° before the sun, it was just far enough from the sun to rise heliacally on the solstice. Before that time, it rose even earlier, persisting longer before dawn and becoming less and less useful as a heliacally rising solstice marker. There is thus a period of time, centered on the time of nominal separation for heliacal rising, during which the star would have been useful. Neither the width of this time period nor the separation angle for precise heliacal rising are exact quantities, since they depend somewhat on the acuity of the observer's vision and on the variable brightness of the predawn sky. In taking 11° as a nominal separation angle for the heliacal rising of a first-magnitude star, I have followed the work of Lockyer (*21*). A reasonable choice for an allowable tolerance about the value is ±1°.

Included in Fig. 8 are the positions of Aldebaran (and of Rigel, Sirius, Betelgeuse, and Capella) from A.D. 1000 to the present in 100-year steps, from the calculations of Hawkins (*25*). Figure 8 also shows the 11° heliacal horizon (the almucantar which lies 11° above the solar almucantar at summer solstice) and a portion of the 10° heliacal horizon for reference. Both of these horizon lines are drawn to include the effects of refraction and the measured dip angle in the FA cairn direction. Aldebaran was on the 11° line (for nominal first-magnitude heliacal rise) in about A.D. 1700. The uncertainty of ±1° in the value of the separation angle corresponds to an uncertainty of about ±200 years in date. Thus the use of Aldebaran as a heliacally rising solstice star implies that the FA cairn alignment was made in the period from A.D. 1500 to A.D. 1900 with a most probable value A.D. 1700. This agrees reasonably well with Grey's dendrochronological earliest date of A.D. 1760 (*26*).

Authenticity

The Big Horn Medicine Wheel is a crude structure of loose, unmortared stones. As with any archeological site, its authenticity is open to question and so is the possibility of serious modification since its discovery. It could easily have been built by a single person in a day, if it were no more than a randomly oriented pattern. In a recent popular article Ransom (*27*) has suggested that the entire structure was redesigned and relaid by U.S. Forest Rangers, using different stone, sometime between 1931 and 1955. Although this can be shown to be an invalid and unsubstantiated suggestion (*28*), the possibility remains that, since the original discovery of the Medicine Wheel, visitors could have significantly altered its form. It was not protected, other than by isolation, until about 50 years ago when the U.S. Forest Service built a low stone wall around the wheel. Although high steel fences have since been substituted, it is still relatively unprotected and unstabilized.

Before any conclusions can be drawn from the apparent astronomical alignment of the structure, it is clearly necessary to answer the question of its

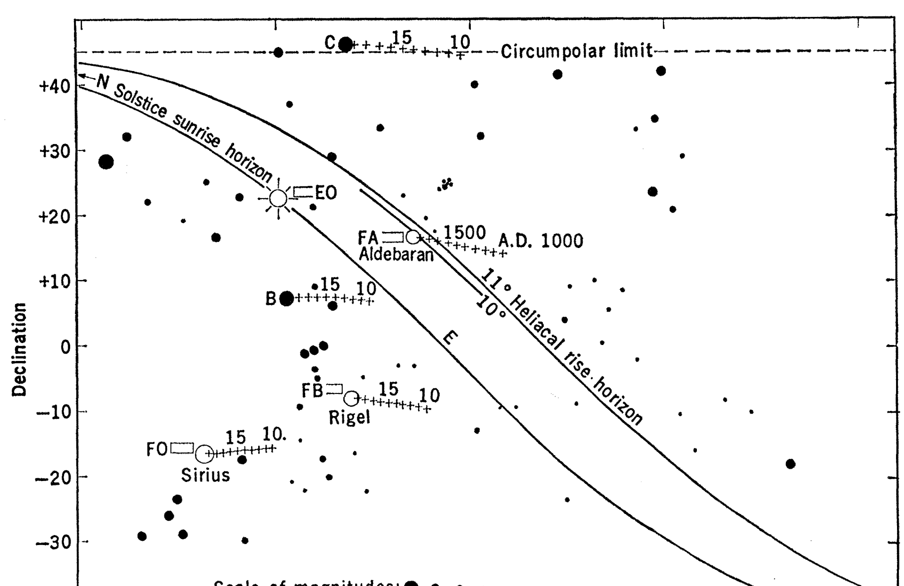

Fig. 8. Diagram of the sky in the vicinity of the solstice sun, with horizon lines calculated for the latitude of the Big Horn Medicine Wheel. Star positions are for the present epoch, with additional positions at century intervals (A.D. 1000 to the present date) for Aldebaran, Rigel, Betelgeuse (*B*), and Capella (*C*), which is circumpolar. The position of the solstice sun has been taken as a fixed reference point in plotting the changing positions of these five brightest stars. Other stars participate in the same relative change, so that the constellation patterns remain essentially the same with time. Declinations (from Table 1) corresponding to cairn alignments EO, FA, FB, and FO are shown as lines of total width 1.5° adjacent to the probable alignment objects.

Table 2. Comparison of surveys of cairn positions.

Cairn	Azimuth of cairn center measured from the central cairn O (deg)			Predicted value (deg)
	Stockwell (1917)	Grey (1958)	Eddy (1972)	
A	014	015	017	
B	080	084	084	
C	121	126	129	125.4 (solstice sunset)
D	171	168	169	
E	235	232	235	235.5 (solstice sunrise)
F	292	293	295	295.8 (sirius rise)

veracity (*29*). The classification of the Medicine Wheel as a genuine artifact of early plains inhabitants must rest on evidence of its age, as established by the methods of archeology and the inferences of astronomy invoked here. The apparent alignments of the cairns on a set of logically related celestial events of the summer solstice add a strong statistical argument that whoever laid down the cairns knew the annual path of the sun and the important stars of the summer dawn.

Definite evidence against any major modification of the wheel in this century is found if one compares historical photographs of the site with the present structure. Grey (*1*) made such a comparison as part of his study of the Medicine Wheel and concluded that the site in 1958 was in no basic way changed from its appearance in 1903. I carried out a similar study, with the help of the Western History Research Library, University of Wyoming, and the U.S. Forest Service, Medicine Wheel District. From a file of photographs dating from 1905, it can be established that the general appearance of the wheel has not changed in this period; more to the point, the cairn positions appear in early photographs just as they do in Figs. 1 and 2.

In addition I have made a comparison of the three extant surveys of the Medicine Wheel: that of Stockwell in 1917 (*20*), Grey in 1958 (*1*), and the work presented here (*30*). Grey compared his survey with the Stockwell map and, after correction for an acknowledged plotting error in the 1917 map, concluded that there was no evidence for change in the structure. My findings corroborate Grey's conclusion and further establish that the azimuths of the centers of the six peripheral cairns are the same in the three surveys, as best these reference positions can be determined. The comparison is given in Table 2. It would seem to establish that the cairn positions have been stable since at least 1917 and that the conclusions presented here concerning their alignment were valid at least at that time.

The number and arrangement of stones in each cairn has undoubtedly been altered through the years, by accident, removal, or intentional probing, so that their original dimensions and precise positions will never be established. We know, for example, that during the Grey survey the interior of each cairn was excavated. But the evidence is that their general positions and hence their relative alignments have been preserved.

Conjecture

It may be that the solstitial alignment of the Big Horn Wheel and its resemblance to the plan of a Medicine Lodge are related. The Medicine Lodge, or Sun Dance Lodge, was commonly built for the conduct of that important ceremony. The Sun Dance was performed traditionally in June—at the time of the summer solstice (*31, 32*), "when the sun is highest and the growing power of the world is strongest" (*24*). The cairns of the Medicine Wheel could have served to fix the time for that ceremony; moreover, certain aspects of the Sun Dance ritual, including the layout of the Medicine Lodge, could logically have been patterned after the Medicine Wheel. The Wheel and its mountain might then be considered sacred places, endowed with the ability to receive the message of midsummer from the sun itself. It would not seem unlikely that in the development and spreading of the Sun Dance ritual the pattern of the Medicine Wheel would have been copied, at least schematically. This suggested sequence—that the Medicine Lodge was patterned after the Medicine Wheel—is the reverse of that usually invoked.

We can imagine that the Big Horn Wheel may have been originally used by a knowledgeable few who climbed to the site in June to mark the day of the summer solstice for an ensuing Sun Dance ceremony. The ceremony itself, which often involved entire tribes, might then have followed, not atop the inhospitable mountain, but at some lower site when the observers came down the mountain with the message from the sun to start. In time, particularly if the secrets of the cairns were known to only a few, this way of initiating the ceremony could have faded from use, and the Medicine Wheel could have been left behind, in the veil of mystery, as an original but unappreciated pattern. This conjecture seems reasonably consistent with the earlier limits of estimated dates for the structure and with reports that local Indians apparently knew nothing of the origin or purpose of the Medicine Wheel when it was first found. It would also add meaning to the Crow legend that the sun built it to show how to make tipis.

Of no less interest is the identity of the architects who first laid out the cairns. Did the nomadic tribes of the northern plains know enough of astronomy to perform this feat? The answer is surely yes. There should be little doubt that any people who lived by the sun would intimately know the dawn, and that any who lived at the mercy of the seasons would know as well the solstices. The next step, of marking these phenomena with stones, would seem to follow naturally or, conceivably, could have been learned in trade and travel from the more advanced Pueblo people to the south, who, in turn, in earlier times, learned these things from the inhabitants of Mexico, if we are to accept the hypothesis of the northward infusion of astronomical culture (*16*).

Why would a nomadic people wish to mark the solstice? Historical accounts of the Plains Indians do not emphasize this practice, or, to my knowledge, even acknowledge it, and indeed the custom is more commonly associated with agricultural societies. Still, there are other reasons for wanting an annual calendar reference, which include ritual, as cited above, and a basic need to plan for colder weather. These needs would survive into the historical era, although the methods of meeting them might change. With the encroachment of a white civilization on the northern plains in the 19th century the Indian's requirement for a natural calendar could have vanished, taking with it certain astronomical traditions.

References and Notes

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2. S. C. Simms, *Am. Anthropol.* **5**, 107 (1903).
3. G. B. Grinnell, *ibid.* **24**, 299 (1922).
4. Grey (*1*) carried out a dendrochronological study of a piece of tree limb found lodged between the two lowest courses of stone in cairn F (Fig. 2). Based on core samples taken from living trees and trees that had recently died in the Medicine Wheel area, he established a tree death date of A.D. 1760 for the limb. If the limb had been placed in the cairn as dead wood at the time of construction, this implies a construction date of about A.D. 1800 for cairn F. If the wood had been added later, the date becomes a latest date for this particular cairn.
5. W. R. Wedel, *Prehistoric Man on the Great Plains* (Univ. of Oklahoma Press, Norman, 1961). Tipi rings (typically 2 to 13 meters in diameter) are often found in clusters and are generally believed to have served to hold down tipi covers.
6. T. F. Kehoe and A. B. Kehoe, *J. Am. Folklore* **72**, 115 (1959).
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9. G. B. Grinnell, *Am. Anthropol.* **16**, 245 (1914).
10. R. Yellowtail, unpublished deposition given to P. L. Heaton, forest supervisor, Big Horn National Forest, 1952.
11. Here, and as defined by A. Thom [*Vistas Astron.* **7**, 1 (1966)], the backsight is nearer the observer, as with the sights on a rifle.
12. I. B. Taylor, Casper (Wyo.) *Herald Tribune* (16 March 1941).
13. H. H. Thompson, Sheridan (Wyo.) *Post* (11 March 1923).
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16. J. E. Reyman, thesis, Southern Illinois University (1971).
17. W. L. Wittry, *Explorer* **12** (No. 4), 14 (1970).
18. W. R. Wedel, *Am. Antiq.* **32**, 54 (1967).
19. E. C. Parsons, *Pueblo Indian Religion* (Univ. of Chicago Press, Chicago, 1939).
20. Copies of the map by A. G. Stockwell are kept in the historic file of the U.S. Forest Service, Medicine Wheel District, and in the Western History Research Library, University of Wyoming. As Grey has pointed out (*1*), it displays distances erroneously as a result of a plotting error.
21. J. N. Lockyer, *The Dawn of Astronomy* (Cassell, London, 1894; reprinted by MIT Press, Cambridge, Mass., 1964).
22. H. N. Russell, R. S. Dugan, J. Q. Stewart, *Astronomy* (Ginn, New York, 1945).
23. Reyman (*16*) has compiled lists of celestial features known to have been recognized and used in ceremony in Mesoamerica and in southwestern pueblos. The lists consist chiefly of planets, constellations, and asterisms. Only six individual stars appear, and one of these, which was known both in Mesoamerica and in Hopi ceremony, was Aldebaran. It may be that the reason for the importance of this star to early people was its heliacal rise at solstice.
24. See, for example, J. G. Neihardt, *Black Elk Speaks* (Univ. of Nebraska Press, Lincoln, 1961; originally published by Morrow, New York, 1932).
25. See, for example, G. S. Hawkins, *Vistas Astron.* **10**, 45 (1968).
26. As is evident in Fig. 8, the precessional change in the declination coordinate is slight for objects in this part of the sky. If we use the deduced A.D. 1700 epoch to recompute in Table 1 the indicated stellar alignments for the lines FA, FB, and FO, the azimuth differences change (column 10) by no more than about 0.5°, which is a negligible correction considering the nature of the cairns. The amount of the change and its direction (favorable for Sirius only) may be seen in Fig. 8 where the apparent declinations of the present cairn alignments are shown as lines alongside the presumed stellar object.
27. J. E. Ransom, *Am. West* **8** (No. 2), 16 (1971).
28. Ransom (*27*) based his conclusion on his personal recollections of how the wheel appeared to him as a youth of 7 and 17 years. He recalled that in 1921 and 1931 the wheel was made of nonlocal quartz and that it had only 18 spokes—a number which fits his theory of an Aztec origin. Abundant evidence in the form of historical photographs and surveys and an historical site record maintained by the U.S. Forest Service clearly establishes the general stability of the structure and negates Ransom's claim.
29. We are fortunate that at the present time the U.S. Forest Service, Medicine Wheel District, and the Department of Anthropology, University of Wyoming, are studying the archeological basis of the structure. Their work represents the first professional study of the Medicine Wheel since the brief report by Grinnell in 1922 (*3*) and the volunteer study led by Grey in 1958 (*1*).
30. Stockwell (*20*) was concerned chiefly with the azimuths of the spokes and the shape of the rim of the wheel; in his map the cairns are shown only schematically. Since the spokes are not linear and according to photographic evidence apparently never were, the usefulness of this survey is limited. I found, however, that, within the limits of straight-line approximation, the number and individual positions of spokes in the Stockwell map agree with those in Grey's survey.
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32. J. E. Brown, Ed., *The Sacred Pipe: Black Elk's Account of the Seven Rites of the Oglala Sioux* (Univ. of Oklahoma Press, Norman, 1953).

33. I am indebted to R. Williams, U.S. Forest Service, Medicine Wheel District, and to C. G. Roundy, formerly research historian, University of Wyoming, for providing historical records and illustrations, and to D. A. Breternitz, D. Mihalas, and R. Levine for helpful comments on the manuscript. I thank G. C. Frison, O. Stewart, R. Lister, and D. Grey for providing useful information in initiating this study. The National Center for Atmospheric Research is sponsored by the National Science Foundation.

Regulation of Bacterial Growth

Mechanisms controlling intermediary and macromolecular metabolism interact to regulate bacterial growth.

Donald P. Nierlich

The growth of a microbe is rarely complicated by the supracellular controls that buffer the cells of higher organisms from the environment, and thus the mechanisms by which a bacterium's growth rate, composition, and metabolism relate to the environment are relatively visible. It is therefore not surprising that the existence of a variety of bacterial cellular regulatory mechanisms has been known for some time. Some of these mechanisms provide control over intermediary metabolism, that is, control over the formation and disposition of the many low molecular weight compounds that are intermediates in the formation of the macromolecular components of the cell, while others are concerned more directly with control of the formation of the macromolecules themselves.

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Intermediary Metabolism

The concept that intermediary metabolism is regulated comes from many observations. Perhaps among the most important of these is the fact that a bacterium growing normally will not lose significant amounts of its many intermediates. This implies the existence of a selectively permeable outer membrane, as well as mechanisms preventing the overproduction of these compounds by the enzymatic pathways making them. As one might predict, when either the membrane of the cell is altered, or when a defect appears in a control mechanism, as a result of a mutation, for example, the cell may excrete a variety of intermediates, as in the first case, or a specific intermediate, as in the second. Even more direct evidence of these control mechanisms comes from the fact that when a specific nutrient is present, it may induce the synthesis of those enzymes needed to utilize it, while if the nutrient is an intermediate which the cell normally makes, then the endogenous synthesis of the compound will be quickly in-